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# Forbes

# Geological Sheet

1:250 000 SI55-7

## EXPLANATORY NOTES

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# Explanatory Notes

# FORBES
# 1:250 000
# GEOLOGICAL SHEET

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## Compiled and edited

by

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AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

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# SUMMARY

The Forbes 1:250 000 map sheet area, which includes the towns of Forbes, Parkes, Grenfell, West Wyalong, and Condobolin, lies towards the western edge of the exposed Palaeozoic rocks of the Lachlan Fold Belt in New South Wales. Bedrock units range in age from Early Ordovician to late Tertiary (mid-Miocene). About 80% of the map sheet area is covered by Cainozoic units. The use of high quality geophysical datasets is invaluable in interpreting the geology.

The oldest rocks are the poorly exposed Early Ordovician Nelungaloo Volcanics and the Yarrimbah Formation, which crop out in the core of the Forbes Anticline between Parkes and Bogan Gate. The Yarrimbah Formation appears to unconformably overlie the Nelungaloo Volcanics, implying a hiatus before the onset of Middle Ordovician volcanism, which exceeded 10 million years, giving rise to the widespread Middle to Late Ordovician intermediate to mafic volcanic rocks and turbidites.

In the Forbes map sheet area, an Ordovician volcanic arc is represented by the Lake Cowal Volcanic Complex, in the west, and the Northparkes Volcanic Group, north and west of Parkes and Forbes. Both units are part of a volcanic belt extending from Junee, south of the map sheet area, to Nyngan, north of the map area. Gold and copper mineralisation is associated with intrusive complexes, notably at Northparkes (just to the north of the Forbes map sheet area) and the Lake Cowal area. The sediments of the Wagga and Girilambone Groups were deposited in a marginal basin to the west, the Wagga Basin. Seafloor spreading in the Wagga Basin was accompanied by extrusion of the Narragudgil Volcanics. Following splitting of the arc, or trench-rollback, and the formation of a new arc to the east (the Molong Volcanic Belt, Bathurst and Dubbo 1:250 000 map sheet areas), the Kirribilli Formation was deposited in the new basin formed between the arc fragments. The Jindalee Group tholeiites were extruded during rifting and spreading of this intra-arc basin.

A belt of Alaskan-type ultramafic bodies, with associated PGE and Ni mineralisation, was emplaced west of the Lake Cowal–Parkes arc during the middle Late Ordovician. Although the ultramafic units are better represented in areas to the north, the Kars Ultramafic Intrusive Complex occurs partly within the Forbes map sheet area.

The marginal basins closed during the Late Ordovician to Early Silurian Benambran Orogeny, and the associated deformation probably initiated the Gilmore, Parkes, and Coolac–Narromine Fault Zones. The associated crustal thickening and heating produced large volumes of principally felsic magma throughout the Lachlan Fold Belt. The Early Silurian S-type Ungarie Suite, the related Ugalong Dacite, and the I-type Bland Diorite were emplaced west of the Gilmore Fault Zone. The Gilmore Fault Zone separates the Lachlan Fold Belt into eastern and central belts. Felsic igneous activity continued, intermittently, during the late Early Silurian and into the Late Silurian, with the emplacement of the S-type Billys Lookout Granite and the Young Granodiorite, and the eruption of the S-type Ina Volcanics (near Burcher) and Douro Group in the Cowra Trough east of Grenfell. Sedimentation was not widespread in the Forbes map sheet area, and was restricted to the Forbes Group, in the Parkes–Forbes area, and the Burcher Greywacke.

Although the evidence is sparse, some deformation may have followed in the middle Late Silurian. A gold–lead–zinc–copper hydrothermal mineralising event occurred near Condobolin and may be associated with this event, although there is some evidence that it occurred later.

At the end of the Silurian, and into the Early Devonian, deposition of the sediments and volcanic units of the Ootha and Derriwong Groups took place during extension and marine incursion throughout the Forbes map area. The Derriwong Group rests on the Forbes Group with a low-angle unconformity. In the Bogan Gate–Wirrinya region, the Jemalong Trough formed by extension of the Ordovician arc. Melting of the Ordovician basement rocks there produced the Byong Volcanics, and their distal correlatives, the Yarnel Volcanics. Minor basalts in the Byong Volcanics had a mantle origin, similar to the Ordovician volcanic rocks. Sedimentation at that time in the Cowra Trough was represented by the Moura Formation in the east of the Forbes map sheet area. S- and I-type granites (Bogalong Suite and Caragabal Granite, respectively) were also emplaced at that time. Minor tin mineralisation is associated with the fractionated Bogalong Suite.

Following a brief hiatus, sedimentation and volcanism resumed in a shallowing marine to subaerial environment. The Trundle Group sediments and volcanic rocks were deposited in the Jemalong Trough and, in a waning rift basin to the west, the Darbys Ridge Conglomerate was deposited in an outwash fan. Volcanic rocks of the Trundle Group (Kadungle and Carawandool Volcanics) had Ordovician source rocks similar to those of the Byong Volcanics.

A major compression around 400 Ma, led to thrusting and strike-slip movement on the Gilmore Fault Zone, less well-documented movement on the Parkes and the Coolac–Narromine Fault Zones, and inversion of the Jemalong Trough (e.g., the Currowong Syncline) and Cowra Trough. However, melting of the Ordovician

basement continued through the late Early to Middle Devonian, producing post-tectonic I-type intrusions (*s.l.*), e.g., the Porters Mount Quartz Diorite, Bundaburrah Granodiorite and smaller mafic dykes. Other granites emplaced at that time include the Dalrida, Berendebba, and Broula Granites.

In the east of the Forbes map sheet area, the production and emplacement of large volumes of I-type magma, at and east of the Coolac–Narromine Fault Zone, resulted in emplacement of the Eugowra Suite (part of the Boggy Plain Supersuite) — and their probable volcanic equivalents, the Coonambro Volcanics. Lesser volumes of S-type magma produced the Cumbijowa Granite west of the Fault Zone. Some skarn copper, gold and iron mineralisation is associated with the Eugowra Suite.

During the Middle Devonian, widely spaced continental rifting took place in the eastern Lachlan Fold Belt. In the east of the Forbes map sheet area, the consequent production of A-type magmas and bimodal volcanic rocks gave the Bindogandri, Grenfell, and Schneiders Granites, and the subaerial volcanics of the Rocky Ponds Group. The peralkaline and A-type Ganantagi and Wirrinya Granites were also probably emplaced at this time.

The eastern Lachlan Fold Belt was subject to widespread continental rifting during the Middle Devonian. In the east of the sheet area, the resulting production of A-type magmas and comagmatic and bimodal volcanics resulted in the Ganantagi, Wirrinya, Grenfell, Schneiders, and Bindogandri Granites, and the Rocky Ponds Group.

The igneous activity ceased by the beginning of the Late Devonian, which was marked by the deposition of fluvial redbed conglomerates, sandstones and shales of the Late Devonian Hervey Group.

The Kanimblan Orogeny in the Early Carboniferous resulted in broad open folding of the Hervey Group. Related movement on pre-existing faults, such as the Coolac–Narromine and Parkes Fault Zones, and their upward propagation, steepened the limbs of some of these folds. Structurally controlled gold mineralisation in the Parkes–Forbes corridor may have formed at that time, as it did in the West Wyalong area. The Marsden Thrust, probably a leading splay of the Gilmore Fault Zone, was activated at that time, when part of the Ordovician Lake Cowal Volcanic Complex was thrust eastwards over rocks of the Hervey Group.

The Carboniferous marked the start of the regolith development, which continues to the present. There are no records of Permian or Triassic sedimentation in the sheet area. In the region of Bogan Gate, rivers flowing towards the Surat Basin deposited up to a kilometre of sediment during the Jurassic. Mafic hot spot volcanism in the Tertiary (Miocene) produced leucitites south of Condobolin, and a vestige of the Mount Canobolas basalt lavas occurs at the eastern boundary of the Forbes map sheet area, near Eugowra. In the Miocene, much of the landscape was deeply incised with the palaeo-Lachlan River and palaeo-Bland Creek system flowing in deep gorges. These have been filled to the level of the surrounding plains. Placer gold deposits are widespread, particularly in the Grenfell, Forbes, and Parkes areas.

The regional metamorphic grade, throughout the map sheet area, is generally lower grade greenschist, while prehnite-pumpellyite grade occurs over the Ordovician volcanics in the Parkes region, and tremolite/biotite grade occurs in the Girilambone Group metasediments around Condobolin and in the granitoids just north of Wyalong. Parts of the Wagga Group display higher regional andalusite grade metamorphism in a belt that crosses into the neighbouring Cargelligo and Nymagee 1:250 000 map sheets.

Minor tectonic activity continues to the present day, with earthquakes focussed along the Eugowra Fault at Eugowra.

*Keywords*: Lachlan Fold Belt, gold, copper, mineralisation, Palaeozoic, Mesozoic, Cainozoic, Forbes, Cowal, Parkes, Northparkes, Gilmore Fault Zone, Parkes Fault Zone, Coolac–Narromine Fault Zone, Marsden Thrust, Jemalong Trough, Ordovician volcanism, regolith, geological map.

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Finally, we would like to thank the residents and landowners of the Forbes map sheet area for their assistance and hospitality.

# ABBREVIATIONS, DEFINITIONS AND EDITORIAL NOTE

## Abbreviations

| | |
|---|---|
| ASI | Aluminium saturation index |
| GPS | Global positioning system |
| HFSE | High field strength elements |
| HREE | Heavy rare earth elements |
| ICPMS | Inductively coupled plasma mass spectrometry |
| LILE | Large-ion lithophile elements |
| LREE | Light rare earth elements |
| MORB | Mid-ocean ridge basalt |
| REE | Rare earth elements |
| SHRIMP | Sensitive high resolution ion microprobe |
| XRF | X-ray fluorescence |
| XRD | X-ray diffraction |

## Geochemical nomenclature

Aluminium saturation index (ASI) = molecular $\frac{Al_2O_3}{(Na_2O + K_2O + CaO)}$.

FeO* means total Fe expressed as FeO, calculated as FeO + $0.9Fe_2O_3$.

Mg-number, or Mg#, = 100 × atomic $\frac{Mg}{(Mg + Fe^*)} = 100 \times \frac{(MgO/40.32)}{(MgO/40.32 + FeO^*/71.85)}$.

$\varepsilon_{Nd}$ is the deviation, in parts per 10 000, from the $^{143}Nd/^{144}Nd$ ratio of the chondritic uniform reservoir (CHUR).

## Magnetic susceptibility

In Système International (SI) units, the magnetic susceptibility, $k$, is defined as $k = \frac{\mathbf{M}}{\mathbf{H}}$,

where **H** is the external field and **M** is the magnetisation of a body placed in **H**. The total field, **B**, is proportional to the sum of **M** and **H** and depends on the magnetic susceptibility because

$$\mathbf{H} + \mathbf{M} = (1 + k)\mathbf{H}.$$

Field measurements of magnetic susceptibility were taken using the following hand-held meters: Geo Instruments model GMS-2; Friskars model JH-8; or Kappameter model KT-5.

## Radiometric readings

Field measurements of gamma-radiation were taken as total counts using a Scintrex GAD-6/GPS-4S spectrometer-sensor combination.

## Additional data

Additional data are contained in AGSO's OZROX database and the Forbes Geoscience database (GSNSW). The METMIN database (GSNSW) contains statewide mineral occurrence data.

## The Palaeozoic timescale for the Forbes map sheet area

The absolute timescale for the Palaeozoic is evolving at a rapid rate. Since 1990, at least ten timescales and revisions to timescales have been formally and informally published for all or part of the Palaeozoic. Most recently, these have included the timescales of Tucker and McKerrow (1995), Young and Laurie (1996; revised in part by Young, 1997a), and Tucker *et al.* (1998). Compilations of parts of these and other timescales have been constructed by Gradstein and Ogg (1996), and VandenBerg (1999).

SHRIMP U–Pb zircon dates combined with fossil control from the northern Lachlan Fold Belt (e.g., Pogson & Watkins, 1998; Meakin & Morgan, 1999; Jagodzinski & Black, 1999; these Notes) provide some general guidelines for the absolute timescale. The data suggest that the dates for the Late and Middle Devonian of Tucker *et al.* (1998) and Fordham (1999) are too old. Further, the data indicate that the dates for the Silurian–Devonian and Ordovician–Silurian boundaries of Young and Laurie (1996) are too young.

The timescale adopted for these Notes is similar to that compiled by VandenBerg (1999) for the Palaeozoic of the Lachlan Fold Belt in Victoria (Table below). VandenBerg (1999) drew heavily on AGSO's 1996 timescale (Young & Laurie, 1996), with variations around the Silurian–Devonian boundary to reflect the work of Tucker *et al.* (1998). The "Forbes timescale" reflects much of VandenBerg's (1999) thinking, but also incorporates Young's (1997a) revision of Young and Laurie (1996).

*Table of relationships between selected recent geological timescales and these Notes for the Devonian, Silurian, and Ordovician Periods.*

| | | | Tucker & McKerrow (1995) | Young & Laurie (1996) | Young (1997) | Tucker *et al.* (1998) | Vanden-Berg (1999) | Fordham (1999) | Forbes map & Notes |
|---|---|---|---|---|---|---|---|---|---|
| **CARBONIFEROUS** | | | | 354 | 354 | 362 | 354 | 363 | 354 |
| DEVONIAN | Late | Fammenian | | 364.5 | 364 | 376.5 | 364.5 | 375 | 364 |
| | | Frasnian | | 369 | 370 | 382.5 | 369.5 | 382 | 370 |
| | Middle | Givetian | | 377.5 | 380 | 387.5 | 377.5 | 389 | 380 |
| | | Eifelian | 391 | 384 | 390 | 394 | 384 | 392 | 390 |
| | Early | Emsian | 400 | 399.5 | 401 | 409.5 | 400 | 407 | 401 |
| | | Pragian | 412 | 404.5 | 408 | 413.5 | 413.5 | 411 | 408 |
| | | Lochkovian | 417 | 410 | 415 | 418 | 418 | 418 | 418 |
| SILURIAN | Late | Pridoli | 419 | 414 | | 419 | 419 | 420 | 419 |
| | | Ludlow | 423 | 420 | | 424 | | 424 | 424 |
| | Early | Wenlock | 428 | 425 | | | 428 | 429 | 428 |
| | | Llandovery | 443 | 434 | | | 441 | 441 | 441 |
| ORDOVICIAN | Late | | 458 | 459 | | | 459 | 460 | 459 |
| | Middle | | | 477 | | | 477 | 470 | 477 |
| | Early | | 495 | 490 | | | 490 | 495 | 490 |

## Palaeontological age abbreviations

Subdivisions of the standard Victorian graptolite biostratigraphic scheme for the Ordovician System are conventionally abbreviated as follows:

| | | | | | |
|---|---|---|---|---|---|
| Lancefieldian | La | Bendigonian | Be | Chewtonian | Ch |
| Castlemainian | Ca | Yapeenian | Ya | Darriwilian | Da |
| Gisbornian | Gi | Eastonian | Ea | Bolindian | Bo |

Within each of these Stages, individual Zones are designated by numerals, with 1 being oldest. Thus Ea3 indicates the third youngest graptolite Zone of the Eastonian Stage (equivalent to a late Late Ordovician age).

## Fossil list

A list of fossils mentioned in the text is given in the Appendix. The references cited in that list are listed separately.

## Editorial note

The order of units in these Notes does not always match that of the map legend. This is usually due to the fact that the lateral variations cannot be expressed in the columns of the legends. For editorial reasons, the units Dtki, Dhma, and greisen have not been written separately but are included in the sections on their parent units.

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# 1. INTRODUCTION

## Location and access

The Forbes 1:250 000 map sheet area (SI55-7) covers 15 600 km$^2$ in the central west of New South Wales, centred about 320 km due west of Sydney (Figure 1.1). It is bounded by latitudes 33° 00' S and 34° 00' S and longitudes 147° 00' E and 148° 30' E. The area includes the major towns of Parkes, Forbes, Condobolin, West Wyalong, and Grenfell. The Forbes 1:250 000 map sheet consists of the six component 1:100 000 sheets: Condobolin, Wyalong, Bogan Gate, Marsden, Parkes, and Grenfell. The map sheet area is also traversed by the transcontinental railway, which passes through Parkes and Condobolin.

The principal access to the Forbes 1:250 000 map sheet area is gained via the Newell Highway, which runs from the northeast to the southwest of the map area; the Mid Western Highway, running east-west in the southern part of the map area; the Lachlan Valley Way, which runs from the centre of the eastern boundary to Condobolin, in the northwest of the map area; and the Barmedman Road, which affords access from the south to the town of Wyalong, in the southwest of the map area.

## Climate, physiography, and landuse

The Forbes 1:250 000 map sheet area has a warm, temperate climate with hot summers and mild to cool winters. January and February are the warmest months with mean daily maxima of 31°C to 33°C and daily minima around 16°C. July is the coldest month, with daily maxima and minima about 18°C and 2°C, respectively. The average rainfall varies across the map area from about 450 mm a year in the drier western part, to about 770 mm a year in the northeastern corner of the area. Throughout the map area, rainfall is more reliable in winter. The eastern third of the Forbes 1:250 000 map sheet area is hilly to rugged, as it is dominated by relatively moderately weathered granites (*sensu lato*), felsic volcanic rocks, and resistant Late Devonian quartz sandstones. Elevations range from less than 300 m above sea level, in valley floors, to over 700 m. The central part of the map area is dominated by plains, about 220 m to 250 m above sea level, hills, lake systems, and the strike ridges of the Jemalong Ridge. The western third of the map area is a mixture of plains, undulating rises, and hills — culminating in the steep slopes and small cliffs formed by the resistant sandstones and conglomerates

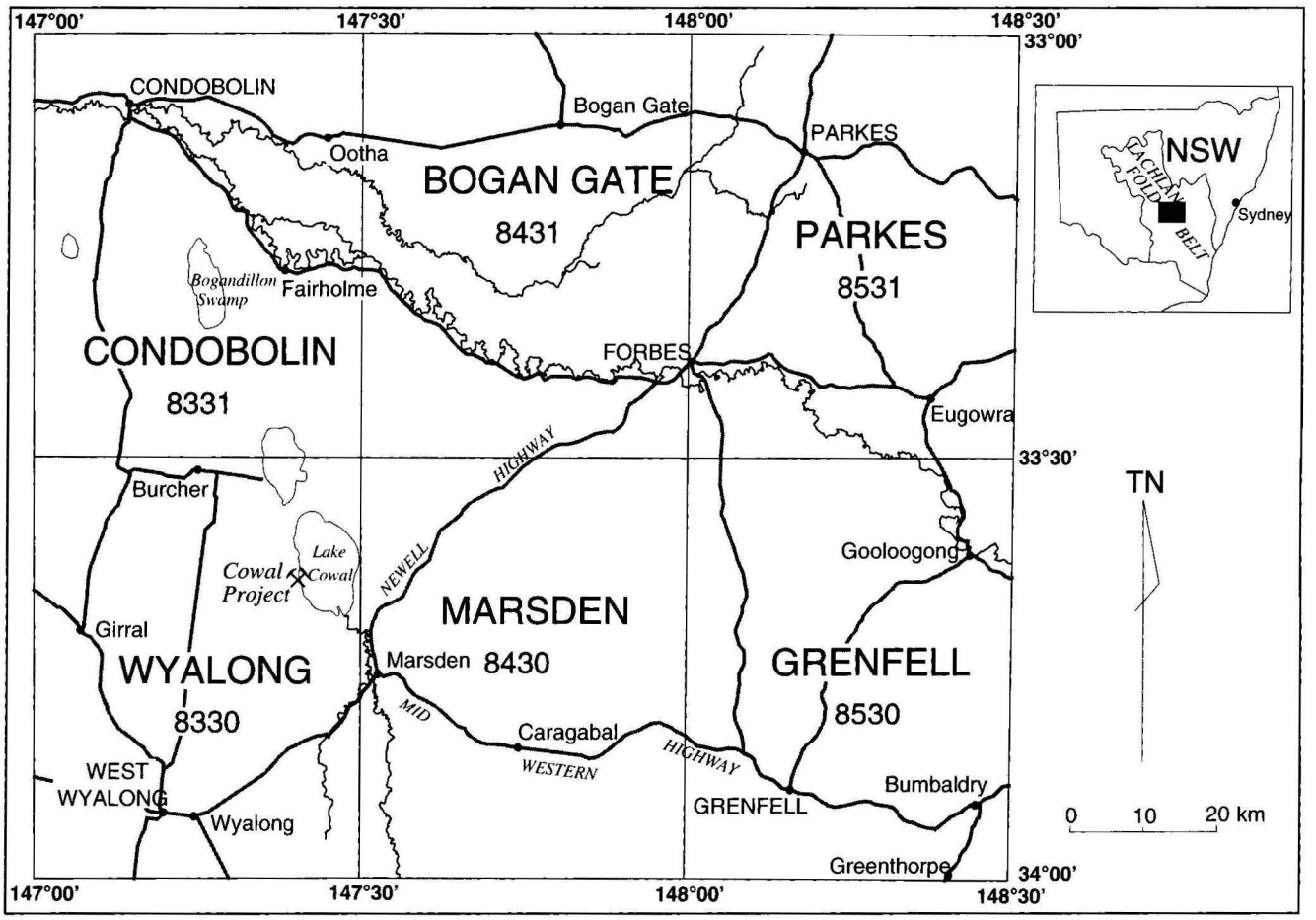



*Figure 1.1. Locality map for the Forbes 1:250 000 geological map sheet area. Also shown are the six component 1:100 000 map sheets, principal towns and localities, and major roads, rivers and lakes.*

Silurian–Devonian Ootha Group. The Lachlan River is the major watercourse, flowing in a generally northwesterly direction across the map area from Gooloogong to Condobolin.

The principal landuse in the Forbes 1:250 000 map sheet area is agriculture. The main winter crop is wheat, with lesser barley and oats and crop rotations of canola (rape), legumes, and pasture. Summer crops, principally maize and sorghum, rely on irrigation. Other landuses are National Parks, Nature Reserves, and State Forests. Mining and quarrying are on a small scale, although the discovery of some sizeable gold deposits, e.g., Cowal, may herald a significant increase in that sector.

King (1998) provided detailed descriptions of climate and physiography, and complemented those descriptions by including further references.

## Previous geological studies

Apart from some mine reports, theses, and reports on fossil occurrences, the first extensive study of the Forbes 1:250 000 map sheet area was by Andrews (1910). Conolly (1965a,b) studied the stratigraphy and origin of the Late Devonian Hervey Group. Sherwin (1971) studied the stratigraphy and palaeontology of the Forbes–Bogan Gate district; and Kemezys (1976) prepared a preliminary geological map of the area between Condobolin and West Wyalong. The first 1:250 000 scale geological map (Brunker, 1972), without explanatory notes, was largely based on aerial photograph interpretation, with ground work done mainly in areas of good outcrop in the east of the map area. Bowman (1976) used the map of Brunker (1972) as the base for his metallogenic map. Although numerous company reports, theses, and research papers have been written since publication of these maps, the only regional study in that time have been by Krynen *et al.* (1990) and Ingpen (1995).

## Mapping methods

The Forbes 1:250 000 map sheet area was mapped under the National Geoscience Mapping Accord (NGMA), a collaboration between the Commonwealth's Australian Geological Survey Organisation (AGSO) and the State geological surveys. This work was a collaboration between AGSO and the Geological Survey of New South Wales (GSNSW) as part of the Lachlan Fold Belt NGMA Project.

Mapping commenced in 1995, and was greatly assisted by use of detailed airborne magnetic, radiometric, and digital elevation data; and by ground-based gravity data. Detailed ground traverses were conducted in all areas of outcrop and significant subcrop. Sites and outcrops were located by the global positioning system (GPS). Compilation was carried out on 1:50 000 scale topographic map bases supplied by the New South Wales Land Information Centre and Australian Surveying and Land Information Group (AusLIG). All data pertaining to sites, including outcrop descriptions, structural measurements, thin sections, geochemistry and isotopic ages, are stored in AGSO's OZROX field database and GSNSW's COGENT database.

## Products

A range of products arising from the NGMA mapping of the Forbes 1:250 000 map sheet area is available:

Simplified solid geology map (1:250 000 scale)

Component geology maps (1:100 000 scale)

Depth to bedrock map (1:250 000 scale)

Regolith landforms map (1:250 000 scale)

Digital data package on CD. Digital map data are stored ARC/INFO, ArcView and MapInfo format.

Geophysical data and map sheets including airborne magnetic, gamma ray spectrometric and digital elevation data and ground-based gravity data.

# 2. GEOLOGICAL HISTORY

## Introduction

The geological history of the Forbes 1:250 000 map sheet area is summarised in the time-space diagram that accompanies the map sheet and is reproduced here (Figure 2.1). The history presented here is brief and is intended as an overview. Detailed accounts of the genesis, age, and boundary relationships of the map units are given in the unit descriptions.

## Ordovician

The oldest rocks are the Early Ordovician mafic Nelungaloo Volcanics and volcanic sandstones, cherts, and siltstones of the Yarrimbah Formation; both units sparsely crop out northwest of Parkes. The Yarrimbah Formation was deposited below wave base over the Nelungaloo Volcanics and contains Early Ordovician graptolites. Because of the restricted distribution of these two units, it is impossible to determine whether they represent the commencement of continuous Ordovician magmatism and associated sedimentation; or if there was a break between the volcanism and sedimentation of the Early Ordovician and the onset of arc volcanism and marginal basin sedimentation in the Middle Ordovician.

By the late Middle Ordovician, arc volcanism, associated with westward subduction, and sedimentation in marginal basins had commenced. The arc rocks are represented by the Lake Cowal Volcanic Complex and the Northparkes Volcanic Group, which were contiguous at the time. Porphyry-related gold and copper mineralisation, best represented in the sheet area by the Cowal gold deposit, accompanied formation of the Ordovician arc. The sediments of the Wagga and Girilambone Groups were depositing in the marginal basin to the west. Some sea floor spreading in this basin was associated with extrusion of the Narragudgil Volcanics.

At about the end of the Middle Ordovician the formation of a new arc to the east (not represented in the map sheet area), either by arc splitting (as in the present-day Marianas arc) or trench-rollback, created a new basin that became the site for further seafloor sedimentation mainly represented by the Kirribilli Formation and Mugincoble Chert. This basin floor, and evidence of spreading or rifting, is preserved as the basalts and dolerites of the Brangan Volcanics, and the ultramafic rocks of the Wambidgee Serpentinite.

During the Late Ordovician, Alaskan-type ultramafic magmas were emplaced into the Girilambone Group, and the sediments and volcanics of the little known Jingerangle Formation were deposited.

Sedimentation in marginal basins and arc volcanism was waning, or had ceased, by the end of the Ordovician Period. Siltstones of the Cotton Formation were deposited on the Northparkes Volcanic Group, and the deposition continued into the early Llandovery of the Silurian Period.

## Silurian

During the earliest Silurian, the Lachlan Fold Belt was subjected to the Benambran Orogeny, which probably commenced during the Late Ordovician. The deformation resulted in the closure of the marginal basins, thrusting of the Wagga Group over the volcanic arc, which initiated the Gilmore Fault Zone, and folding of the turbidite sequences. The Parkes and Coolac–Narromine Fault Zones were probably initiated at this time. The volcanic arc rocks appear to have been little, or inhomogenously, affected by orogeny. The associated uplift may have caused the cessation of deposition of the Cotton Formation.

Anatexis associated with crustal thickening and heating resulted in the generation of large volumes of S-type magma, and lesser amounts of I-type magma. The granites of the Ungarie Suite are the predominant examples of this magmatism. The regional metamorphic grade was no higher than greenschist facies, although there were localised areas of higher grade metamorphism. This episode of orogenic plutonism and volcanism continued until the end of the Early Silurian.

Sedimentation and volcanism during the middle Silurian was restricted to areas in the west and east of the map sheet area. East of the Coolac–Narromine Fault Zone, the S-type felsic volcanic rocks of the Douro Group were deposited in the Cowra Trough. The Forbes Group was derived from, and deposited over, rocks from the dormant remnants of the Northparkes Volcanic Group. In the west, the Burcher Greywacke was unconformably deposited on part of the Girilambone Group. Its detrital material was probably derived from the Ugalong Dacite, a volcanic cognate of the Ungarie Suite.

Minor deformation may have been occurring toward the end of the Silurian, as evidenced by hydrothermal mineralisation in the Condobolin area.

## Siluro-Devonian

Following the Benambran Orogeny, extension throughout the Forbes 1:250 000 map sheet area, possibly caused by retreat of the subduction zone, resulted in basin formation and marine incursion. Deposition of the conglomerates and sandstones of the Ootha and Derriwong Groups commenced during the Pridoli, or perhaps latest Ludlow of the Late Silurian, and continued until the middle Lochkovian of the Early Devonian. The axis of extension was located near the centre of the map sheet area and resulted in the formation of the Jemalong Trough. There, rifting separated the Lake Cowal Volcanic Complex from the Northparkes Volcanic Group and allowed the deposition of the Byong Volcanics, and their distal equivalents, produced by melting of some of the Ordovician arc basement. S- and I-type granites were also produced during

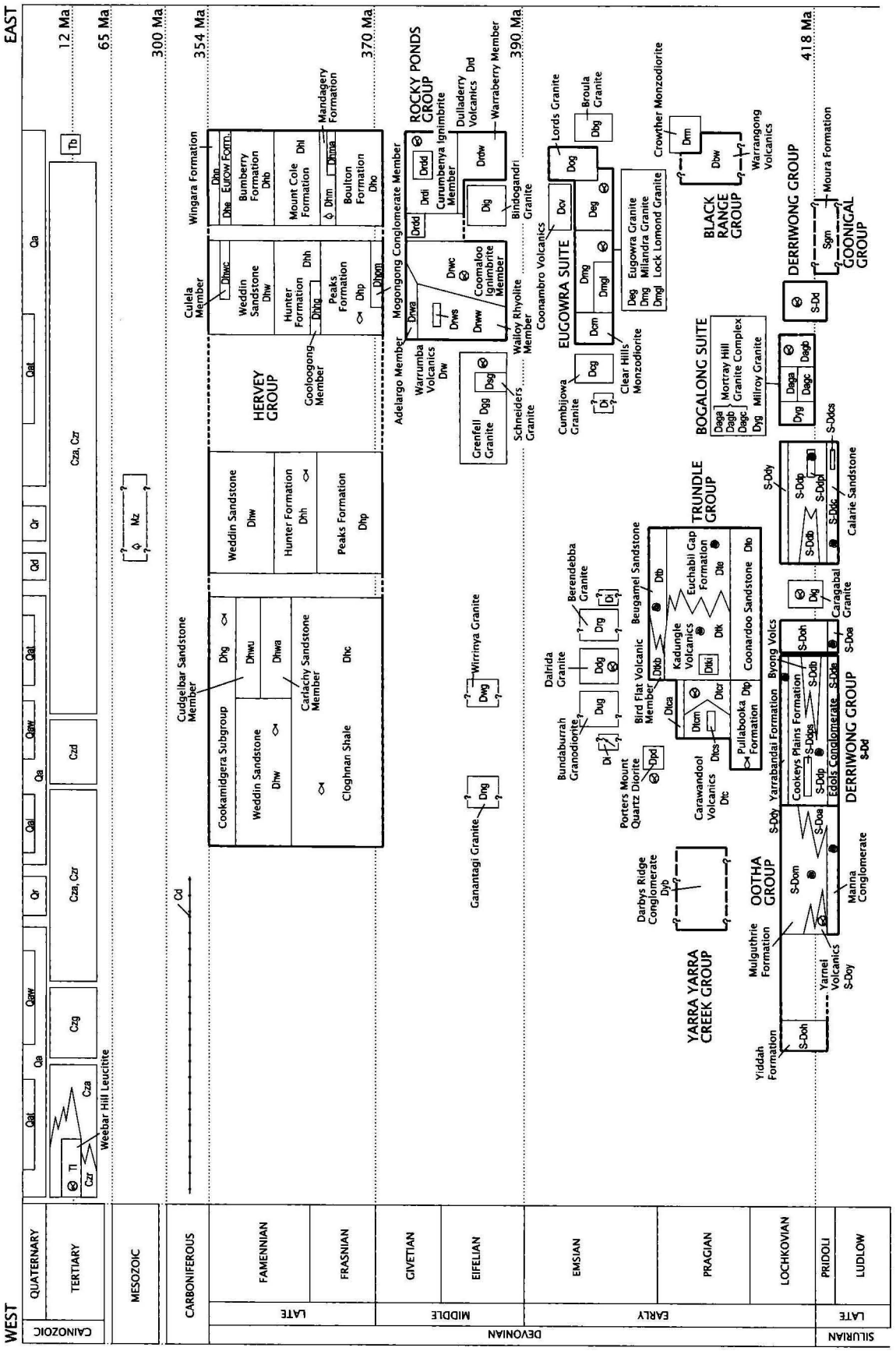
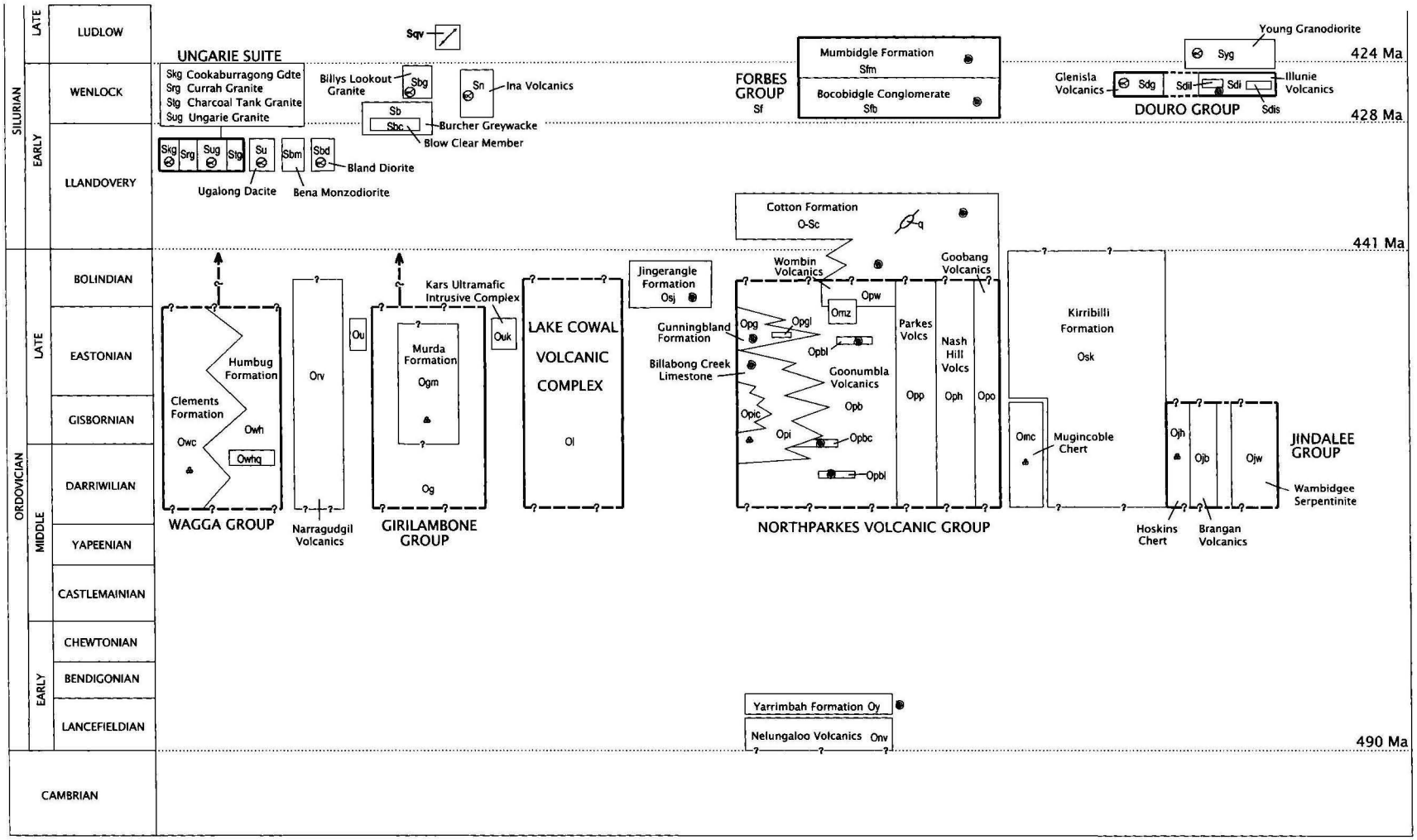



*Figure 2.1. Time–space plot for the Forbes 1:250 000 map sheet area.*


SILURIAN
ORDOVICIAN
CAMBRIAN
LATE
EARLY
MIDDLE
LUDLOW
WENLOCK
LLANDOVERY
BOLINDIAN
EASTONIAN
GISBORNIAN
DARRIWILIAN
YAPEENIAN
CASTLEMAINIAN
CHEWTONIAN
BENDIGONIAN
LANCEFIELDIAN
424 Ma
428 Ma
441 Ma
490 Ma
UNGARIE SUITE
Skg Cookaburragong Gdte
Srg Currah Granite
Stg Charcoal Tank Granite
Sug Ungarie Granite
Billys Lookout Granite
Sbg
Sqv
Sn
Ina Volcanics
Sb
Sbc
Burcher Greywacke
Blow Clear Member
Bland Diorite
Ugalong Dacite
Bena Monzodiorite
FORBES GROUP
Sf
Mumbidgle Formation
Sfm
Bocobidgle Conglomerate
Sfb
Young Granodiorite
Syg
Glenisla Volcanics
Sdg
Sdil
Sdi
Illunie Volcanics
Sdis
DOURO GROUP
Cotton Formation
O-Sc
Jingerangle Formation
Osj
Wombin Volcanics
Opw
Omz
Goobang Volcanics
Gunningbland Formation
Opg
Opgl
Opbl
Billabong Creek Limestone
Goonumbla Volcanics
Opb
Opic
Opi
Opbc
Parkes Volcs
Opp
Nash Hill Volcs
Oph
Opo
NORTHPARKES VOLCANIC GROUP
Kirribilli Formation
Osk
Omc
Mugincoble Chert
Ojh
Ojb
Ojw
JINDALEE GROUP
Wambidgee Serpentinite
Hoskins Chert
Brangan Volcanics
WAGGA GROUP
Humbug Formation
Clements Formation
Owh
Owc
Owhq
Orv
Narragudgil Volcanics
Ou
Kars Ultramafic Intrusive Complex
Ouk
Murda Formation
Ogm
Og
GIRILAMBONE GROUP
LAKE COWAL VOLCANIC COMPLEX
Ol
Yarrimbah Formation Oy
Nelungaloo Volcanics Onv

this crustal melting. The Cowra Trough, located to the east in the Bathurst 1:250 000 map sheet area, also formed during the Late Silurian extension, and a part of its fill is represented in the Forbes sheet area by the Moura Formation of the Goonigal Group.

## Devonian

The Devonian was a period of extensional and compressional tectonics, with associated plutonism and volcanism, and sedimentation in marine and subaerial basins.

Extension, interrupted by a brief hiatus with some minor folding, continued during the Early Devonian but became more confined to the Jemalong Trough where the sedimentary and volcanic rocks of the Trundle Group were deposited. The volcanic rocks of the Trundle Group were sourced, similarly to the Byong Volcanics, from melting of parts of the Ordovician arc. Sporadic epithermal alteration occurred in the Trundle Group volcanic rocks. A waning basin in the west of the sheet area became the site for deposition of outwash fan sediments producing the Darbys Ridge Conglomerate. Volcanic rocks of the Black Range Group were erupted in the Cowra Trough at this time, in the southeast of the sheet area.

Deformation during the early Emsian changed the tectonic regime, from extensional to compressional, sometime between about 410 Ma and 400 Ma. This resulted in reactivation of the Gilmore Fault Zone and formation of the Booberoi Shear Zone, and activation, or reactivation, of the Parkes Fault Zone and the Coolac–Narromine Fault Zone by thrusting and reverse faulting. The Trundle Group rocks were folded into the Currowong Syncline during inversion of the Jemalong Trough, and the Moura Formation of the Cowra Trough was folded at this time. Further crustal melting occurred during the Emsian deformation, producing large volumes of mainly I-type magmas, in contrast to the mainly S-type magmas of the Benambran Orogeny, particularly in the east of the sheet area where the granites of the Eugowra Suite, and the probably cognate Coonambro Volcanics, were emplaced.

The beginning of the Middle Devonian marked another change back to extension, resulting in the formation of rifts across the eastern Lachlan Fold Belt, accompanied the production of A-type magmas and bimodal, subaerial volcanism. In the Forbes 1:250 000 map sheet area, this rifting was manifest, in the east, by the intrusion of the Grenfell and Bindogandri Granites and the eruption and deposition of the volcanic rocks of the Rocky Ponds Group. Hydrothermal alteration and gold mineralisation was associated with the volcanic rocks, particularly in the southeast of the sheet area.

The Middle Devonian rifting may have been the start of basin formation resulting in a pan-Lachlan Fold Belt deposition of shallow marine and redbed sequences during the whole of the Late Devonian, and represented in the map sheet area by the fluviatile Hervey Group. It is not clear whether the present-day distribution of the Hervey Group marks the site of separate basins or whether it is the vestiges of a more widely-spread basin sequence. The presence of longitudinally distributed Hervey Group rocks within the Jemalong Trough may be evidence for the existence of separate basins. Regardless, it suggests that the Jemalong Trough remained a depocentre throughout the Devonian, despite the late Early Devonian inversion.

## Carboniferous

The last orogeny to affect the Lachlan Fold Belt, the Kanimblan Orogeny, occurred at the end of the Devonian Period and into the Carboniferous when the New England Fold Belt began to be accreted. The Kanimblan Orogeny caused open folding of the Hervey Group and older rocks (e.g., the Tullamore Syncline and Forbes Anticline), reactivation of the major fault zones, and the formation of new faults, such as the Bumberry Fault. Some limbs of synclines formed in Hervey Group rocks were steepened and overturned during reverse faulting. In the west of the sheet area, parts of the of Ordovician Lake Cowal Volcanic Complex were thrust eastwards, on the Marsden Thrust, over Hervey Group rocks of the Jemalong Trough.

Major gold mineralisation in the Silurian granites around West Wyalong occurred during the Kanimblan Orogeny, and probably did also in the Parkes Fault Zone.

Regolith formation may have commenced following the Carboniferous deformation and uplift.

## Post-Palaeozoic

During the Jurassic Period, north-flowing rivers, draining into the Surat Basin, deposited up to a kilometre of sediment, which is preserved and exposed in the northeast of the sheet area near Gunningbland. Tertiary volcanism, widespread through eastern Australia, is manifest in the eruption of leucitite lavas in the northeast of the sheet area. Some flood basalts from the Mount Canobolas eruption, east of the sheet area, are preserved northeast of Eugowra. Erosion and deep incision of the landscape took place through the Miocene, followed by sediment infill up to the present day.

# 3. ORDOVICIAN

## Jindalee Group (Oj) Basden (1982)

The Jindalee Group comprises mafic and ultramafic igneous rocks, metamorphosed to low grade, and associated metasedimentary rocks, principally chert. It occurs mainly in the Cootamundra and Wagga Wagga 1:250 000 map sheet areas to the south. In the Forbes 1:250 000 map sheet area, the Jindalee Group is more disrupted, but remains distributed along the controlling structure of the Coolac–Narromine Fault Zone.

*Nomenclature and derivation of name*

The Jindalee Group is named from Jindalee Hill (now known as Morrisons Hills, but the survey point is still called Jindalee Trigonometrical Station), GR 599600 mE 6177800 mN in the Cootamundra 1:250 000 map sheet area.

*Distribution and outcrop*

The Jindalee Group extends in a north–south belt, from the southern edge of the Forbes 1:250 000 map sheet area south of Grenfell to about 12 km due east of Parkes (Figure 3.1). Outcrop is not continuous, but the mafic rocks and cherts are well-exposed where they occur.

*Constituent units*

In the Forbes 1:250 000 map sheet area, the constituents of the Jindalee Group are the Brangan Volcanics, the Hoskins Chert, and Wambidgee Serpentinite. The newly recognised Brangan Volcanics and the Hoskins Chert, (formerly 'Hoskins Formation') have not previously been included in the Jindalee Group. However, Ryall (1974) and Gilligan & Scheibner (1978) suggested that the chert unit now named the Hoskins Chert may be correlated with the Jindalee Group. Warren *et al.* (1995) similarly suggested that the basalts and dolerites now named the Brangan Volcanics correlate with the Jindalee Group. New age data and structural continuity have allowed these correlations to be confirmed.

### Brangan Volcanics (Ojb) *nov*

*Derivation*

The Brangan Volcanics are named after Brangan Hill (also known as Birangan Hill) at GR 607700 mE 6262000 mN, about 13 km due north of Grenfell.

*Distribution*

The Brangan Volcanics occur mainly in the eastern part of the Forbes 1:250 000 map sheet area, from about 15 km due east of Parkes, at their northern end, to 5 km northwest of Grenfell, at their southern end. They are a discontinuous series of metabasalts and minor chert. The best-developed part of the sequence occurs at the southern end as a narrow (<2 km wide) body of metabasalt and minor chert about 12 km long. This body is enclosed by the Devonian Grenfell Granite. Small outcrops of the metabasalt occur throughout the Coolac–Narromine Fault Zone, notably at GR 616600 mE 6302000 mN and GR 616600 mE 6317000 mN.

*Type locality*

A type locality for the Brangan Volcanics may be found at GR 608100 mE 6265630 mN, a few hundred metres east of 'Akuna' homestead, south of Warraderry State Forest

*Description and geochemistry*

The Brangan Volcanics are MORB-type basalts and associated volcanogenic cherts. The Brangan Volcanics are relatively primitive (MgO ~7 wt%) olivine tholeiites, characterised by high HFSE contents (e.g., $TiO_2$ ~1.8 wt%), low $K/Na_2O$, and flat to slightly depleted LREE patterns. They are, thus, distinguished from the Northparkes Volcanic Group rocks in the Parkes–Forbes area. Cherts peripheral to the volcanic rocks are thinly bedded and sometimes banded.

*Environment of formation*

The Brangan Volcanics in the Grenfell area (and the Narragudgil Volcanics south of Wyalong) represent basaltic rocks of very different character to the Parkes/Forbes/Lake Cowal calc-alkaline volcanic rocks. The geochemistry of the Brangan Volcanics suggest that these MORB-type rocks were derived from depleted asthenospheric mantle, possibly in a well-developed back-arc basin or an intra-plate continental rift environment (S.-S. Sun, pers. comm., 1999).

*Age and relationships*

There are no absolute ages for the Brangan Volcanics. However, a Middle to Late Ordovician age is indicated by the probable equivalence of the minor associated cherts with the Hoskins Chert.

Contacts with the Kirribilli Formation and the Hoskins Chert are not exposed and are poorly understood. The minor cherts in the Brangan Volcanics are probably equivalent to the Hoskins Chert. The outcrop at GR 616600 mE 6302000 mN is inferred to be in faulted contact with the Kirribilli Formation. The part of the Brangan Volcanics enclosed by the Grenfell Granite is interpreted to be a detached slab of basement incorporated into the granite as a large roof pendant.

### Hoskins Chert (Ojh) modified from Bowman (1977a)

*Nomenclature, distribution, outcrop and type locality*

The Hoskins Chert, originally termed the 'Hoskins Formation' (Bowman, 1977a), is named after the Hoskins manganese mine (GR 604000 mE 6249500 mN), about 3 km west of Grenfell, which produced 25 700 tonnes of $MnO_2$ from 1915 to 1941. The Hoskins Chert occurs throughout the exposed extent of the Jindalee Group within

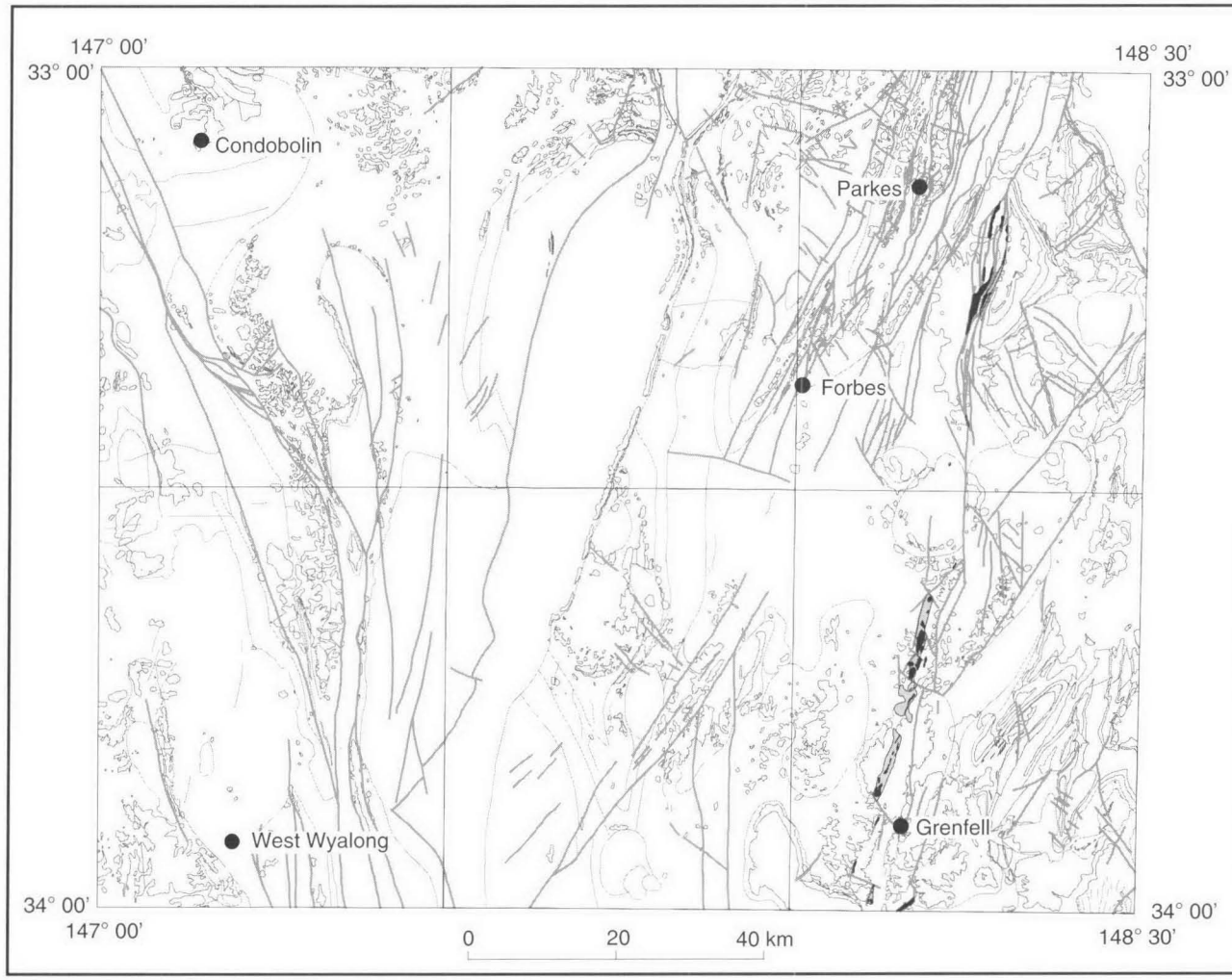



*Figure 3.1. Distribution of the Jindalee Group in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

the Forbes 1:250 000 map sheet area. Its most southerly outcrop is about a kilometre north of the southern boundary of the map area near GR 603000 mE 6238300 mN. The Hoskins Chert extends on a north-northeast trend to about 12 km east of Parkes. There is a 35 km gap in exposure, which is nearly coincident with the Lachlan River flood plain. The type locality is at the Hoskins manganese mine.

Outcrop of the Hoskins Chert varies from float and subcrop to excellent exposures near manganese mines and in quarries and creeks.

*Description*

The Hoskins Chert consists of reddish to purple and cream to grey cherts (Figure 3.2) and cherty siltstones, strongly deformed siltstones, and minor basalt. The cherts are generally bedded, often jasperoidal, and frequently manganiferous. Gilligan & Scheibner (1978) reported the presence of dismembered ophiolites in the Hoskins Chert.

Locally the chert has been subsumed by, and reacted with the volcanic rocks, resulting in intense ferruginisation causing recrystallisation of the chert to dark microcrystalline quartzite with sinuous veins of hematite. Localised concentrations of manganese (predominantly as rhodonite) produced by these reactions were sufficiently high to be commercially exploited, until the 1940s, at several localities within the Brangan Volcanics.

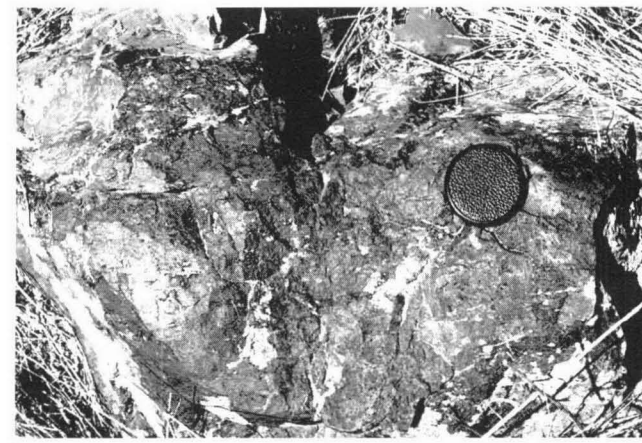


*Figure 3.2. Ferruginous chert in Hoskins Chert near Bald Hill. (GR 608100 mE 6265600 mN) (O.L. Raymond photograph)*

*Age and relations*

The presence of conodont *?Walliserodus* sp. in chert associated with the Brangan Volcanics (I.G. Percival, pers.

comm., 1999) has established that the volcanic rocks are of Ordovician age. If the Hoskins Chert correlates with the cherts elsewhere in the Jindalee Group, then the age can be constrained to Middle to Late Ordovician.

The contacts between the Hoskins Chert and the Brangan Volcanics and the Kirribilli Formation are nowhere exposed so the relationships remain uncertain. East of Parkes, some faulted contacts can be interpreted from magnetic data.

### **Wambidgee Serpentinite** (Ojw) Basden *et al.* (1978)

*Nomenclature and derivation of name*

Basden *et al.* (1978) named the Wambidgee Serpentinite after Wambidgee Railway Siding in the Cootamundra 1:250 000 map sheet area.

*Distribution, outcrop and description*

The Wambidgee Serpentinite is mapped at the southern boundary of the Forbes 1:250 000 map sheet area, about 11 km south of Grenfell, where it is about 1 km wide and 2.5 km long, and trends northeast–southwest. Although it does not crop out, its existence is recognised by the presence of very weathered and crumbly serpentinite and talc–carbonate float, in ploughed paddocks, and dark brown soil. A small outcrop existed until the late 1970s before it was broken up and ploughed into the soil.

The Wambidgee Serpentinite has a high magnetic intensity, with magnetic susceptibilities, measured in the Cootamundra 1:250 000 map sheet area, typically around $10\,000 \times 10^{-5}$ SI, and its distribution has been mapped using magnetic data.

The nearest outcrop of the serpentinite is at Arramagong Hill (GR 604150 mE 6231000 mN) in the Cootamundra 1:250 000 map sheet area. There it is a coarse-grained, serpentinised peridotite (M.B. Duggan, pers. comm., 1998).

*Boundary relationships and age*

The Wambidgee Serpentinite is enclosed by the Ordovician Kirribilli Formation. Although the contacts are not exposed, their sharpness, as inferred from magnetic data, and the nature of the serpentinite where it is exposed in the Cootamundra 1:250 000 map sheet area, strongly indicate that they are faulted contacts.

Cherts within the parent Jindalee Group contain Middle to Late Ordovician conodonts, *Aphelognathus* or *"Plectodina"* (Percival, 1999c).

## **Wagga Group** (Ow) Warren *et al.* (1995)

The Wagga Group comprises a thick quartz turbidite sequence occupying the southwestern part of the Forbes 1:250 000 map sheet area (Figure 3.3), extending south into the Cootamundra 1:250 000 map sheet area and beyond, and northwest past Ungarie into the Lake Cargelligo 1:250 000 map sheet area. Warren *et al.* (1995) summarised the general characteristics of the Wagga Group and proposed the name for the sedimentary and metasedimentary rocks of the Wagga Metamorphic Belt, previously referred to as 'Wagga Metamorphics'. In the Forbes 1:250 000 map sheet area, and adjoining Cootamundra 1:250 000 map sheet area, substantial portions of the Wagga Group are essentially unmetamorphosed — or are metamorphosed, at most, to lower greenschist grade. Higher grades of metamorphism are generally restricted to the easternmost outcrop areas adjacent to the Ungarie Granite and related rocks. Metasediments of the Wagga Group were extensively intruded by large S-type plutons, including the Ungarie Granite and Wantabadgery Granite.

Warren *et al.* (1995) recognised three units (sequences) within the Wagga Group in the Cootamundra 1:250 000 map sheet area, based on lithological differences, but did not name them or depict them separately on the map. Equivalents of these units are distinguishable in the Forbes 1:250 000 map sheet area and have been upgraded to formation status as the Clements Formation and the Humbug Sandstone.

### **Clements Formation** (Owc) *nov*

*Nomenclature, derivation, distribution and relations*

The lithological characteristics of the Clements Formation are similar to those of sequence 1 of the Wagga Group described by Warren *et al.* (1995). The name is derived from Clements Lane, a minor road joining the Mid-Western Highway and Tallimba Road, 15 km west of West Wyalong.

The Clements Formation forms the western outcrop areas of the Wagga Group in the southwestern corner of the Forbes 1:250 000 map sheet area, extending from the southern boundary of the map sheet area to just north of the Mid-Western Highway. In the area of the Condobolin 1:100 000 map sheet, the Clements Formation forms the eastern outcrop area and occurs as ridges along a north-northwest to south-southeast trend, west of Humbug Creek. Previously, the latter outcrops had been mapped by Kemezys (1976) as the Devonian Euglo Formation. There are also inliers surrounded by the Weebar Hill Leucitite adjacent to Wallaroi Creek.

Generally, contacts of the Clements Formation are concealed by unconformably overlying Cainozoic and Quaternary alluvium, colluvium, or the Weebar Hill Leucitite. In the southwestern corner of the Forbes 1:250 000 map sheet area the contact with the Humbug Sandstone is possibly exposed, but the deep weathering makes its precise identification difficult and it can only be narrowed to a few hundred metres. The contact with the Ugalong Dacite is interpreted as unconformable, and the Clements Formation is faulted against the Burcher Greywacke, Ordovician ultramafic rocks, and the Girilambone Group. It has been intruded by the Silurian Ungarie Granite and Carboniferous mafic dykes.

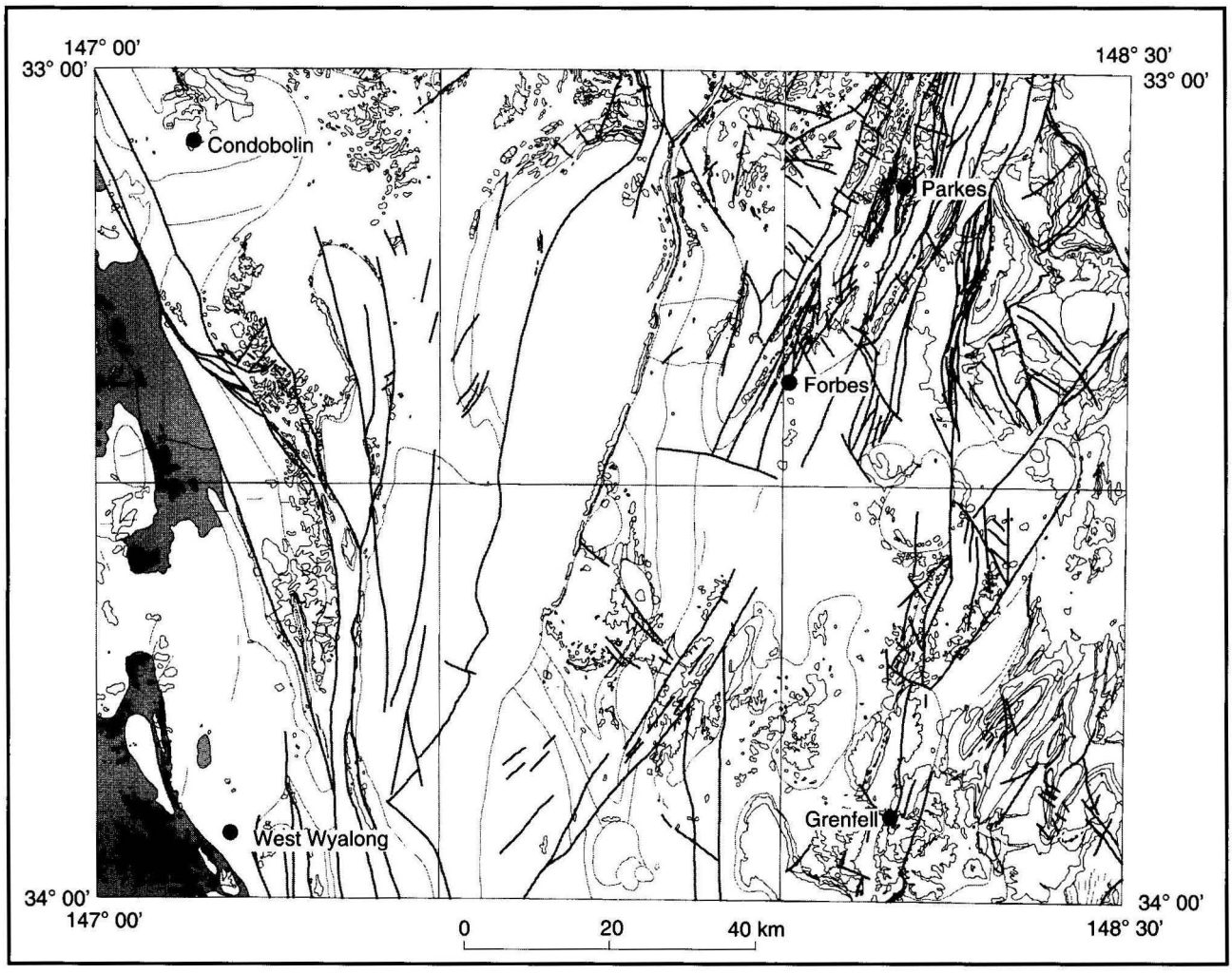



*Figure 3.3. Distribution of the Wagga Group in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

*Representative localities*

No type section has been identified for the Clements Formation but a representative section crops out on Tallimba Road, between Clements Lane and Charcoal Tank Road, in the south western corner of the Forbes 1:250 000 map sheet area. Other well-exposed representative areas are road base quarries from GR 504100 mE 6311200 mN to GR 504700 mE 6310700 mN.

*Description and outcrop*

The Clements Formation typically consists of finely laminated quartzose sandstones and siltstones, siliceous shales and cherts, interbedded with more massive fine-grained sandstone units and, west of West Wyalong, thick, prominently outcropping chert horizons. Finer-grained sequences are often laminated on the centimetre scale (Figure 3.4).

Interbedded sandstone and siltstone of the Clements Formation show turbiditic characteristics, with BCD Bouma horizons common, asymptotic cross-bedded C horizons, convolute bedding, abrupt bases and grading (Figures 3.5, 3.6). The cherts form grey to honey-coloured translucent beds, 1 cm to 10 cm thick, containing conodonts.

Bedding in the Clements Formation has steep to moderate dips on the limbs of tight to isoclinal folds, which have variable plunge from shallow to vertical. Mesoscopic folds are common, and have a spaced cleavage with aligned biotite and sericite. At GR 512470 mE 6293200 mN an earlier cleavage is crenulated by a 5 mm-spaced metamorphic segregation banding with aligned sericite. Fold plunges and strike trends are the north–south or north-northeast–south-southwest — which is anomalous, as most of the Wagga Group trends northwest–southeast (e.g., Warren *et al.*, 1995).

Thin sections of quartzose sandstone, lithic sandstone and quartzite were described by Barron (1998), as grey, beige, reddish brown, and cream coloured, with well-sorted 0.5 mm- to 2 mm-sized grains. Quartz grains include possible worn volcanic quartz, and lithic fragments recognised are rhyolitic crystal chips, microcrystalline ?felsite, crenulated mudstone, and metasandstone. Accessory biotite, muscovite, feldspar, (Ti-)magnetite, apatite, zircon, tourmaline, and ankerite in the matrix make

up the sandstones. Staining for potassium was positive in 2% to 20% of samples (diffusely to differentially) in the matrix and some grains, and by clay absorption along bedding planes.

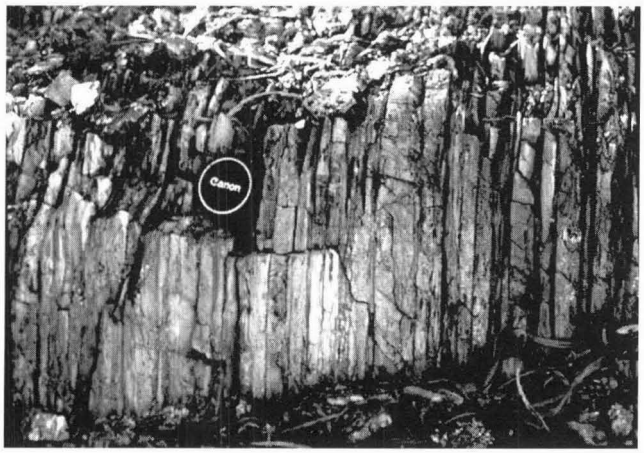



*Figure 3.4. Laminated chert interbedded with shale and siltstone (metamorphosed to slate and phyllite) of the Clements Formation. (GR 503500 mE 6241300 mN) (M.B. Duggan photograph)*

*Figure 3.5. Interbedded sandstone and siltstone of the Clements Formation. (GR 504130 mE 6311240 mN) (M.M. Scott photograph)*

Aligned biotite and sericite formed during the earliest deformation of the Wagga Group, and are overgrown by 0.3 mm to 2 mm cordierite porphyroblasts that are retrogressed to massive and bladed muscovite, illite, and sericite (Barron, 1998). The cordierite is commonly not rotated, but some samples are bearded and subrotated, indicating compression during regional metamorphism. Widespread cordierite development in the Wagga Group indicates high palaeo-heatflows with broad (regional-like) contact metamorphic aureoles around Silurian granites. The inliers at the Weebar Hill Leucitite, and outcrop at GR 512470 mE 6293200 mN, have sericite as the highest grade regional metamorphic mineral species, which indicates a cordierite–biotite/muscovite–sericite isograd trends north-northwest parallel to the Gilmore Fault Zone.

Rocks of the Clements Formation have low magnetic susceptibilities ($5 \times 10^{-5}$ SI to $20 \times 10^{-5}$ SI), and relatively high K and Th count rates on aerial radiometric images.

*Figure 3.6. Interbedded sandstone and asymmetric cross-bedded shale with erosional bases in the Clements Formation. (GR 504700 mE 6310700 mN) (M.M. Scott photograph)*

*Age*

Orange–brown and grey–white cherts and light brown cherty siltstones of the Clements Formation exposed in three road base quarries, near Wallaroi and Humbug Creeks (GRs 504100 mE 6311200 mN, 508500 mE 6296500 mN, 507100 mE 6299400 mN) contain diverse and abundant Darriwilian conodonts (Percival, 1999a). They include *Pygodus serra* and *Eoplacognathus* sp., indicating a Da2 to

Da4 range, from the middle *variabilis* to *anserinus* conodont zones (Percival, 1999a).

*Environment of deposition*

The turbiditic character of the beds, and the conodont fauna in the cherts, indicate deep-water basinal deposition for the Clements Formation. Detrital lithic grains indicate the source region was quartz-rich, metamorphosed and deformed, and included felsic volcanic rocks.

## **Humbug Sandstone** (Owh, Owhc) *nov*

*Nomenclature, derivation, distribution and relations*

The lithological characteristics of the Humbug Sandstone are similar to those of sequence 3 of the Wagga Group described by Warren *et al.* (1995). The name is derived from Humbug Creek, which drains a substantial part of the outcrop area of the unit northwest of West Wyalong

The Humbug Sandstone is more extensive than the Clements Formation and occupies a corridor extending from the southern boundary of the Forbes 1:250 000 map sheet area south of West Wyalong to the western boundary, near Weebar Hill, west-southwest of Condobolin.

Most of the outcrop margins of the Humbug Sandstone are unconformably overlain by Cainozoic alluvium and colluvium. The Humbug Sandstone has conformable and faulted contacts with the Clements Formation and is unconformably overlain by the Silurian Ugalong Dacite. It was intruded by the Ungarie Granite, the Charcoal Tank Granite, and the Cookaburragong Granodiorite, all of Silurian age. The contacts with those granitoids are not exposed, but a mixed contact, resembling a migmatite, with abundant high-grade xenoliths of Wagga Group rocks in the Ungarie Granite (Figure 3.7) can be seen in exposures in the creek near Rootes Lane (GR 509900 mE 6258800 mN). A high-grade aureole, about a kilometre wide, surrounds the Charcoal Tank Granite. In places, the contact with the Ungarie Granite is faulted, as shown by the presence of mylonite at the contact on the western side a low hill about 9 km west-northwest of West Wyalong. Mafic dykes of ?Carboniferous age are interpreted to have also intruded the Humbug Sandstone.

*Representative localities*

No type section has been defined for the Humbug Sandstone. A representative locality is beside Tallimba Road, 2 km west of the Newell Highway junction (GR 514000 mE 6244500 mN); and there is a steeply dipping, westward-younging sequence, from GR 503700 mE 6308200 mN to GR 500000 mE 6307300 mN. Consistent younging directions for bedding along this transect suggest a minimum thickness of 2 km, with further section to the west in the Cargelligo 1:250 000 map sheet area.

*Description*

The Humbug Sandstone consists of interbedded sandstone, siltstone, phyllite, and massive quartzite. Rock types are laterally continuous and can be followed along strike, with quartzite forming distinctive marker horizons along ridges. Cleavage is weakly developed in finer-grained beds, being rough, anastomosing, discontinuous, and commonly subparallel to bedding. Magnetic susceptibilities are low ($5 \times 10^{-5}$ SI to $15 \times 10^{-5}$ SI). On gamma ray spectrometric images, outcrop areas show relatively high K and Th count rates, except for low-count rate quartzites.

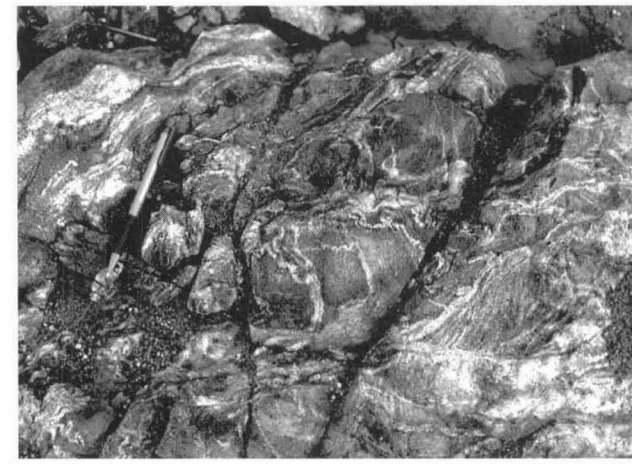


*Figure 3.7. High grade metamorphic rocks of the Wagga Group near the contact with the Ungarie Granite. Some of the leucosomes may be granite veins. (GR 508870 mE 6263870 mN) (M.B. Duggan photograph)*

The sandstones and siltstones of the Humbug Sandstone are cream, beige, olive or grey, and have bedforms that vary from 1 m to 2 m thick. They vary from internally massive to thinly interbedded and laminated (Figure 3.8). Cross beds with straight and curved crests, erosional truncations, and grading in the sandstone and siltstone are common (Figure 3.9).

Barron (1998) described thin sections of quartz- and lithoclastic rocks of the Humbug Sandstone containing accessory magnetite, tourmaline, and zircon. When stained for potassium, 5% to 12% of each rock, mostly the interstitial clay component, was positive. Regional metamorphism formed cordierite spots, aligned muscovite, sericite, and biotite, overgrowths on tourmaline, and porphyroblastic blades of ankerite. Cordierite is retrogressed to pinite. Weathering has formed limonite in outcrops.

The quartzite of the Humbug Sandstone (Owhc) is commonly massive, although there is occasional internal bedding, (Figure 3.10), and forms laterally continuous beds. As the quartzite forms outcrops in isolation, the exact nature of their relationship to the rest of the unit is unclear. It is light grey to beige, with a sugary texture, and with rounded quartz grains from 0.05 mm to 0.3 mm. At the Gnarly Au prospect (GR 500200 mE 6313300 mN; Palmer, 1998), there is intense silicification and alteration, with recrystallisation and suturing of quartz grains. Alteration at the Gnarly prospect may be due to hydrothermal fluid flow at the margin of the Cookaburragong Granodiorite. Quartzites of the Humbug Sandstone have low magnetic susceptibilities ($<5 \times 10^{-5}$ SI), and low K and Th count rates.

Barron (1998) described thin sections of quartzite containing accessory tourmaline, magnetite, muscovite, ?feldspar, zircon, apatite, and a trace of digenetic sulphide. Regional metamorphism formed overgrowths on tourmaline. Deformation produced strong suturing of grain contacts and grain reshaping, forming a vague foliation with trace sericite.

*Figure 3.8. Thinly interbedded sandstones and siltstones of the Humbug Sandstone. (GR 500210 mE 6305680 mN) (M.M Scott photograph)*

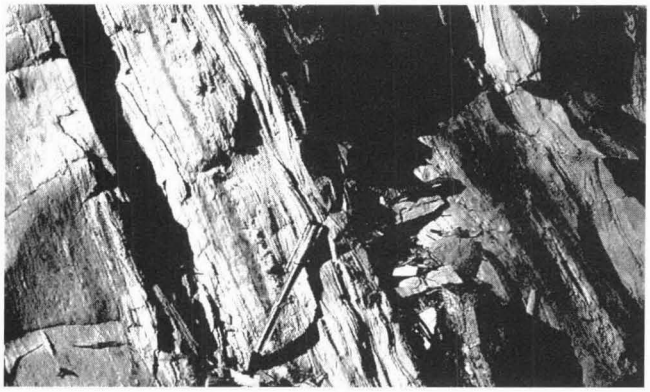


*Figure 3.9. Small-scale cross-bedding in fine-grained sandstones of the Humbug Sandstone. (GR 511140 mE 6248700 mN) (M.B. Duggan photograph)*

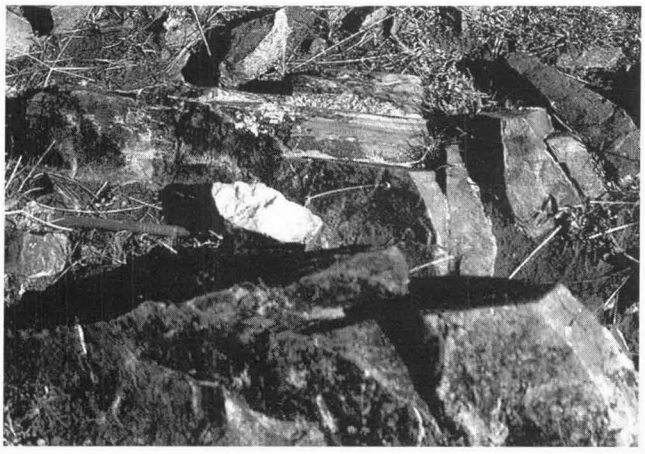


*Figure 3.10. Internal bedding in quartzite unit in the Humbug Sandstone near the Lauriston prospect. (GR 502340 mE 6307720 mN) (M.M. Scott photograph).*

*Age*

No fossils have been found in the Humbug Sandstone, but its age is probably similar to the Clements Formation by stratigraphic considerations.

*Environment of deposition*

The thick sequence of laterally extensive turbidites of the Clements Formation, and laterally continuous massive very quartz-rich sand deposits of the Humbug Sandstone, indicates deposition in a deep marine basin.

## **Girilambone Group** (Og) modified from Andrews (1915)

*Nomenclature, derivation, distribution and relations*

Andrews (1915) described "... sandstones, quartzites, slates, phyllites, and schists ..." cropping out near Hermidale and Girilambone northwest of Nyngan, and named them the 'Girilambone Series'. Russell & Lewis (1965) and Rayner (1961; 1969) renamed the unit the Girilambone Group and recognised low metamorphic grade and multiple deformations. Brunker (1969) included the 'Ballast Beds' (Ballast Formation) and 'Weltie Beds' and changed the name to 'Girilambone Beds', although later authors (Baker *et al.*, 1975; Baker, 1978) considered the 'Ballast Beds' to lie unconformably over the 'Girilambone Beds' because of their lower metamorphic grade and lesser deformation. Pogson & Felton (1978), noting that the differences in grade and deformation were gradational, re-incorporated the 'Ballast Beds', and restored the name Girilambone Group to comply with the International Stratigraphic Code (Pogson, 1982).

More-complete descriptions of the nomenclature of the Girilambone Group may be found in MacRae (1987), Pogson (1991), and Glen (1994).

The Girilambone Group is named after the town of Girilambone (Cobar 1:250 000 map sheet area).

The Girilambone Group has a wide distribution in central New South Wales, cropping out in the northwestern part of its range between Nyngan and Cobar, and north to Bourke. The southern end of this belt crops out in the western part the Forbes 1:250 000 map sheet area (Figure 3.11).

Within the Forbes 1:250 000 map sheet area, the Girilambone Group crops out around and north of Condobolin, and about 25 km east-northeast of Condobolin. South of the Lachlan River, where it has not been previously recognised, it occupies a narrow arcuate belt, immediately west of the Booberoi Shear Zone, and extends from Burcher and Nerang Cowal State Forest, to just south of the railway crossing on Wilsons Lane (GR 530600 mE 6265000 mN). Kemezys (1976) mapped these rocks as the Silurian Banar Formation.

As the bottom of the Girilambone Group is not exposed, it has uncertain basal stratigraphic relationships. Also, because of its poor outcrop, contacts with other units are

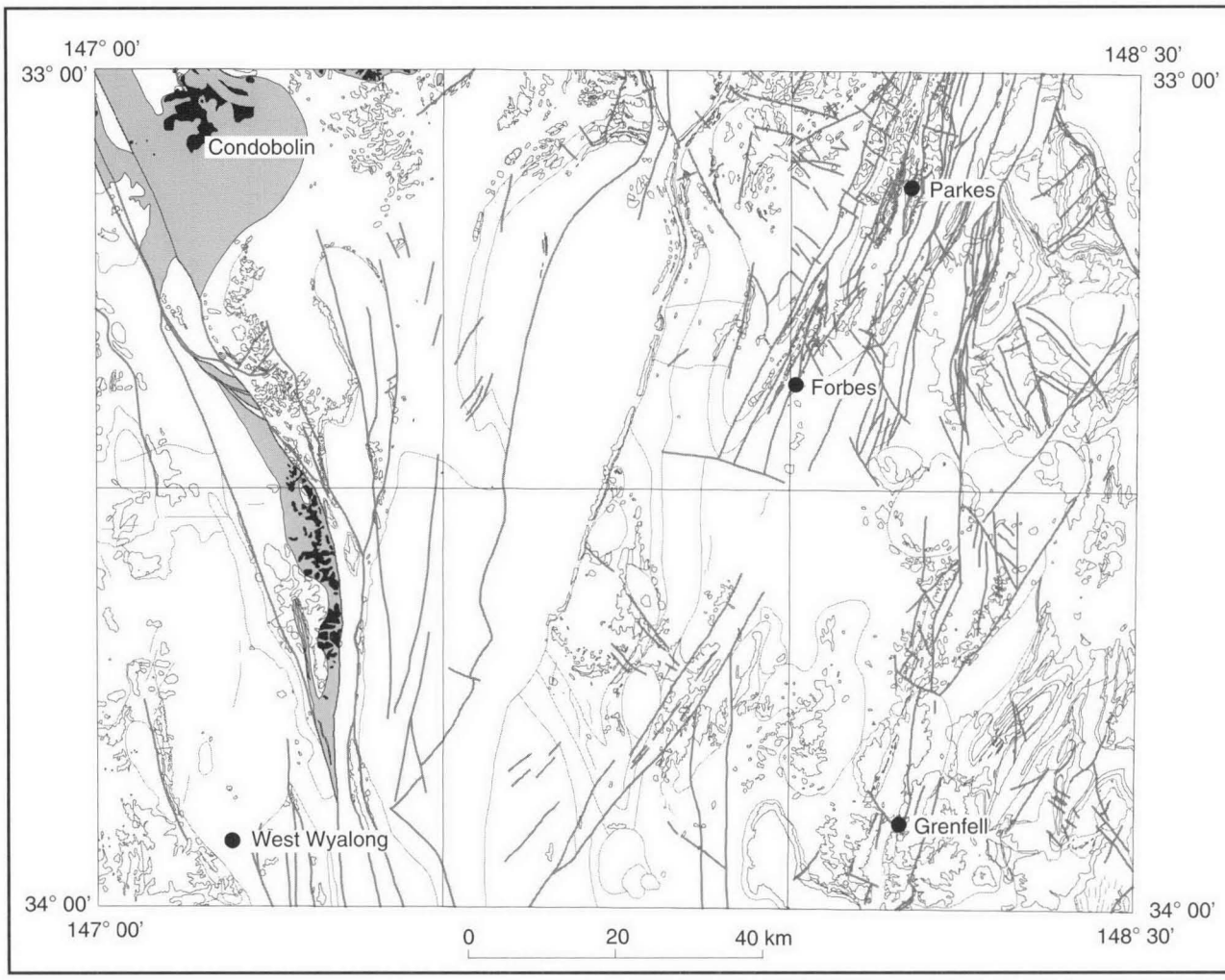



*Figure 3.11. Distribution of the Girilambone Group in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

not exposed, but may be strongly inferred. It is faulted against the Ordovician Lake Cowal Volcanic Complex, and it is unconformably overlain by the Silurian Burcher Greywacke; ignimbrite of the Silurian Ina Volcanics; the Siluro-Devonian Manna Conglomerate; and Cainozoic deposits. It has been intruded by the Silurian Billys Lookout Granite and the Ina Volcanics (in part). Within the Gilmore Fault Zone, the unit has inferred faulted contacts with undifferentiated Ordovician ultramafic rocks and the Siluro-Devonian Ootha Group.

*Constituent units*

North of Condobolin, magnetite quartz sandstone, red siltstone, phyllite and chert, which comprise the Murda Formation, are differentiated within the Girilambone Group.

North of the Forbes 1:250 000 map sheet area, the Girilambone Group has been differentiated into the Alandoon Chert, Break O'Day Amphibolite (Pogson, 1991), Mount Dijou Volcanics, Merrere Conglomerate Member (Byrnes *et al.*, 1992), Whinfell Chert Member (Gilligan *et al.*, 1994), Ballast Formation (Iwata *et al.*, 1995), Mount Royal Formation, Bogan Schist and Carolina Forest Formation of the Tottenham Subgroup (Sherwin, 1996), Tritton Formation (Fogarty, 1998) and Murrawombie Schist (Berthelsen, 1998).

*Type area and thickness*

The type area for the Girilambone Group is in the vicinity of the Girilambone Copper mine (Andrews, 1915). Well-exposed representative sections in the Condobolin region are nominated at a road base quarry (GR 511200 mE 6345600 mN) and Condobolin railway cutting (GR 514100 mE 6339250 mN). South of the Lachlan River, a section of the Girilambone Group is exposed in a cutting of the West Wyalong–Burcher railway at GR 522960 mE 6281800 mN. The thickness of the Girilambone Group is not known due to its structural complexity and the lack of basement exposure. On the northeastern limb of the Condobolin Anticline, where there is some bedding control, the Girilambone Group has an approximate maximum outcrop thickness of 3 km. This is an estimated maximum as mesoscopic folding has structurally thickened the unit.

*Description*

In the Forbes 1:250 000 map sheet area, the Girilambone Group is typical of other areas of the group mapped

elsewhere (e.g., Pogson, 1991; Sherwin, 1996), and consists of tightly folded turbiditic quartzose siltstone, phyllite, greywacke/sandstone, and chert. With the exception of the chert, rocks of the group are characteristically laminated with a millimetre-scale differentiated layering ($S_2$), usually parallel to bedding. Where the proportion of micaceous layering is relatively high, the rocks are almost schistose. The metamorphic grade is low but may have attained mid-greenschist facies. Outcrop of the Girilambone Group is generally poor and it is moderately to strongly weathered. In some exposures, the differentiated layering has been etched by weathering with the quartz-rich layers standing proud of micaceous layers by about a millimetre. In more weathered rock, it can take on the appearance of a deeply weathered flow-banded rhyolite. Colours in outcrop vary: generally grey to cream or yellow, green, and reddish purple.

The quartz-rich layers are dominated by poorly sorted, subangular to subrounded quartz (about 90%) up to 1 mm, with undulose extinction. Grain boundary suturing is common and the finer-grained quartz shows a weak preferred orientation. They also contain minor detrital feldspar (about 5%) and ?tuffaceous quartz chips, and accessory muscovite, biotite, magnetite, apatite, zircon, tourmaline, titanite, and rutile (Barron, 1998). The micaceous layers consist of fine-grained muscovite, biotite, and chlorite (after biotite).

Most of the Girilambone Group has low magnetic susceptibilities ($5 \times 10^{-5}$ SI to $20 \times 10^{-5}$ SI), although within the Murda Formation, and occasionally elsewhere they reach $500 \times 10^{-5}$ SI. On total magnetic images the unit shows generally low magnetisation, except for linear anomalies with a north-northwest trend, west of Billys Lookout, which are interpreted to be ultramafic rocks — *cf.* Yathella Serpentinite (Sherwin, 1996) — either faulted into place, or as transposed layers. Gamma ray spectrometric images show that the group has relatively low to moderate Th, and low K except for an arcuate high-K anomaly adjacent to quartz veins north of Condobolin.

Bedding ($S_0$) in the Girilambone Group is only occasionally seen in outcrop, although this may reflect the scarcity of outcrop rather than a complete overprinting of $S_0$ during deformation. In the cutting on the West Wyalong–Burcher Railway, graded bedding is clearly visible and has not been obliterated by the development of later fabrics (Figure 3.12). Cross bedding and erosional bases can be seen in outcrops around Condobolin.

Pogson (1991) identified $S_1$, in thin section, as rare relict mica lenticles with their mineral cleavage discordant to bedding. Around Condobolin, $S_1$ may be occasionally seen in outcrop as a weakly developed, spaced cleavage. The dominant planar fabric is $S_2$, which is a metamorphic differentiation, or an enhancement of $S_0$. It is usually parallel to bedding and is generally upright with a meridional to sub-meridional strike. Associated $F_2$ folds of bedding are very rare. Near Condobolin, where the best outcrops are, a near-recumbent $F_2$ fold of bedding contains a 1 mm to 5 mm, spaced, quartz-muscovite metamorphic segregation, axial plane cleavage ($S_2$) that overprints $S_1$ (Figure 3.13).

A variably spaced crenulation cleavage, $S_3$, overprints the earlier fabrics in the Girilambone Group and is well-developed in the mica-rich rocks (Figure 3.14). In the psammites it is partitioned into centimetre-scale folds. It is generally parallel, or sub-parallel, to $S_2$ in $F_3$ limbs.

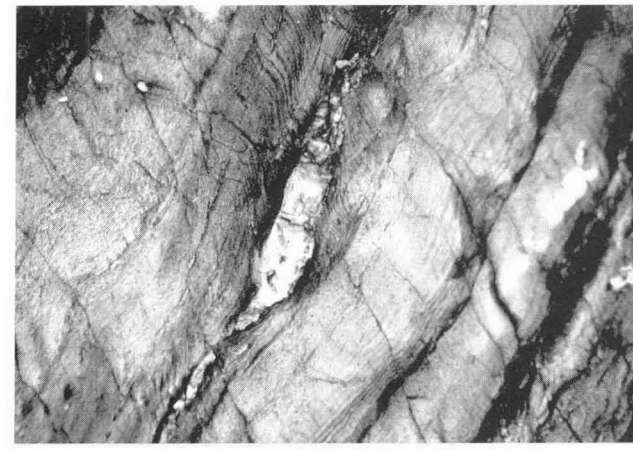


*Figure 3.12. Graded bedding ($S_0$), $S_2$, and $S_3$ visible in Girilambone Group rocks in a cutting on the West Wyalong–Burcher Railway. Bedding (steeply west-dipping) is defined by compositional banding, shown as light grey to dark grey. The light grey bands are psammitic beds that grade into the dark grey pelites. $S_2$ is parallel to bedding, but is difficult to see in this photograph. $S_3$ can be seen as a fine banding, running from top left to bottom right, in the top centre of the photograph. The dismembered quartz vein, shown in the centre, is parallel to $S_2$, although the boudinage suggests that it may have formed in $S_1$. (Field of view approx. 15 cm × 10 cm). (P. Lyons photograph)*

*Figure 3.13. $S_0$, $S_2$, and $F_2$ in Girilambone Group rocks exposed in the Condobolin railway cutting. (GR 514500 mE 6339250 mN) ( M.M. Scott photograph)*

A regional event that folded the overlying Siluro-Devonian rocks resulted in a reorientation of Girilambone Group structures in the Condobolin Anticline (Scott, 1999), but did not result in any discernible fabric development within the group.

In places, centimetre-scale kinks in the Girilambone Group are evidence of a post-$D_3$ event. However, the lack of outcrop makes the meaning of these kinks an uncertain one.

*Table 3.1. Bedding, and other surfaces, folds and deformations of the Late Ordovician to Early Silurian Benambran Orogeny, recognised in Girilambone Group rocks around Condobolin.*

| Structural Elements | | | Description | Orientation |
|---|---|---|---|---|
| $S_0$ | | Bedding | Cross bedding, grading, erosional bases in thinly bedded turbiditic sandstone and siltstone, not commonly recognised in outcrop. | Dips northeast on northern limb of Condobolin Anticline, variable dips on southern limb due to $F_2$, $F_3$ folding. |
| $S_1$ | $D_1$ | Cleavage | Weak developed and rarely preserved, with no associated $F_1$ folds observed. | Shallow to moderate angle to $S_2$ cleavage. |
| $S_2$ | $D_2$ | Quartz-sericite differentiated cleavage | Dominant structural fabric with striped appearance from metamorphic segregation of quartz and sericite. Axial plane to $F_2$ folds and crenulates $S_1$. | Mean of 52°/054° and 42°/182° on limbs of Condobolin Anticline. |
| $F_2$ | $D_2$ | Mesoscopic folds | Rare, tight to isoclinal, near-recumbent folds (see Figure 3.13). | A single measurement of 29°/213°. |
| | | Condobolin Anticline | Macroscopic fold with angular fold closure, and no associated cleavage. Delineated by folded $S_2$ and $S_0$. | |
| $S_3$ | $D_3$ | Crenulation cleavage, kink band axial surface | Crenulation cleavage and axial surfaces to kink bands, across which $S_0$, $S_1$, $S_2$ are reoriented. | Preferred direction 77°/301° with mean 49°/293°. Also subhorizontal kink fold axial surfaces. |
| $F_3$ | $D_3$ | Kink folds, mesoscopic folds | Kink bands, chevron and rounded, conjugate and box kink folds, and mesoscopic folds with round fold closures. | Plunge north and south down limbs of the Condobolin Anticline. |

*Figure 3.14. Early $S_1$ cleavage overprinted by a differentiated layering ($S_2$) formed by strong metamorphic segregation into granoblastic quartz and sericite. Both of these fabrics are overprinted by $S_3$ kink bands. Girilambone Group near the Phoenix mine. Cross polars. Field of view 3.5mm x 2.2mm. (GR 511250 mE 6343520 mN) (M. Scott photograph)*

Whether or not they have been formed in response to a regional stress or to movement on the Gilmore Fault Zone is not known. Pogson (1991) identified a fourth order structural surface in Girilambone Group rocks close to the Cobar Supergroup and in fault-bounded blocks.

In the Condobolin area, two structural domains in the Girilambone Group are recognised by consistently oriented structural elements on the limbs of the Condobolin Anticline. North of the anticline, $S_0$ strikes northwest to southeast and $S_2$ dips moderately to the east-northeast. South of the anticline, $S_2$ commonly dips moderately to steeply to the south and southeast. The Condobolin Anticline plunges 26° towards 120°, but has no associated axial plane cleavage. Massive, milky-white quartz veining is abundant in the Girilambone Group, and is associated with the deformation and metamorphism. Structural elements of the Girilambone Group rocks around Condobolin are summarised in Table 3.1.

Folding ($F_{1-3}$) and metamorphism of the Girilambone Group occurred during the Late Ordovician to Early Silurian Benambran Orogeny (Pogson & Felton, 1978; Scott, 1999).

*Age*

Late Ordovician conodonts were obtained from samples of the Murda Formation (Percival, 1999a). These are comparable to Darriwilian to Gisbornian age conodonts and radiolaria obtained from chert and black siliceous mudstone of the Ballast Formation (Stewart & Glen, 1985; Iwata *et al.*, 1995), although the temporal range of the fossils from the Murda Formation extends through all of the Late Ordovician.

*Environment of deposition*

Turbiditic sandstone and siltstone, and conodont-bearing cherts, indicate a deep marine environment of deposition — a back arc basin west of the Parkes–Narromine belt of Ordovician island arc volcanism. The predominantly quartzose nature of the Girilambone Group suggests an eroded continental source similar to other Ordovician quartzose turbiditic units of the Lachlan Fold Belt.

## **Murda Formation** (Ogm) *nov*

*Nomenclature, derivation, distribution and relations*

The Murda Formation is a newly recognised unit within the Girilambone Group, named after Murda Trigonometrical Station at GR 520100 mE 6345100 mN. Being resistant to erosion, the unit forms a ridge trending northwest–southeast between the Condobolin–North Condobolin road and the Condobolin–Fifield road.

The Murda Formation forms a marker horizon within the Girilambone Group, and is overlain unconformably with angular discordance by the Manna Conglomerate in the Narromine 1:250 000 map sheet area at GR 514100 mE 6348780 mN. The Murda Formation has been intruded by mineralised Silurian quartz veins. It is overlain unconformably by Cainozoic alluvium.

The Murda Formation has lithological similarities with quartz–magnetite sandstones in the Mount Royal Formation at Tottenham (Sherwin, 1996), and quartzite marker horizons of the Tritton Formation at Girilambone and Tritton (Fogarty, 1998; Berthelsen, 1998).

*Type area and thickness*

A section of the Murda Formation along the western boundary road of the Murda State Forest, between GR 516500 mE 6345500 mN and GR 516700 mE 6347100 mN, including a road base quarry at GR 516750 mE 6346630 mN, is nominated as the type section. A thickness of 750 m is estimated, although this is a maximum due to structural thickening by mesoscopic folding.

*Description*

Magnetite-bearing, massive, laterally extensive sandstone beds give the Murda Formation its distinct character, which allows it to be differentiated from the rest of the Girilambone Group. Oxidation of magnetite to hematite gives the rocks their distinctive red colouration. There are also beds lacking magnetite, with white sandstone and grey siltstone, phyllite, and chert also forming parts of the formation. Sandstone and cherty siltstone are commonly massive, 1 m to 2 m thick, and can be traced along strike. Grey chert forms 2 cm to 3 cm thick beds in an intensely folded sequence at GR 516750 mE 6346630 mN.

Magnetic susceptibilities ($10 \times 10^{-5}$ SI to $500 \times 10^{-5}$ SI) are variable, and have a greater range and higher values than in undifferentiated Girilambone Group. On total magnetic images, the formation is subtly more magnetic. Striking parallel to the Murda Formation are highly magnetic linear anomalies, which, although not found in outcrop, are interpreted to be magnetite-rich horizons. On gamma ray spectrometric RGB images, the formation shows low K and Th, but it has a distinctive signature allowing differentiation from undifferentiated Girilambone Group.

Barron (1998) described thin sections of reddish beige, pale red to red-purple quartzose sandstone and radiolarian chert from the Murda Formation. The sandstones contain well-sorted (0.3 mm) rounded grains of quartz, a trace of feldspar, and metamorphic sandstone fragments in a minor muddy matrix, with accessory muscovite, tourmaline, magnetite, apatite, zircon, and brookite. The chert is slump-folded and has minor opaque minerals, which, based on its relatively high magnetic susceptibilities, are probably magnetite.

Recrystallisation during metamorphism and deformation of the Murda Formation produced mildly to strongly sutured grain boundaries and subgraining, and minor aligned sericite defining cleavage (Barron, 1998). Trails of two-phase inclusions cross several grains, and quartz veins cut across cleavage. The main cleavage ($S_2$) is well-developed, with a spacing of 1 mm to 2 mm in sandstones. $S_2$ is deformed by $F_3$ folds and angular kinks.

*Age*

The ages of conodonts identified in samples taken from the road base quarry at GR 516750 mE 6346630 mN span almost all of the Late Ordovician (Percival, 1999a).

*Environment of deposition*

The Murda Formation, as part of the Girilambone Group, was deposited in a back arc basin west of the Parkes–Narromine Ordovician volcanic arc. Specifically, anomalous quantities of magnetite in the Murda Formation suggest a localised concentration of iron-rich minerals, possibly pyrite, during the time of sedimentation, which were subsequently oxidised to magnetite during metamorphism. Correlation with similar units within the Girilambone Group, associated with copper mineralisation, suggest the Murda Formation and its adjacent relatively high magnetic stratigraphic horizons in the Girilambone Group could also be prospective for copper.

## **Lake Cowal Volcanic Complex** (Ol) Miles (1993)

*Nomenclature, distribution, and relations*

Miles (1993) used the term 'Lake Cowal Volcanics' and Miles & Brooker (1998) applied the informal name 'Lake Cowal volcanic complex' to the Ordovician volcanic and intrusive rocks hosting the Lake Cowal Au–Cu province. The name is derived from Lake Cowal, in the central west of the Forbes 1:250 000 map sheet area. Although there is almost no outcrop of the volcanic complex, being overlain by as much as 100 m of Cainozoic cover, not including overlying younger bedrock, it has a distinct magnetic signature allowing its distribution to be mapped from aeromagnetic data. Therefore, the name given by Miles (1993) has been formalised to Lake Cowal Volcanic Complex.

Surface exposures of the Lake Cowal Volcanic Complex are confined to a small area, less than a square kilometre,

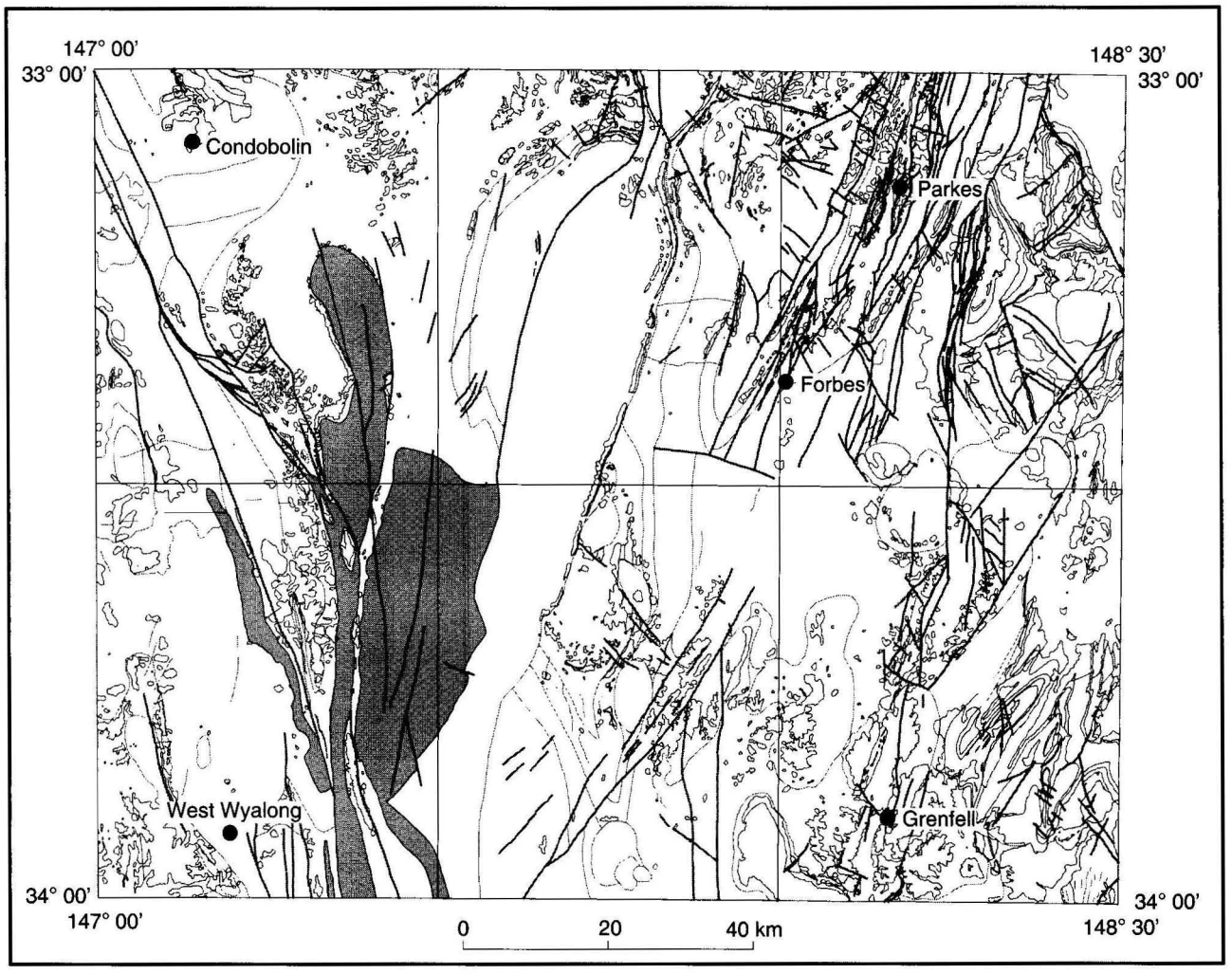



*Figure 3.15. Distribution of the Lake Cowal Volcanic Complex in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

of sheared and altered rocks cropping out (GR 532400 mE 6272600 mN) just west of the West Wyalong–Burcher railway, near Lake Cowal Siding. There are other minor occurrences: as weathered subcrop and float of granodiorite south of Lake Cowal in the vicinity of GR 538000 mE 6270300 mN; and at about GR 541500 mE 6285000 mN, on a small point of the northeastern shore of Lake Cowal (I. Miles, pers. comm., 1997). Disregarding a narrow strip of overlying Siluro-Devonian Manna Conglomerate, the Lake Cowal Volcanic Complex extends northwards from the southern boundary of the Forbes 1:250 000 map sheet area, between eastings 533000 mE and 534800 mE, to the Lachlan River flood plain a few kilometres north of the Lachlan Valley Way; a distance of about 85 km (Figure 3.15). Its maximum width is about 25 km in the vicinity of Nerang Cowal, the ephemeral lake immediately north of Lake Cowal.

The Lake Cowal Volcanic Complex continues southwards into the Cootamundra 1:250 000 map sheet area, where the rocks have been named the Belimebung Volcanics (Warren *et al.*, 1995). However, as the Belimebung Volcanics are not exposed, any possible discrimination between the two units, as named, cannot be made on geological grounds. Therefore, the name Lake Cowal Volcanic Complex has been applied within the Forbes 1:250 000 map sheet area where the name has precedence over the name Belimebung.

No type locality can be given for the Lake Cowal Volcanic Complex due the lack of outcrop. What is known about the rocks of the Lake Cowal Volcanic Complex comes mainly from drillcore.

The Lake Cowal Volcanic Complex is fault-bounded to the west by the Booberoi Shear Zone, and faulted against the Ordovician Girilambone Group. To the east, the complex has been thrust over the Late Devonian Hervey Group along the Marsden Thrust. It is unconformably overlain by the Silurian Ina Volcanics (a unit west of Nerang Cowal confined to an area no more than 5 $km^2$) and the Siluro-Devonian Ootha Group. The extent of the complex shown by aeromagnetic data is probably complete because the overlying units are essentially non-magnetic and allow detection of the complex to depths over 200 m.

*Description*

The outcrops near Lake Cowal Siding are not representative of the Lake Cowal Volcanic Complex. They

are a fine-grained, sheared, and extensively chlorite–epidote–carbonate-altered quartz-bearing rock (the protolith is unknown but was probably sedimentary or quartz-bearing volcanic rock); an epidote-altered plagioclase-phyric basalt; and possibly a quartz diorite, which does not crop out but was excavated during trench-digging for the high-pressure gas pipeline (which passes the Lake Cowal Siding outcrop less than a kilometre to its north). The foliation in the sheared outcrop dips 75° towards 105°.

Miles & Brooker (1998) used drillcore and percussion chips to describe the Lake Cowal Volcanic Complex beneath Lake Cowal as consisting of intermediate calc-alkaline volcanic, associated volcaniclastic, and epiclastic rocks, and trachyandesite lava flows, intruded by syenite, granodiorite, diorite, and gabbroic rocks. Miles (1993) derived a local stratigraphic sequence for the Endeavour 42 (Cowal) Au deposit (GR 536900 mE 6276200 mN), which includes polymict conglomerate, sandstone, laminated pelites, trachyandesite lava flows, and associated hyaloclastites.

Drilling by Newcrest Mining Limited (pers. comm., 1999), north of Nerang Cowal and near Marsden, about 30 km northwest of Wyalong, also intersected diorites, andesites, volcaniclastic rocks, and shales (phyllites).

Regionally, the Lake Cowal Volcanic Complex is probably largely undeformed, except for a zone about 5 km wide along the western margin, where rocks of the complex were affected by the Booberoi Shear Zone. There, the shearing has produced pronounced north–south trends that show in magnetic images. The eastern edge of the deformed margin is prominent as a lineament of relatively low magnetisation, broadening to the north and south into relatively unmagnetised corridors. All outcrops coinciding with these corridors are of the Siluro-Devonian Manna Conglomerate, which may have been deposited in a narrow rift within the Lake Cowal Volcanic Complex. Elsewhere, numerous lineaments defined by low magnetic intensity (assumed to be a consequence of demagnetisation of the rock) and are probably localised faults and shears. Such demagnetisation is likely to be caused by destructive alteration of magnetite. Within the Endeavour 42 deposit, the sequence dips about 30° to the west (Miles & Brooker, 1998), but drillcore samples show no development of axial plane cleavage. Circular and oval magnetic anomalies, such as the one centred near GR 542000 mE 6284000 mN, are granodiorites, diorites, and gabbroic intrusions (Miles & Brooker, 1998).

*Geochemistry*

The geochemistry of the Lake Cowal Volcanic Complex is discussed under Ordovician volcanic geochemistry at the end of this chapter. In summary, rocks of the Lake Cowal Volcanic Complex are similar to other Ordovician arc volcanic suites of the Lachlan Fold Belt (e.g., the Molong High). The geochemical data for the Lake Cowal Volcanic Complex suggests mantle-derived subduction-related magmatism of a calc-alkaline nature.

*Environment of formation*

Because the Lake Cowal Volcanic Complex is virtually unexposed, it is difficult to expand on the environment of formation. It is part of an island arc formed during Middle to Late Ordovician subduction, and the presence of laminated shales shows that at least some of the deposition was taking place below wave base. It is impossible to say whether the Lake Cowal Volcanic Complex was ever emergent. The polymict conglomerates are evidence of mass-flow deposition. The lack of known limestone or coralline debris means that it is impossible to know whether there were fringing reefs.

*Age*

Perkins *et al.* (1995) reported a K–Ar age of 456 Ma for a hornblende from the subcropping granodiorite south of Lake Cowal. Detrital zircons in the Manna Conglomerate, which are interpreted here to have been derived from the Lake Cowal Volcanic Complex, gave a consistent U–Pb age of 452.2 ± 2.0 Ma (L.P. Black, pers. comm., 1999). However, both those ages must be minima because Perkins *et al.* (1995) cautioned that their K–Ar data may have recorded some Ar loss. Given that the Wagga Group, which was deposited in the Wagga Marginal Basin to the west, contains Darriwilian conodonts (Percival, 1999a), it is likely that the subduction–related volcanism commenced no later than late Middle Ordovician. Perkins *et al.* (1995) indicated that the Lake Cowal mineralising event occurred at about 440 Ma, which implies that the volcanism must have ceased by the beginning of the Silurian.

## **Northparkes Volcanic Group** (Op) *nov*

*Derivation of name*

The Northparkes Volcanic Group is named after the Northparkes mine, about 27 km northwest of Parkes, near the southern margin of the Narromine 1:250 000 map sheet area. Establishment of this new stratigraphic unit was made necessary by raising of the former 'Gunningbland Shale Member' and 'Billabong Creek Limestone Member' (of the Goonumbla Volcanics) to full formation status. The name Northparkes was selected to reflect the economic significance to the region of constituent stratigraphic units within the Northparkes Group.

*Distribution and outcrop*

In the Forbes 1:250 000 map sheet area, outcrops of Northparkes Volcanic Group rocks are scattered from immediately east of Parkes to as far west as Gunningbland, and south to the vicinity of the Forbes abattoir. The maximum east–west extent of this outcrop is about 25 km (Figure 3.16). Also included in the Northparkes Volcanic Group is an isolated outcrop of Goobang Volcanics, 15 km northeast of Parkes, which represents the surface expression of a much larger unexposed tract interpreted from geophysical evidence. The main outcrop belt of the Northparkes Volcanic Group extends for approximately 40 km in a generally northeasterly direction onto the

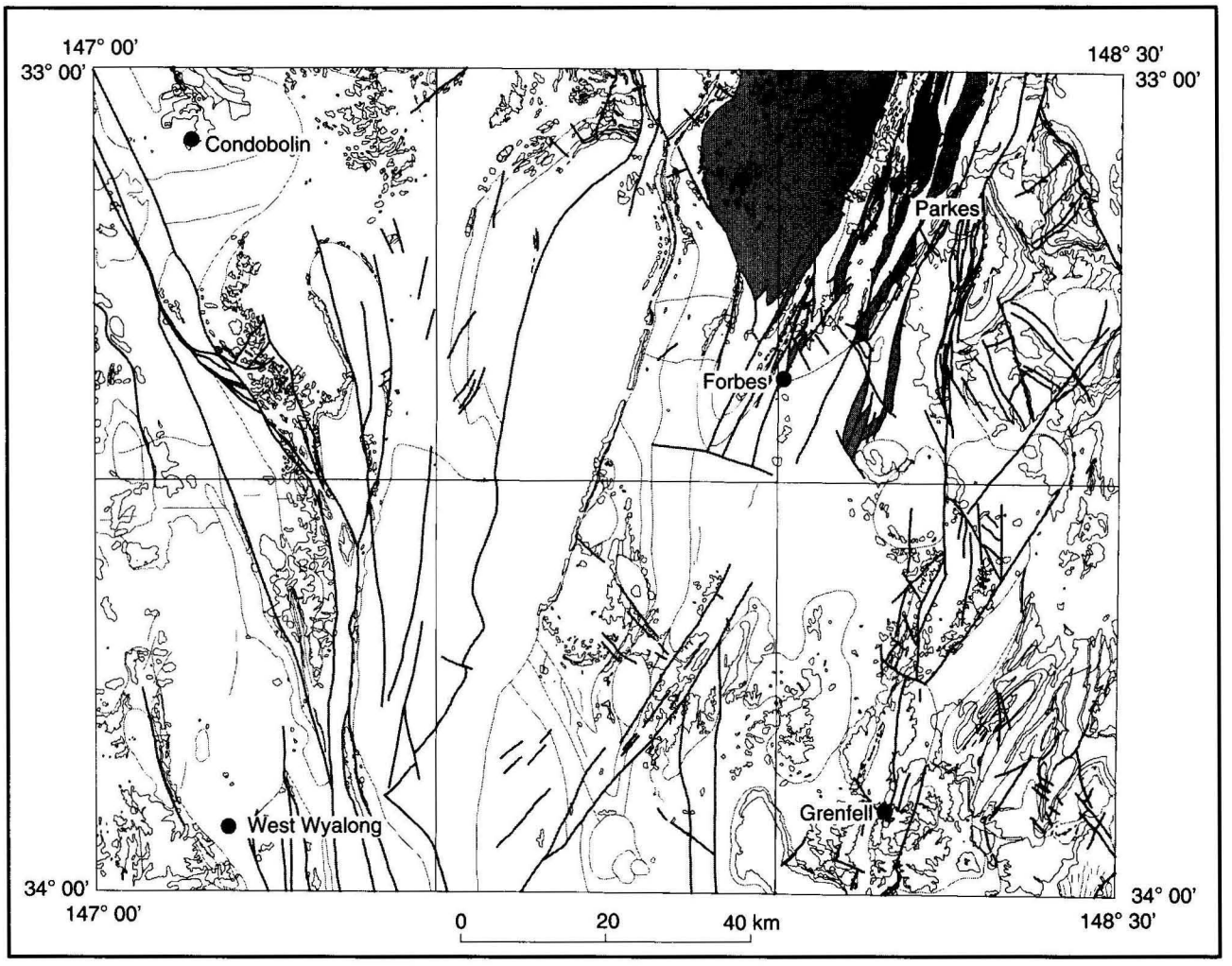



*Figure 3.16. Distribution of the Northparkes Volcanic Group in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

adjoining Narromine 1:250 000 map sheet area. Float of volcanic units attributed to the Northparkes Volcanic Group is associated with mine dump material as far north as Tomingley, about 50 km beyond the northern edge of the Forbes 1:250 000 map sheet area. Aeromagnetic data indicate that inferred volcanic units continue further north, where they are overlain by Mesozoic and Cainozoic rocks of the Great Australian Basin.

Outcrop of rocks included in the Northparkes Volcanic Group is generally of low to moderate relief, with representative exposures sited around Parkes (e.g., Nash Hill — also the location of Parkes Trigonometrical Station — 5.5 km north of the city, and Millers Lookout, 7 km northwest), in an open cut associated with mining operations at the London-Victoria mine west of Parkes, and in the Goonumbla Quarry. Volcanic and volcaniclastic rocks forming much of the group are otherwise poorly exposed as low rises and, where obscured by soil, rubble and float in ploughed paddocks may provide an indication of the occurrence of these units. Sedimentary rocks in the vicinity of Gunningbland are occasionally moderately well exposed, particularly the limestones, whereas associated fine-grained clastic and volcaniclastic rocks generally lack solid outcrop except in artificial exposures such as quarries.

*Constituent formations and units*

The Northparkes Volcanic Group comprises the following seven formations (listed in approximate ascending stratigraphic order) and an unnamed unit of intrusions:

Goonumbla Volcanics (Opb, including limestone lenses indicated as Opbl, and an unnamed volcaniclastic conglomerate member mapped as Opbc);

Billabong Creek Limestone (carbonate rocks designated Opi; interbedded volcaniclastic and clastic strata mapped as Opic);

Gunningbland Formation (Opg, with limestone lenses designated Opgl);

Wombin Volcanics (Opw);

Parkes Volcanics (Opp);

Nash Hill Volcanics (Oph);

Goobang Volcanics (Opo); and

Unnamed monzonite intrusions (Omz).

*Age and boundary relationships*

Fossils from the Billabong Creek Limestone indicate a late Darriwilian age for the base of this formation (Pickett & Percival, 2000). Isolated limestone pods beneath this level, of uncertain stratigraphic assignation but possibly low in the Goonumbla Volcanics, contain probable early Darriwilian conodonts and are the oldest indicators of age of the Northparkes Volcanic Group. A contact between the Early Ordovician Yarrimbah Formation or Nelungaloo Volcanics is nowhere exposed, but (given the significant time gap between these older units and the Northparkes Volcanic Group) the relationship is assumed to be unconformable. Evidence for this includes the presence of chips of probable Yarrimbah Formation in the limestone breccia at the base of the Billabong Creek Limestone, indicating active erosion of an exposed Early Ordovician basement. Graptolites indicate a late Eastonian age for a level near the top of the Gunningbland Formation. The uppermost Goonumbla Volcanics, which overlie these strata, are therefore presumably of early Bolindian age. At "The Secrets" section, 2 km east of Nanardine railway siding, Goonumbla Volcanics are overlain by the Cotton Formation, here bearing early Llandovery graptolites (Sherwin, 1976). The exact boundary between the two formations is masked by 30 m of non-exposure. Because, further south towards Forbes, the Cotton Formation includes strata with a late Bolindian age, the nature of the boundary relationship at "The Secrets" is possibly unconformable, or else could be faulted. There is no evidence that the Goonumbla Volcanics, or any of the other volcanic formations in the uppermost part of the Northparkes Volcanic Group, extends into the Silurian.

## **Goonumbla Volcanics** (Opb) Sherwin (1973b), modified after Brunker (1972a)

*Nomenclature*

Although first named and mapped on the first edition of the Forbes 1:250 000 geology map sheet (Brunker, 1972a), the Goonumbla Volcanics were not described until the following year by Sherwin (1973b), who specified a provisional type area, and excluded outcrop of the newly-recognised Nelungaloo Volcanics. Formal definition of the Goonumbla Volcanics was given by Krynen *et al.* (1990), who restricted distribution of the formation to that area west of the Parkes Thrust. Local subdivisions of the Goonumbla Volcanics into a lower 'The Secrets Andesite' and an upper 'Black Ridge Tuff', made by Bowman *et al.* (1983) in the vicinity of Goonumbla, cannot be recognised away from that immediate area. Usage of these names is therefore not supported. The concept of the Goonumbla Volcanics is further modified here to exclude the Billabong Creek Limestone, and the Gunningbland Formation, both of which were previously members of the Goonumbla Volcanics but are now each accorded formation status.

*Distribution, outcrop and type locality*

Outcrop of the Goonumbla Volcanics in the Forbes 1:250 000 map sheet area is closely related to the Forbes Anticline. An extensive belt, which includes the quarry at GR 605700 mE 6344200 mN defined as the original type area (here retained), is aligned along the eastern limb of the anticline for a strike length of about 40 km. Scattered outcrops adjacent to the Parkes–Bogan Gate road just west of Gunningbland represent the westernmost extent of the formation. South of Gunningbland, a few restricted outcrops are mapped on 'New Durran' before exposures disappear further south beneath cover associated with the floodplain of Goobang Creek. Similarly, isolated outcrops of Goonumbla Volcanics approximately 10 km southwest of Parkes represent the southern surface extent of the formation on the eastern limb of the Forbes Anticline near the Goobang Creek floodplain.

The Goonumbla Volcanics have a distinctive red radiometric signature, reflecting their high K content. Measurements of magnetic susceptibility of outcrops yielded values in the range $300 \times 10^{-5}$ SI to $400 \times 10^{-5}$ SI.

Outcrop of the Goonumbla Volcanics extends for 30 km to 40 km onto the Narromine 1:250 000 map sheet to the north, with exposures located west of Peak Hill. Geophysical evidence indicates continuity of subcrop further north, before disappearing beneath the Great Australian Basin.

*Description*

Krynen *et al.* (1990) and Clarke (1990a) provided detailed descriptions of major rock types found within the Goonumbla Volcanics, and their work is summarised here.

The dominant rock type is a plagioclase–pyroxene–oxide-phyric volcanic rock. At Goonumbla Quarry (GR 605700 mE 6344200 mN), the rock is porphyritic in plagioclase, pyroxene, and oxides, and was originally vesicular. The groundmass was composed of alkali feldspar, plagioclase, oxides, and glass, and now contains abundant pumpellyite and chlorite, especially in the dark matrix of the rock. Vesicles are filled with aggregates of pumpellyite–prehnite–carbonate–quartz–chlorite. The rock is strongly carbonate veined. Other abundant irregular veins present include quartz, albite, and epidote. Volcanic rocks from Goonumbla Hill (GR 602100 mE 6352200 mN) differs slightly in appearing more strongly porphyritic in plagioclase, and in having a high apatite content. Sedimentary rocks in the vicinity of this latter outcrop include immature siltstones composed of mainly fine-grained detrital alkali feldspar and plagioclase, with distinctive sand-sized apatite grains, and are presumably derived from erosion of those volcanic rocks.

Flow structure is generally not recognisable in many exposures of the Goonumbla Volcanics, leading to suggestions that some of the formation may be of intrusive rather than eruptive origin. Definite eruptive phases have, however, been recognised in several places. Crystal–lithic tuff, containing crystals of plagioclase, pyroxene, oxides, and apatite, and clasts of plagioclase-phyric volcanic rock in a matrix of alkali feldspar and oxides, is found in low exposures immediately west of the massive outcrop that makes up Millers Lookout, at GR 603000 mE

6335500 mN. Detailed mapping in the area of 'The Secrets' (GR 605500 mE 6340600 mN) and Black Ridge (GR 606900 mE 6342200 mN) enabled Bowman *et al.* (1983) to recognise local flows and tuffaceous beds. Strongly altered flow-brecciated vesicular volcanic rocks are porphyritic in plagioclase, pyroxene, oxides, biotite, olivine, and apatite, in a flow-foliated groundmass of plagioclase, alkali feldspar, pyroxene, oxides, and glass. These rocks, informally termed 'The Secrets Andesite' by Bowman *et al.* (1983), are divisible into a mafic phase overlain by a felsic phase. The mafic flows are distinguished by larger pyroxene phenocrysts, less-abundant vesicles, less flow-brecciation, and more-abundant oxides, which give rise to a stronger magnetic response.

Sedimentary rocks interbedded with the mafic flows at 'The Secrets' include volcanic conglomerates and a 20 cm thick bed of magnetite-rich arkose containing large clasts (up to 6 cm) of rugose and tabulate corals.

Silicic tuffaceous rocks, informally termed the 'Black Ridge Tuff' by Bowman *et al.* (1983), overlie the flows and interbedded sedimentary rocks described above. They have a total thickness of about 100 m and are made up of three horizons of welded lithic–crystal tuff, separated by unwelded lithic–crystal tuff and minor amounts of volcanic and volcanogenic epiclastic rocks. The crystal tuffs have crystals of plagioclase, biotite, pyroxene, and oxides, together with volcanic clasts, set in a plastically deformed, flow-foliated matrix rich in welded glass shards. Bowman *et al.* (1983) interpreted the tuffaceous unit as having been deposited by pyroclastic flows, rather than airfalls.

A volcaniclastic conglomerate unit (Opbc) is mapped intermittently on both limbs of the Forbes Anticline. This unit is included in the Goonumbla Volcanics as the volcanic content more closely relates it to that formation, rather than the Billabong Creek Limestone, with which it appears to be associated on "Wilga" at GR 597000 mE 6340300 mN. Previously, this conglomerate was described as a slump bed containing large clasts of laminated chert, believed to represent material eroded from the Yarrimbah Formation of Early Ordovician age, and was included in that unit (Sherwin *et al.*, 1987; Krynen *et al.*, 1990). However, trilobites found in finer-grained variants of the conglomerate have been re-identified as *?Dividuagnostus* sp., suggestive of a Darriwilian to early Gisbornian age. This reassessment is supported by associated brachiopods, which include types not known to occur in strata older than late Middle Ordovician. Accordingly, the volcaniclastic conglomerate unit is now assigned to a level within the lower part of the Goonumbla Volcanics.

Limestones (designated Opbl) are of very minor occurrence in the Goonumbla Volcanics, and few are of sufficient size to plot at map scale (1:250 000). They are of significance in providing one of the few indications of age in the Goonumbla Volcanics. One, found at GR 600600 mE 6329600 mN, near the southern limit of outcrop of the formation, contains a Fauna III coral assemblage (Pickett, 1984a) of late Eastonian (Ea3) age, identical to the age indicated by corals in the magnetite-rich arkose at "The Secrets" referred to previously.

*Environment of deposition and accumulation*

The Goonumbla Volcanics are interpreted to represent accumulation of lavas and tuffs to form an emergent volcanic island during an extended period of predominantly extrusive volcanism. Associated volcaniclastic rocks, ranging from siltstone to arkose and conglomerate, were derived from erosion of the volcanic rocks, and may have formed as beach and nearshore deposits. Minor limestones probably accumulated offshore in shallow water. Much of the Goonumbla Volcanics are believed to be laterally equivalent to both the Billabong Creek Limestone and the overlying Gunningbland Formation, which contain fossil assemblages indicative of deeper water shelf and basinal depositional environments that would have surrounded the volcanic island.

*Thickness*

Krynen *et al.* (1990) estimated a thickness of 2.5 km to 4 km for the Goonumbla Volcanics outcrop belt on the eastern flank of the Forbes Anticline.

*Age and boundary relationships*

Indications of the age of the Goonumbla Volcanics are derived from fossils in limestones (Opbl), volcaniclastic conglomerate (Opbc) and arkose (undesignated). The youngest age is given by corals of Fauna III age (Late Eastonian, Ea3) in arkose at "The Secrets", and an assemblage of comparable age in limestone at GR 600600 mE 6329600 mN (Pickett, 1984a). Trilobites and brachiopods from the volcaniclastic conglomerate unit on 'Wilga' suggest an age as old as Darriwilian to early Gisbornian for a level within the lower part of the formation.

It is possible that the base of the Goonumbla Volcanics could be as old as early Darriwilian. This is based on the presence of conodonts in isolated limestone pods interbedded with poorly exposed volcanic and volcaniclastic rocks beneath the defined base of the Billabong Creek Limestone on 'Nelungaloo' (Pickett & Percival, 2000). Outcrops in that area, which occur as float mostly obscured by alluvium, are too small to show on the map. The apparent relative dominance of volcanic and volcaniclastic rocks in this succession support assignation to the Goonumbla Volcanics rather than the Billabong Creek Limestone.

The time-space plot for the region (Figure 2.1 and map surrounds) depicts an interdigitating relationship between the Goonumbla Volcanics, interpreted to have formed a volcanic island, and formations to the west (in the Gunningbland area) that are known from fossil evidence to have been deposited contemporaneously further offshore. As indicated above, data supporting a Goonumbla Volcanics basement to the Billabong Creek Limestone are difficult to assess, although the presence of Darriwilian fossils eliminates potential confusion with the Early Ordovician phase of volcanism. In contrast, there is good

reason to believe (based on evidence from outcrops west of 'New Durran') that a phase of widespread volcanism early in the Bolindian finally overwhelmed the accumulation of sedimentary rocks that formed the Gunningbland Formation. The interfingering nature of the formations is partly facies-controlled but elsewhere, particularly above the upper Billabong Creek Limestone, it reflects a possible incursion of volcanic rocks from the island into the basal Gunningbland Formation, coincident with a marked increase in water depth.

Outcrops generally lack sufficient continuity across critical boundary intervals to precisely confirm the relationships shown for the Goonumbla Volcanics in the time-space plot. Sherwin (1976) documented a section at 'The Secrets' where the formation was overlain by early Llandovery (Early Silurian) siltstones of the Cotton Formation above a gap of 30 m of no exposure, which may conceal a fault or an unconformity. Northeast of Gunningbland, the Goonumbla Volcanics are overlain, possibly conformably, by the Wombin Volcanics. Again, the available outcrop is insufficient to resolve the precise nature of the boundary.

## **Billabong Creek Limestone** (Opi) modified after Sherwin (1970)

*Previous nomenclature*

Packham (1967) informally referred to the limestone at Billabong Creek when recognising its Late Ordovician age. Sherwin (1970), in further refining the age of the formation, first used the name by which it is now known, and described its distribution between Gunningbland and Billabong Creek (also known as Goobang Creek). Formal definition was provided by Sherwin (1973b), who specified as a type area the exposure in Billabong Creek that had been the focus of the report by Packham (1967). Subsequent mapping by mineral exploration companies during the 1970s and 1980s extended distribution of the Billabong Creek Limestone along a trend of discontinuous outcrops northeast from Gunningbland to Goonumbla. Arguing that this correlation was unwarranted because contemporaneity of the limestones had not been demonstrated, Sherwin *et al.* (1987) and Krynen *et al.* (1990) downgraded the unit to the status of a member within the Goonumbla Volcanics, and restricted the concept to the original exposures mapped by Sherwin (1970, 1973b).

Krynen *et al.* (1990) included other limestones, some stratigraphically underlying their 'Billabong Creek Limestone member', within the Goonumbla Volcanics as separate lenses. These lenses included levels from which Pickett (1984b, 1985) had reported the conodont *Pygodus anserinus* of Darriwilian–Gisbornian age.

Detailed study of the Ordovician biostratigraphy of the Gunningbland region (Pickett & Percival, 2000) has led to reassessment of the significance and extent of the Billabong Creek Limestone. Here reinstated to formation status, it is redefined to include at its base the limestone breccia containing *Pygodus anserinus* recorded by Pickett (1985) on 'Nelungaloo', southeast of Gunningbland. The top of the formation includes the outcrop noted by Packham (1967) at Billabong Creek adjacent to the Bogan Gate–Forbes road.

*Distribution, type locality and outcrop*

The Billabong Creek Limestone is now proved to extend from the original type area at Billabong Creek, northwestwards parallel to the Bogan Gate–Forbes road (as mapped by Sherwin, 1973b), to north of the Parkes–Broken Hill railway on 'Keilor', then at least as far to the northeast as exposures on 'Kirkup'. The strike length of the exposures is approximately 15 km. Discontinuous outcrops along strike further northeast are possibly part of the Billabong Creek Limestone (and have been so depicted on the Forbes 1:250 000 geological map sheet, second edition), although further detailed palaeontological work is necessary to differentiate those outcrops from younger limestones associated with the overlying Gunningbland Formation. The maximum outcrop width, as measured on Nelungaloo in the vicinity of the type section and also including the outcrops in the original type area on Billabong Creek, is 1 km.

Excluded from the revised concept of the Billabong Creek Limestone is a small lensoidal exposure on 'New Durran'. This is interpreted as a slump horizon including allochthonous blocks of the formation that were displaced and redeposited during accumulation of the Gunningbland Formation.

The type section is located on 'Nelungaloo', 6 km southeast of Gunningbland. The base of the Billabong Creek Limestone commences at a prominent ridge of limestone breccia, at GR 589900 mE 6329700 mN, and extends almost due west to a shallow excavation immediately east of the Bogan Gate–Forbes road at GR 588700 mE 6329800 mN. Exposure is intermittent in the lower part of the section, which consists of limestones (above the initial limestone breccia) interbedded with poorly exposed volcaniclastic beds and fine-grained clastic rocks. The limestones become thick-bedded to massive in the middle and upper parts of the type section. Excavation of a doline at GR 589200 mE 6329650 mN revealed a substantial thickness of maroon and grey, thick-bedded limestone, atypical of the surface outcrop but indicative of the continuity of carbonate rocks in the section. Just south of the type section, a prominent outcrop of massive limestone extends parallel to the road almost to the 'Nelungaloo' turnoff.

The original type area of the Billabong Creek Limestone, as noted by Packham (1967) and Sherwin (1970, 1973b), is situated in and adjacent to the eponymous creek immediately south of the 'Nelungaloo' turnoff. Fossils in that outcrop indicate that the strata are younger than in the revised type section, and there is no overlap between the two. However, structural complications are implied by locally east-dipping beds in the outcrop at Billabong Creek (Sherwin, 1970), whereas all strata in the type section dip to the west. Notwithstanding that the outcrop at Billabong

Creek is probably fault-bounded, the original type area is retained as subsidiary type area to the revised type section, in order to incorporate characteristics of the upper limestone in the concept of the formation.

*Description*

The limestones comprising the formation vary from carbonate-cemented breccias (at the base), containing chert and volcanic clasts eroded from the underlying Early Ordovician section, to massive grey and maroon limestone in the middle and upper parts of the type section, to fine-grained bioclastic yellow and dark grey limestones at the top of the unit. Fine-grained clastic rocks, including mudstones and volcaniclastic horizons, form recessive beds in the lower part of the formation. Areas where these non-carbonate rock types predominate are indicated by the designation Opic on the map.

The Billabong Creek Limestone is distinguished from the overlying Gunningbland Formation by its relatively more dominant limestone content. In the Gunningbland Formation, limestones are very much subordinate to deep water clastic rocks.

*Thickness*

The thickness of the Billabong Creek Limestone is estimated at 320 m in the type section. An additional 30 m to 50 m may be present in the outcrops of the upper limestone at Billabong Creek. An unknown amount of strata has been lost from the outcrop due to faulting between these exposures, so those values, when combined, represent a minimum thickness for the formation.

*Environment of deposition*

Maroon limestones in the lower part of the Billabong Creek Limestone are commonly pisolitic, suggesting a depositional environment in shallow clear water. Interbedded fine-grained clastic rocks are indicative of increased terrestrial sediment, probably in more turbid conditions, which would have been unsuitable to algal-dominated carbonate accumulation. The interplay between the two types of deposit implies a scenario of an eroding island fringed by carbonate banks, which were intermittently overwhelmed by mud and volcaniclastic debris (although active contemporaneous volcanism is not indicated). The water depth increased towards the top of the formation, where fossilised organisms in the limestones have been interpreted (Percival, 1995) as having lived in water depths of 20 m to 60 m (Benthic Assemblage 3, below normal wave base).

*Boundary relationships and age*

Poor outcrop obscures the contacts of the Billabong Creek Limestone with both the underlying basal Goonumbla Volcanics, and the overlying Gunningbland Formation. Away from the type section, the distinctive limestone breccia at the base of the Billabong Creek Limestone is not exposed, and it is possible that the formation may unconformably overlie Early Ordovician units such as the Yarrimbah Formation and Nelungaloo Volcanics. The boundary with the Goonumbla Volcanics is presumed to be conformable, based on the observation of isolated limestone lenses in that formation just below the Billabong Creek Limestone being consistently older (but not greatly so) than the age obtained for the basal limestone breccia. Hence deposition was probably proceeding continuously at the time, with components of clasts in the breccia being derived from rocks exposed on the adjacent eroding island.

The Gunningbland Formation was deposited in water depths initially much greater than those in which the upper Billabong Creek Limestone accumulated. Despite this, there does not appear to be any significant time break involved, and so the two formations are considered to be conformable.

The age of the Billabong Creek Limestone ranges from late Darriwilian (Da4), *Pygodus anserinus* Zone (Pickett, 1984a, 1985), to middle Eastonian. A succession of Gisbornian and early Eastonian faunas have been recognised between these basal and uppermost levels, indicating that no major time breaks are present in the formation. The middle Eastonian (Ea2) age is supported by rich faunas obtained from the exposures on Billabong Creek at the original type area. These include corals, stromatoporoids, trilobites, brachiopods, gastropods, and ostracodes (Webby, 1971a, 1971b, 1973, 1974; Schallreuter & Siveter, 1988; Percival, 1991, 1995). In addition, this outcrop is the type locality of the alga *Goobangia pyriformis* (Webby & Trotter, 1992). Co-occurrence of corals of Webby's Fauna II and the *Pliomerina austrina* Trilobite Faunule with Brachiopod Fauna B (Percival, 1991, 1992) confirm that the upper beds of the Billabong Creek Limestone correlate with the Quondong Limestone at Bowan Park and the Trilobite Hill Limestone Member in the Cliefden Caves Limestone Subgroup.

## **Gunningbland Formation** (Opg) after Sherwin et al. (1987)

*Nomenclature*

Previously termed the 'Gunningbland Shale Member' (of the Goonumbla Volcanics) by Sherwin *et al.* (1987) and Krynen *et al.* (1990), this unit is here raised to formation status within the Northparkes Volcanic Group. Its new designation as a formation is indicative of the variety of rock types recognised, none of which is predominant. The informally named 'Currajong Park Beds' (introduced without definition by Percival, 1992) represents strata in the upper part of the Gunningbland Formation.

*Distribution, outcrop and type localities*

The arcuate outcrop belt of the Gunningbland Formation passes through the village of the same name, being best (though intermittently) exposed between the Parkes–Broken Hill railway line and the Parkes–Condobolin road to the north. In the absence of a suitable type section, given the generally poor outcrop, this area is the designated type locality. Shallow excavations on 'Currajong Park' (GR 585300 mE 6334500 mN) and 'Sunnyside' (GR 586200 mE 6334000 mN) reveal limestones and

shales, and small road gravel quarries 1.5 km northeast of Gunningbland at GR 587250 mE 6333300 mN provide good exposures of laminated siltstones. At its southern limit of outcrop on 'New Durran', south of Gunningbland, siltstone beds of the unit are exposed in a costean (GR 587300 mE 6330700 mN). These artificial exposures provide the most information on rock types of the formation, particularly fine-grained clastic rocks that are otherwise observed only as blocky float in ploughed paddocks. The substantial thickness of siltstones exposed in the quarries suggests that the Gunningbland Formation is areally extensive beneath a thin soil cover. Outcrop is more limited north of the Parkes–Condobolin road, with only three definite areas of the unit mapped.

*Description*

Fine-grained clastic rocks, including siltstone, shale, fine- to medium-grained sandstone, and volcaniclastic rock types, are most widespread in the Gunningbland Formation, while limestones are of relatively minor occurrence (in contrast to the underlying Billabong Creek Limestone). Fresh exposures of shale and siltstone are olive-coloured, with indistinct laminae. Some thin bands, 1 mm to 5 mm thick, in siltstone from the gravel quarry northeast of Gunningbland, are composed almost entirely of subhedral feldspathic fragments altered to clays. Lithic sandstones with a high feldspar content are exposed in the costean on 'New Durran'. The occurrence of such bands and layers rich in feldspar crystals suggests ash-falls from contemporaneous volcanism. Volcaniclastic rocks are poorly exposed in ploughed fields between the Bogan Gate–Forbes road and 'New Durran' homestead. Krynen *et al.* (1990) describe those units as volcaniclastic conglomerates.

Carbonate rocks in the Gunningbland Formation range from marls and blue-grey siltstones with a calcareous matrix, found on 'Currajong Park', to massive and bedded fossiliferous limestones. The latter are separately mapped with the symbol Opgl. The limestones vary from grey to red-grey, and from fine- to coarse-grained. Whereas most of the limestone bodies appear to be autochthonous, one outcrop (on 'New Durran' at GR 587600 mE 6330300 mN) is a slump horizon including allochthonous blocks of the underlying Billabong Creek Limestone.

*Environment of deposition*

In contrast to the Billabong Creek Limestone, which is interpreted to be largely of shallow-water origin, the Gunningbland Formation is mostly comprised of fine-grained clastic rocks that contain a distinct deep-water fauna. These include graptolites, trinucleid trilobites, lingulate and diminutive strophomenoid brachiopods, and straight nautiloids. This association is almost identical with that found in the Malongulli Formation in the Molong Volcanic Belt to the east (Webby, 1974, 1992; Webby *et al.*, 1997). Both formations are interpreted to have accumulated in water depths of as much as 300 m (Benthic Assemblage 6). There is also evidence in the Gunningbland Formation of depositional environments in shallower water, which are characterised by limestones and calcareous siltstones. Brachiopods and trilobites in the latter are consistent with a mid-shelf setting (Benthic Assemblage 3) in water depths of 20 m to 60 m, surrounding pinnacle, reef-like knolls (now coralline limestone) that grew upwards into shallow clear waters at, or near, wave base. Steep shoreline-to-basin gradients, which typify volcanic islands, provide a model in which the interpreted spectrum of deep to shallow water depositional environments exist near each other (Percival & Webby, 1996).

*Thickness*

Accurate estimates of thickness for the Gunningbland Formation are hampered by generally poor and discontinuous outcrop. Krynen *et al.* (1990) suggested a thickness for the unit of less than 500 m. Outcrop width in the type locality is comparable to that of the Billabong Creek Limestone. Assuming a similar dip prevails in this area for both units, the thickness of the Gunningbland Formation is estimated at approximately 300 m to 400 m.

*Age and boundary relationships*

Graptolites found in the Gunningbland Formation on 'New Durran' and northeast of Gunningbland railway siding (Sherwin, 1973b) indicate a late Eastonian (Ea3) age. Corals and stromatoporoids, documented by Webby (1972, 1988) and Webby & Morris (1976), correspond to Webby's Fauna III, also of late Eastonian age. That age is confirmed by associated conodonts including *Taoqupognathus tumidus*, reported as occurring in limestone lenses within the Gunningbland Formation by Pickett & Percival (2000). The unit contains representatives of two brachiopod Faunas, C and D, elements of which were described by Percival (1978, 1979a,b). Brachiopod Fauna C, of Ea3 age, is present in the lower part of the formation on 'New Durran'. The presumed Ea4 age (Percival, 1992) of Fauna D, from overlying beds on 'Currajong Park', has recently been confirmed by the discovery of graptolites in adjacent strata that range as young as the top of the Eastonian (Pickett & Percival, 2000). This level lies close to the upper boundary of the Gunningbland Formation.

Although the actual boundary between the Gunningbland Formation and the underlying Billabong Creek Limestone is unexposed, no significant time break is known to occur between these units, and parallel trends imply a conformable relationship. It is, however, possible that a strike fault disrupts continuity of section between the entrance to 'New Durran' and the property homestead, as the upper beds of the Billabong Creek Limestone (visible several kilometres further southeast on trend) are not exposed there. Discontinuous outcrops of volcanic rocks assigned to the uppermost Goonumbla Volcanics lie further west of west-dipping exposures of the Gunningbland Formation on 'New Durran'. The contact between these formations is always covered by alluvium, so that the nature of the upper boundary of the Gunningbland Formation is unknown.

## **Wombin Volcanics** (Opw) Bowman *et al.* (1982)

*Nomenclature*

Bowman *et al.* (1982) distinguished volcanic rocks at the top of the Goonumbla Volcanics as constituting a separate formation, the Wombin Volcanics, which was thought to have an unconformable relationship with the older Goonumbla Volcanics. Jones (1985) referred to (without definition) a 'Wombin Group', and stated that these rocks lay conformably on the Goonumbla Volcanics. While subsequent authors have noted a close petrogenetic relationship between these two volcanic units, thereby supporting their conformity, the hierarchical position of the Wombin Volcanics has varied from formation status (Sherwin *et al.*, 1987; Krynen *et al.*, 1990; Clarke, 1990a) to that of a member of the Goonumbla Volcanics (Sherwin, 1996). Here the Wombin Volcanics are restored to a formation within the Northparkes Volcanic Group, overlying the Goonumbla Volcanics. Previous authors (e.g., Krynen *et al.*, 1990; Clarke, 1990a; Sherwin, 1996) have included intrusive rocks of monzonitic affinity within the Wombin Volcanics, whereas here these are regarded as a separate unit (designated Omz) – albeit closely related to the Wombin Volcanics.

*Distribution and type locality*

The Wombin Volcanics display similar outcrop characteristics to those of the Goonumbla Volcanics. In the Forbes 1:250 000 map sheet area, exposures are limited to an area 20 km to 30 km northwest of Parkes, with discontinuous outcrops extending to the north on the adjacent Narromine 1:250 000 map sheet to about half way between Trundle and Alectown. Although Krynen *et al.* (1990) noted that the original type locality, defined by Bowman *et al.* (1982), is unsatisfactory as it occurs in an area of little or no outcrop, they did not specify a more representative area – nor has a new one been selected in the Forbes map sheet area.

*Description*

The most obvious feature distinguishing rocks of the Wombin Volcanics from those of the Goonumbla Volcanics is the reddish-orange colouration in hand specimens of the former. In comparison, volcanic rocks of the Goonumbla Volcanics are dark bluish grey. Krynen *et al.* (1990, p.27) attributed this difference to the "... higher content of haematite-stained alkali feldspar in, and therefore the more felsic composition of, the Wombin Volcanics."

Various rock types are present in the Wombin Volcanics, including dacite, andesite, and rhyolite tuffs (Bowman *et al.*, 1982). In practice, strict petrological classification is inappropriate for these rocks, many of which are highly altered, fractured and veined, especially in the Coradgery area 10 km northwest of Goonumbla where they are associated with porphyry copper–gold deposits. Away from this area, alteration is low to moderate. Krynen *et al.* (1990) described the volcanic rocks as strongly porphyritic in plagioclase and pyroxene, and porphyritic to a lesser extent in hornblende, biotite, and oxides, with microphenocrysts of apatite and rare sphene, in a groundmass of alkali feldspar, oxides, and in places minor quartz. Those authors also provided a detailed description (not reiterated here) of the more altered phases present around Coradgery (Narromine 1:250 000 map sheet area). That area is interpreted as part of an eroded caldera, with the Wombin Volcanics representing the centre.

*Age and boundary relationships*

There is no evidence to support an unconformable relationship between the Goonumbla Volcanics and the Wombin Volcanics, which provided the basis of a Late Silurian age for the latter as interpreted by Bowman *et al.* (1982). Such an age was also derived from isotopic age dating of highly altered Wombin Volcanics from the Coradgery–Goonumbla porphyry copper–gold deposits (Jones, 1985), which most probably does not reflect the original age of the volcanic rocks. Clarke (1990a) reported age data derived from relatively fresh primary igneous phases, an intrusive mafic rock providing a biotite K–Ar age of 435 ± 6 Ma, and a porphyritic volcanic rock yielding a whole rock K–Ar isotopic determination of 430 ± 6 Ma. Given the prevailing low metamorphic grade (prehnite–pumpellyite facies) in these rocks, there is unlikely to have been any release of argon caused by a high temperature thermal event subsequent to crystallisation. These ages, calculated using the preferred decay constants of Steiger & Jäger (1977), indicate an age range within the Llandovery (Early Silurian). Clarke (1990a) also quoted a Rb–Sr isochron for an intrusive rock associated with the Wombin Volcanics, which suggests a Late Ordovician age, although this has such a large statistical error that little reliance can be placed on it.

Arguing against a latest Ordovician to Early Silurian age is the close geochemical similarity between the Wombin Volcanics and Goonumbla Volcanics. Hence it can be postulated that the Wombin Volcanics represents an early Bolindian final phase of volcanism, concluding the Darriwilian to Late Ordovician episode represented predominantly by the Goonumbla Volcanics. Exposure and erosion of the Wombin Volcanics took place in late Llandovery time, subsequent to cessation of Cotton Formation deposition. Clasts believed to be derived from the monzonites that intrude the Wombin Volcanics are present in the Bocobidgle Conglomerate, of mid-Silurian age. The outcrop belt of Wombin Volcanics is discordantly overlain by the Siluro-Devonian Derriwong Group.

## **Parkes Volcanics** (Opp) Bowman (1977a), modified by Sherwin *et al.* (1987)

*Previous nomenclature*

Initially termed the 'Parkes Andesite' (Bowman, 1977a), and renamed Parkes Volcanics (Sherwin *et al.*, 1987), the formation was described in detail by Krynen *et al.* (1990). Now also included in the Parkes Volcanics is the former 'Daroobalgie Volcanics' of Sherwin *et al.* (1987) and Krynen *et al.* (1990). This latter unit, which is limited in extent to a few outcrops just north of Forbes, may represent

a separate volcanic centre but otherwise does not appear to differ significantly from the Parkes Volcanics exposed to the north immediately west and southwest of Parkes.

*Distribution, outcrop and type locality*

The Parkes Volcanics are confined to a highly sheared narrow belt between the western outskirts of Parkes and the London-Victoria Fault. Outcrop extends southwest for about 5 km towards Tichbourne. Another small group of exposures (the former 'Daroobalgie Volcanics') is found immediately west of Daroobalgie, approximately 6 km north of Forbes. Alluvium obscures any continuity between these two areas of outcrop.

The best exposures are along the London-Victoria line of lode, particularly within the Victoria open-cut mine. These rocks are sheared and altered, as are the outcrops at Bowman's (1977a) type locality for the unit, a low rise just west of Parkes (GR 607020 mE 6332700 mN). The type locality for the former 'Daroobalgie Volcanics' is in a quarry at Bald Hill (GR 596300 mE 6312750 mN), where these rocks are apparently overlain by the Cotton Formation (Krynen *et al.*, 1990).

*Description*

Hydrothermal alteration and shearing is pervasive throughout the outcrop of the Parkes Volcanics, so much so that in the vicinity of the London-Victoria mine, volcaniclastic rocks have a superficial similarity to laminated sedimentary rocks. The volcaniclastic rocks are interpreted as both pyroclastic and epiclastic origin. Few rocks displaying primary igneous textures can be recognised in the unit. Krynen *et al.* (1990) mentioned the following occurrences: plagioclase-phyric volcanic rocks crop out poorly at the Mount Morgan mine (GR 608400 mE 6336000 mN), and are more abundant at the Nibblers Hill mine (GR 605800 mE 6327200 mN). Outcrops of similar rocks near the Parkes Golf Course (GR 606900 mE 6331700 mN) are less affected by deformation and retain primary groundmass quench texture. Near Forbes, rocks of the former 'Daroobalgie Volcanics' have been described (Krynen *et al.*, 1990) as being strongly porphyritic in plagioclase, and to a lesser degree porphyritic in pyroxene, oxides, and olivine. The coarse-grained groundmass is composed mainly of alkali feldspar with accessory apatite. Alteration varies from moderate to extreme, similar to that in rocks of the Parkes Volcanics nearer to Parkes.

*Thickness*

Near the type locality west of Parkes, Krynen *et al.* (1990) estimated a minimum thickness of 500 m for the Parkes Volcanics, based on measurement of the width of the outcrop belt – but this has no doubt been affected by strong shearing and is unlikely to be representative. A thickness of 200 m to 400 m was estimated by Krynen *et al.* (1990) for the former 'Daroobalgie Volcanics' at Bald Hill near Forbes, based on a section across the anticlinal structures at that locality.

*Boundary relationships and age*

Contacts of the Parkes Volcanics with adjacent formations in the strongly sheared belt west of Parkes are not exposed, but are likely to be faulted. Krynen *et al.* (1990) claimed that there, the Parkes Volcanics are conformably overlain by the Cotton Formation. Relationships are more contentious at Bald Hill near Forbes, where rocks formerly assigned to the 'Daroobalgie Volcanics' are clearly in contact with the Cotton Formation, which at that locality yield poorly preserved graptolites of Bolindian (latest Ordovician) age. Krynen *et al.* (1990) presented two interpretations of this contact: either the volcanic rocks formed as a series of deep marine lava flows conformably overlain by the graptolitic sedimentary rocks; or they intruded as a sill into semi-consolidated sediments of the Cotton Formation.

There is no internal evidence of an age for the Parkes Volcanics, and its highly altered nature does not allow for reliable isotopic age determinations. The Bolindian age of the Cotton Formation in contact with the unit at Bald Hill provides the sole constraint on a minimum age for the Parkes Volcanics.

## **Nash Hill Volcanics** (Oph) Bowman (1977), modified Krynen *et al.* (1990)

*Previous nomenclature and type locality*

Bowman (1977) designated Nash Hill (GR 611300 mE 6334700 mN), a prominent feature on the northeastern outskirts of Parkes, as the type locality. The scope of this term has been expanded to include the Back Yamma Volcanics (Bowman, 1977; Krynen *et al.*, 1990), about 12 km south of Parkes. The 'Bushmans Volcanics' (Duggan *et al.*, 1999) in, and just north of, Parkes, revert to their original classification of Nash Hill Volcanics (Krynen *et al.*, 1990).

*Outcrop and distribution*

The Nash Hill Volcanics form a very prominent hill at the type locality but produce a barely discernible ridge only a few kilometres north and south of Parkes. At Back Yamma, about 20 km south of Parkes, the volcanic rocks form a distinct ridge above an alluvial plain. The Back Yamma Volcanics have been included with the Nash Hill Volcanics because both units have a distinct, high Th gamma ray spectrometric signature, and are separated only by about 5 km of no outcrop along a strong, continuous magnetic anomaly. The Bushmans Volcanics in Parkes are linked to the Nash Hill Volcanics south of Parkes by a prominent linear magnetic anomaly beneath alluvial cover, and are considered to be the same unit.

*Description*

Krynen *et al* (1990) gave detailed outcrop descriptions of the Nash Hill Volcanics. The volcanic rocks comprise brecciated, plagioclase-phyric, clinopyroxene-phyric and non-porphyritic basalt to andesite. They are variably vesicular. Some areas of hornblende-phyric andesites may represent discrete volcanic centres. Mafic epiclastic

sandstones derived from erosion of these rocks also occur. Secondary clay, chlorite, epidote, sphene and carbonate alteration is not uncommon, notably at and near gold deposits adjacent to fault splays of the Parkes Fault Zone. The volcanic rocks are strongly magnetic, and are easily traced beneath alluvial cover using aeromagnetic data.

*Environment of deposition*

The Nash Hill Volcanics were deposited in a marine to locally emergent island arc environment, coeval with the other volcanic units of the Northparkes Volcanic Group.

*Boundary relationships and age*

The Nash Hill Volcanics have problematic contact relationships. Their overall composition suggests some relationship with the Parkes and Goonumbla Volcanics, except for their distinctive high Th gamma ray spectrometric signature. Although there is a parallel trend with probable Late Ordovician sediments, it is probable that the concealed boundaries are faulted. The contact with the overlying Cotton Formation at Middleton (GR 609500 mE 6331000 mN; Krynen *et al.*, 1990, p. 31) is very weathered but does suggest a conformable contact rather than a fault. Aeromagnetic data show abrupt, linear margins to the strongly magnetic volcanic rocks, which suggest mostly faulted contacts within the Parkes Fault Zone. The overlying Cotton Formation indicates that the age is pre-Bolindian (Late Ordovician), more or less coeval with the rest of the Northparkes Volcanic Group.

## **Goobang Volcanics** (Opo) *nov*

*Nomenclature, type locality and distribution*

The Goobang Volcanics is a new name for a belt of presumably Late Ordovician intermediate to mafic volcanic rocks, which are defined largely from aeromagnetic interpretation. Only a few small outcrops occur in the Forbes and Narromine 1:250 000 map sheets areas. These outcrops were included in the Nash Hill Volcanics by Krynen *et al.* (1990). The type locality is at the only outcrop of the Goobang Volcanics in the Forbes 1:250 000 map sheet area, about 17 km northeast of Parkes (GR 621120 mE 6345450 mN), where andesitic volcanic rocks are faulted against the Mugincoble Chert. The volcanic rocks are interpreted from aeromagnetic data to extend in a fault bounded wedge, up to 3 km wide, about 20 km southwest from the type locality to beneath the Parkes airport, and another 15 km north into the Narromine 1:250 000 map sheet area.

*Description*

The single outcrop of Goobang Volcanics in the Forbes 1:250 000 map sheet area comprises fine-grained andesitic sandstone. The rock consists primarily of moderately well-sorted (up to 1 mm), equant, zoned, strongly sericitised, plagioclase crystals (~60%), and fresh, equant clinopyroxene crystals (5% to 10%). Elongate, poikolitic hornblende crystals up to 8 mm across, and fine-grained magnetite also comprise a few percent each of the crystal population. All grains are euhedral to subrounded, indicating a proximal source. The sandstone is typically grain-supported, with a very fine-grained matrix, which is completely altered to sericite and chlorite. Although the rock superficially appears to be a porphyritic andesite, the high proportion of crystals and the grain-supported structure of the rock indicate that it is epiclastic.

The sandstone is strongly magnetic ($2000 \times 10^{-5}$ SI) and occurs at the eastern margin of the elongate magnetic anomaly that defines the subsurface extent of the Goobang Volcanics.

*Boundary relationships and age*

The Goobang Volcanics are interpreted from aeromagnetic data to be faulted against the Kirribilli and Cotton Formations. At the type locality, a zone of strongly silicified and quartz-veined rock marks the faulted contact with the Mugincoble Chert. The Goobang Volcanics are probably of Late Ordovician age, having similar lithology and magnetic character to other intermediate to mafic volcanic rocks of the Northparkes Volcanic Group.

## **Unnamed monzonite** (Omz) modified from Krynen *et al.* (1990)

*Distribution*

Unnamed monzonite intrusions occur in the core of the Forbes Anticline where they sporadically crop out in an area centred about 15 km west-northwest of Parkes.

*Representative locality*

Although no type locality is given, a good exposure of one of the intrusions is located on the Condobolin road at GR 599000 mE 6337300 mN, about 12 km west of Parkes.

*Description*

Generally, the monzonites are pyroxene–quartz monzonites to monzodiorites, some associated with minor sulphide mineralisation. They have potassic calc-alkaline to shoshonitic chemical affinities, similar to the surrounding volcanic rocks and are moderately altered to clay, sericite, epidote, and chlorite. Secondary prehnite and pumpellyite were also reported to occur (Krynen *et al.*, 1990). At Goonumbla, about 7 km north of the Forbes 1:250 000 map sheet area, similar small monzonite intrusions are associated with porphyry style copper–gold mineralisation (e.g., Muller *et al.*, 1994).

*Age*

Although no contacts are exposed, the monzonite bodies appear to have intruded the Late Ordovician Goonumbla Volcanics and Wombin Volcanics. Their shoshonitic composition and association with gold mineralisation suggest they are subvolcanic equivalents of the Late Ordovician Northparkes Volcanic Group.

## Ungrouped Ordovician Units

### Nelungaloo Volcanics (Onv) Sherwin (1973b)

*Previous nomenclature*

The Nelungaloo Volcanics were given separate status from the 'Goonumbla Volcanics' by Sherwin (1973b, p. 55), who referred to volcanic rocks forming "...the low hill about 5 km southwest of Nelungaloo Railway Station." (p. 55) The railway station, closed in 1974, no longer exists but was beside the present siding and silos. The low hill (GR 590700 mE 6329700 mN) includes at least one minor intrusion and some sedimentary units of uncertain relationship, possibly referable to the overlying Yarrimbah Formation. This locality was not specified as the type area but only as the southern limit of the Nelungaloo Volcanics. Because of the problems in identifying suitable boundaries for this unit at 'Nelungaloo', Krynen *et al.* (1990) designated a type area covering outcrops at "Wilga" (GR 597100 mE 6340450 mN) and at "Yarrimbah" (GR 599900 mE 6339800 mN), as well as the hill in the eastern part of 'Nelungaloo'.

Sherwin *et al.* (1987) designated a sedimentary unit within the Nelungaloo Volcanics, the 'Yarrimbah Chert Member', but it is now believed to overlie the Nelungaloo Volcanics and is regarded as a separate formation — herein named as the Yarrimbah Formation.

*Distribution and outcrop*

Undoubted outcrops of the Nelungaloo Volcanics occur only in the core of the Forbes Anticline and can be recognised northeast of Nelungaloo, almost as far as Goonumbla (GR 605150 mE 6348050 mN). The outcrops on 'Wilga' are restricted to a small area at the foot of the slope, to the east of the house. Aeromagnetic data indicate that the Nelungaloo Volcanics are present beneath Cainozoic sediments, at least as far north as 'Taweni' (Narromine 1:250 000 map sheet area, GR 607700 mE 6369500 mN), about 45 km northeast of the Nelungaloo locality. Because the outcrops are so patchy it is possible that some may belong to younger intrusive units.

The Nelungaloo Volcanics crop out poorly, at best, and are deeply weathered. The unit as a whole is associated with very gentle rises. The best outcrops are on 'Yarrimbah' to the north of the sheds (GR 599900 mE 6339800 mN), although, even there, the outcrops are only just above the soil. Elsewhere the surface is covered with weathered float. The exception is the basalt (GR 593460 mE 6335760 mN) north of Nelungaloo, which forms a bouldery to almost sheet-like outcrop.

*Description*

Most of the volcanic rocks assigned to the Nelungaloo Volcanics are purplish brown, porphyritic extrusive rocks. Krynen *et al.* (1990) noted that the rock ranged "...from sparsely to strongly plagioclase-phyric." On the roadside north of Nelungaloo (GR 593460 mE 6335760 mN), there is an aphanitic basalt believed to be part of the Nelungaloo Volcanics. It is notably fresh in outcrop and contains quartz veins up to 12 cm thick. Clarke (1990a) described all extrusive outcrops as "characteristically amygdaloidal, with flattened quartz amygdales up to 10 cm across" (p. 99) The basaltic unit is also strongly magnetic, measuring $2600 \times 10^{-5}$ SI to $3000 \times 10^{-5}$ SI (Clarke, 1990a).

A thin section cut from a sample from 'Yarrimbah' (T65380, GR 599800 mE 6340000 mN shows some flow banding and possible vesicles, and contains about 35% K-feldspar in the submicrolitic matrix. The phenocrysts are plagioclase ($An_{40}$), K-feldspar, ?orthopyroxene, and augite, with montmorillonite–iddingsite alteration. Other alteration includes epidote, overprinted by carbonate and sericite, with a veinlet of quartz, zeolite, and montmorillonite. The accessory minerals include apatite and magnetite. The rock is probably a strongly fractionated product of a trachylatite magma. Krynen *et al.* (1990) described the aphanitic basalt north of Nelungaloo as a quenched volcanic rock with a "... groundmass of alkali feldspar, magnetite, sphene [sic], and pale-green [sic] pyroxene" (p. 13) and "... sparse phenocrysts of plagioclase, pyroxene, oxides, and hornblende ..." (p.13). Krynen *et al.* (1990) noted a more porphyritic phase marginal to the aphanitic basalt, with "phenocrysts of abundant plagioclase and lesser pyroxene and oxides, and amygdales of quartz–prehnite–chlorite [sic]".

*Age and boundary relationships*

The Nelungaloo Volcanics forming the hill at Nelungaloo were intruded by a small monzonitic plug of uncertain age, although it resembles other nearby monzonitic intrusions of established Late Ordovician to Early Silurian age. The volcaniclastic sedimentary rocks at that locality, assigned to the Yarrimbah Formation, appear to overlie the Nelungaloo Volcanics, although no actual contacts are exposed. West of this hill, and presumed to overlie both Yarrimbah Formation and the Nelungaloo Volcanics, is the west-dipping Northparkes Volcanic Group. The discordant trends of the two lines of outcrop imply an angular unconformity, although the true nature of the contact is obscured by surficial deposits.

At 'Yarrimbah', the Nelungaloo Volcanics are overlain by a volcanolithic conglomerate at the base of the Yarrimbah Formation, implying a time break of uncertain length. The Yarrimbah Formation contains a Lancefieldian–Bendigonian (Early Ordovician) graptolite fauna, so the minimum age for the Nelungaloo Volcanics is earliest Ordovician to Late Cambrian.

Zircons for radiometric dating were not found in mafic rocks of the Nelungaloo Volcanics during this study. However, Perkins *et al.* (1990) quoted a U–Pb zircon age of 438 ± 7 Ma, but did not give the location of the sample, which it is believed to be from the aphanitic basalt north of Nelungaloo. Such an age is clearly at odds with the fossil-based age of at least earliest Ordovician.

**Yarrimbah Formation** (Oy) Sherwin *et al.* (1987) modified.

*Nomenclature and boundary relationships*

The 'Yarrimbah Chert Member' was believed to lie wholly within the Nelungaloo Volcanics (Krynen *et al.*, 1990). However, at the type locality on Yarrimbah Station (GR 599900 mE 6339800 mN), there is evidence only that it overlies the Nelungaloo Volcanics. The member status is thus considered redundant. There is no evidence of an intrusive relationship with the Nelungaloo Volcanics, although no contact is actually exposed. The upper contact of the formation is obscured by surficial deposits. Because the lower part of this unit has rock types other than chert, its name has been amended to Yarrimbah Formation.

*Distribution and outcrop*

The Yarrimbah Formation crops out poorly, being well-exposed only in the gravel pit at the type section, and in shallow scrapes and pits on 'Cardiff' (GR 603700 mE 63446000 mN) and 'Limestone' (GR 605400 mE 6346300 mN) stations. Natural outcrops are well-exposed only at 'Yarrimbah' station. Outcrop and subcrop occur in a narrow belt between 'Timaroo' (GR 594600 mE 6336750 mN) and 'Limestone' stations, although some small sandstone outcrops at Nelungaloo may also belong to this formation.

Thinly bedded Early Ordovician siltstones north of the Forbes 1:250 000 map sheet area, near Peak Hill (Sherwin, 1993), have been assigned to this formation.

*Description*

At the type locality, the Yarrimbah Formation has a thin, basal volcaniclastic sandstone, no more than a few metres thick and conglomeratic in part, overlain by thinly bedded cherts and laminated siltstones. The pebbles and cobbles are angular to subrounded, and look to be from the same source as the lithic sandstone matrix. The outcrops of the conglomerate are too small and scattered to allow comment on internal bedding features.

The bedding thickness of the Yarimbah Formation in its upper part (above the conglomerate) varies from a few millimetres to several centimetres. The general appearance is of pale, reddish brown to off-white, well-sorted siltstone. There is little obvious variation in grainsize, suggesting little variation in the conditions of deposition. Judging by the fine grainsize and laminated bedding, deposition is believed to have been by traction currents, probably well away from the shoreline and sufficiently below wave base to avoid disruption to the thin bedding. It is uncertain if the cherty nature of many beds represents primary chert deposition or later silicification.

Some cherty siltstones of the Yarrimbah Formation are very much like those in the Late Ordovician to Early Silurian Cotton Formation, so much so that isolated outcrops of these siltstones could prove difficult to assign to the relevant formation without palaeontological control. The Cotton Formation contains a reasonably abundant Late Ordovician to Early Silurian graptolite fauna (Sherwin, 1973b; 1974; 1976), whereas the Yarrimbah Formation is of Early Ordovician age.

*Age*

Early Ordovician graptolites have been recorded from several localities within the Yarrimbah Formation west of Parkes (Sherwin, 1979; Krynen *et al.*, 1990). The presence of *Tetragraptus approximatus* indicates a Lancefieldian 3–Bendigonian 1 age using the ranges determined by Vandenberg & Cooper (1992).

**Kirribilli Formation** (Osk) after Sherwin *et al.* (1987)

*Nomenclature, distribution and boundary relationships*

The Kirribilli Formation is a formalisation of the 'Kirribilli Beds' originally proposed by Sherwin *et al.* (1987) and later Krynen *et al.* (1990). The unit is named after the 'Kirribilli', about 18 km east of Forbes. Brunker (1972a) and Bowman (1976) mapped the formation as part of undifferentiated Ordovician metasediments.

The Kirribilli Formation occurs in a north-northeast to south-southwest trending belt in the east of the Forbes 1:250 000 map sheet area, extending from the map boundary south of Grenfell and passing about 10 km east of Parkes towards the northern boundary (Figure 3.17). In the south central part of the Forbes 1:25 000 map sheet area, the Kirribilli Formation is present between Pullabooka and Caragabal Creek, where it crops out in the area of the Pinnacles–Ironbarks gold district and in the Piney Range area.

Much of the Kirribilli Formation is covered by thick Cainozoic alluvial and colluvial sediments and, where the formation is exposed, it is commonly as weathered subcrop. The Kirribilli Formation also commonly presents as low rises, on which bedrock does not crop out, but is covered by a thin, *in situ* soil layer and abundant metamorphic quartz vein float. The thickness of the Kirribilli Formation is unknown due to probable repetition by faulting and folding, and the lack of internal stratigraphic markers. Krynen *et al.* (1990) suggested a thickness for the Kirribilli Formation in the order of thousands of metres.

In the area of Caragabal Creek, the Kirribilli Formation has been intruded by the Early Devonian Bogalong Suite of granites, and is overlain by the Late Devonian Weddin Sandstone of the Wheoga Range. In the Pinnacles–Ironbarks area, the Kirribilli Formation occurs mainly within the Parkes Fault Zone and also forms part of the hanging wall. At its western margin, the Kirribilli Formation is unconformably overlain by the Siluro-Devonian Ootha Group and was intruded by the Devonian Wirrinya and Berendebba Granites.

The Kirribilli Formation was probably intruded by the Early Devonian Caragabal Granite in the Wheoga Hill area. The contact with the granite is linear and appears faulted in aeromagnetic images. However, there is little deformation

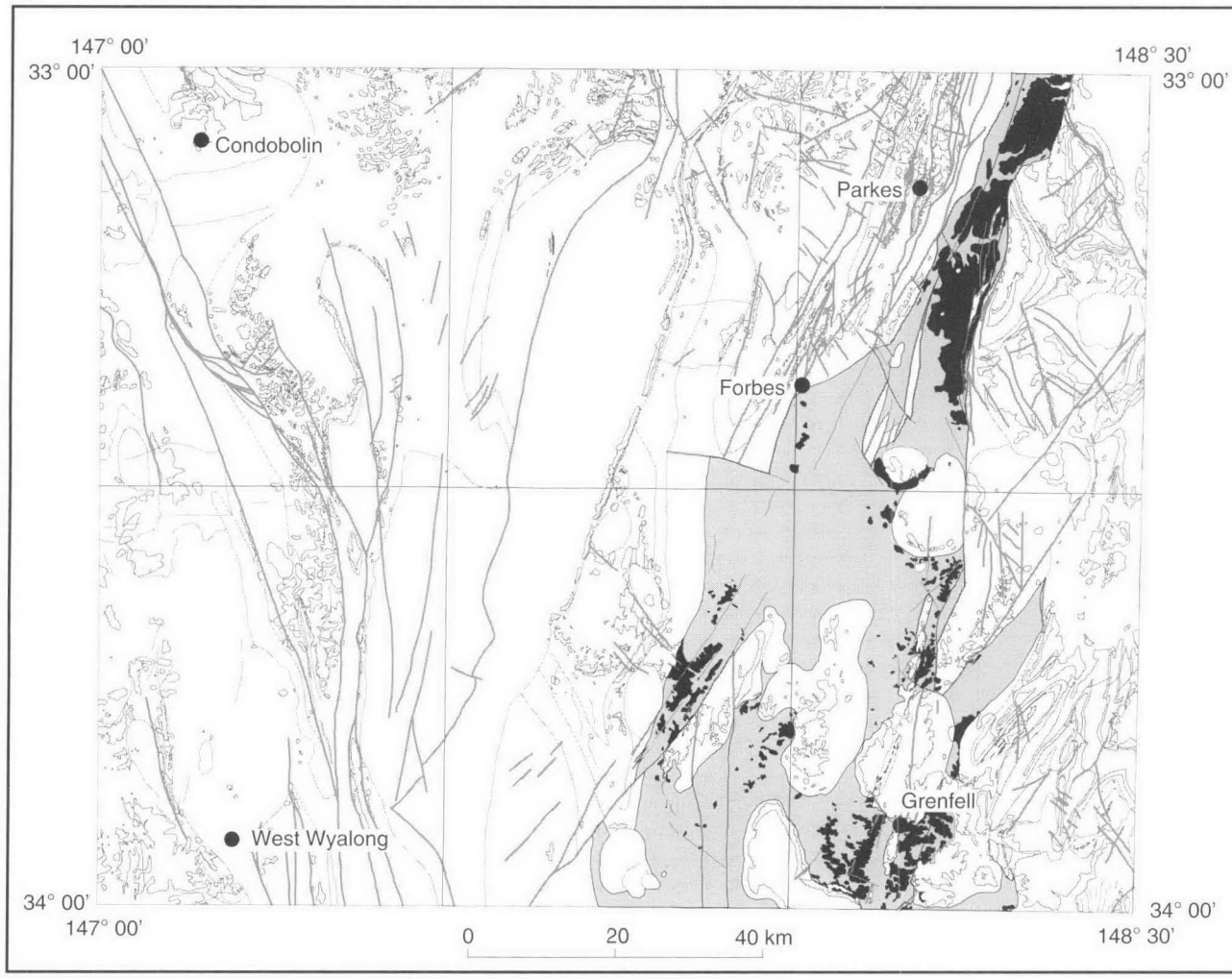



*Figure 3.17. Distribution of the Kirribilli Formation in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

in the granite associated with the contact. This may be due to a pre-existing fault plane of the Parkes Fault Zone, along which the granite has intruded. Alternatively, ductile deformation was confined to the Kirribilli Formation. The latter implies that the Caragabal Granite was faulted and that the western block was lifted sufficiently above the level of the present land surface to have been completely removed.

In the northeast of the Forbes 1:250 000 map sheet area, the Kirribilli Formation forms a broad belt, with a north-northeast to south-southeast trend, in the hangingwall of the Coolac–Narromine Fault Zone. The Kirribilli Formation is faulted against the Middle Devonian Dulladerry Volcanics and the Early Silurian Glenisla Volcanics. An arcuate outlier of Dulladerry Volcanics probably overlies the Kirribilli Formation immediately west of the faulted contact. The Kirribilli Formation was intruded by the Bindogandri Granite, with a narrow zone of cleavage destruction adjacent to the granite contact.

The Kirribilli Formation is probably conformable with the Hoskins Chert Member of the Brangan Volcanics. In the southeast of the Forbes 1:250 000 map sheet area, the Kirribilli Formation is probably conformable with the Brangan Volcanics. It was intruded by the Devonian Grenfell Granite, Schneiders Granite, and Cumbijowa Granite and the Eugowra Suite, and is unconformably overlain by the Siluro-Devonian Derriwong Group; the Devonian Rocky Ponds Group and Hervey Group; and is most likely in fault contact with the mid-Ordovician Wambidgee Serpentinite.

*Description and thickness*

The Kirribilli Formation is a thick, monotonous pile consisting primarily of thinly bedded, buff to grey, green and maroon shale and phyllite, with interbedded siltstone and fine-grained sandstone. The rocks are generally quartzose, but lesser quartz–lithic sandstones, and rare carbonaceous shales also occur. The unit is generally tightly to isoclinally folded and fine-grained metamorphic muscovite commonly defines a penetrative weak to strong foliation usually developed only in the finer-grained rocks. A spaced cleavage is sometimes present in psammitic units. Chlorite and biotite are well-developed in pelitic units (Figure 3.18).

*Figure 3.18. Strongly foliated, thinly interbedded fine-grained chloritic schist and sandstone of the Kirribilli Formation. (GR 624550 mE 6340650 mN) (O.L. Raymond photograph)*

About 25 km northeast of Forbes (GR 613090 mE 6318060 mN), a rare example of a comparatively less-deformed part of the Kirribilli Formation can be found (Figure 3.19). Rare, very small-scale cross-bedding occurs. Andalusite spotting is present in shales within the contact metamorphic aureole of the Wirrinya Granite (Figure 3.20).

*Figure 3.19. Shallow-plunging folds in interbedded sandstone and shale of the Kirribilli Formation. Such preservation of fold closures in the Kirribilli Formation is rare. (GR 615400 mE 6318110 mN) (O.L. Raymond photograph)*

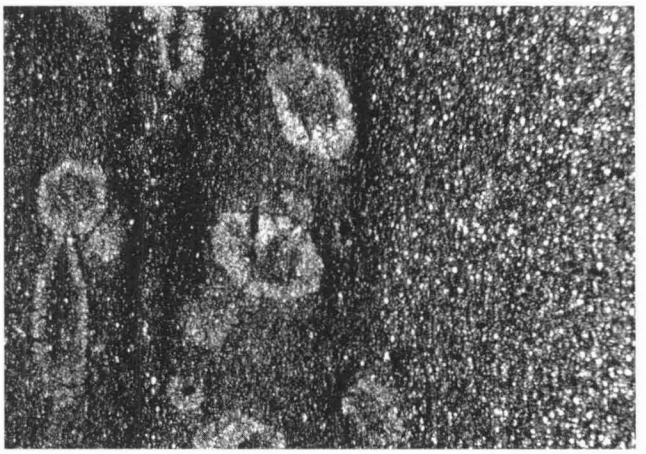


*Figure 3.20. Photomicrograph of andalusite spotting in a shale of the Kirribilli Formation in the contact aureole of the Wirrinya Granite. Field of view approximately 4 mm. (GR 576400 mE 6264440 mN) (O. Raymond photograph)*

The foliation in shales and phyllites of the Kirribilli Formation becomes strong to intense in the vicinity of major structures such as the Parkes Fault Zone and Coolac–Narromine Fault Zone, where bedding and the dominant foliation are generally parallel to subparallel to the fault zones, and have steep to vertical dips. Local dismembering of bedding occurs in more intensely sheared areas. Kink bands may be developed at high angles to the main foliation (Figure 3.21). Within the vicinity of the fault zones, folding is probably isoclinal, but is difficult to characterise due the paucity of younging evidence and lack of exposed fold closures. Thin quartz veins, typically 1 cm to 10 cm wide, commonly cut across the penetrative foliation at low angles (Figure 3.22). In the Pinnacles–Ironbarks gold district, these veins host gold mineralisation.

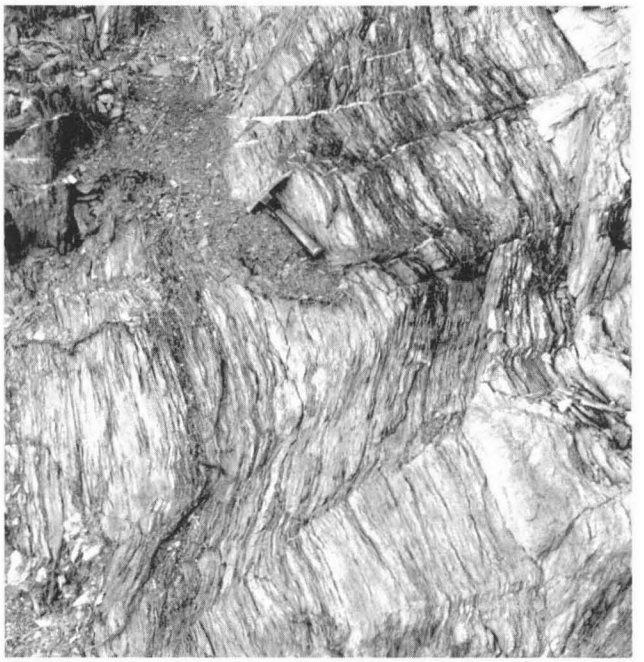


*Figure 3.21. Strong cleavage, kink bands and quartz-filled tension gashes in chloritic phyllites of the Kirribilli Formation. (GR 585220 mE 6279410 mN) (O.L. Raymond photograph)*

*Figure 3.22. Quartz veining subparallel to strong cleavage in Kirribilli Formation phyllites in the Pinnacles–Ironbarks gold district. (GR 585220 mE 6279410 mN) (O.L. Raymond photograph)*

The thickness of the Kirribilli Formation is unknown due to the intense deformation and the lack of fossils. Krynen *et al.* (1990) suggested a thickness in the order of thousands of metres.

The magnetic susceptibility of the Kirribilli Formation is very low ($10 \times 10^{-5}$ SI to $30 \times 10^{-5}$ SI). Gamma ray spectrometric count rates for K, Th and U are fairly high due to detrital clays and metamorphic micas, but are commonly subdued due to poor outcrop and soil cover.

*Depositional environment*

The Kirribilli Formation was deposited in a deep marine, possibly distal, submarine fan environment. The thinly interbedded, fine-grained sedimentary units suggest deposition from distal turbidites. Krynen *et al.* (1990) noted Bouma sequences, but these are rarely preserved due to deformation.

*Age and correlation*

No fossils have been recorded in the Kirribilli Formation. But stratigraphic correlation with the Mugincoble Chert indicates a Middle to Late Ordovician age.

## **Jingerangle Formation** (Osj) Bowman (1976)

*Derivation of name and type locality*

The Jingerangle Formation is named after the Jingerangle State Forest, about 37 km east of West Wyalong. The representative locality is at the road aggregate quarries in the vicinity of Gibber Trigonometrical Station (GR 560500 mE 6244000 mN) immediately south of the Jingerangle State Forest.

Despite their assertion that Bowman (1976) first described the Jingerangle Formation — no such name or distinguishing description appears either on the Forbes 1:250 000 metallogenic map or in the accompanying explanatory notes — it was in fact Warren *et al.* (1995) who provided the initial naming of the unit and its formal description.

*Distribution*

In the Forbes 1:250 000 map sheet area, outcrops of the Jingerangle Formation are distributed over a small area defined by a low hill about 3 km long and 1 km wide (Figure 3.23). The unit is also known from three outcrops in the Cootamundra 1:250 000 map sheet area to the south (Warren *et al.*, 1995). Outcrop of the unit is contained within a wedge-shaped north–south magnetic zone, up to 15 km wide, which contains many linear magnetic anomalies that may indicate interbedded volcanic units. The magnetic zone extends some 20 km north of the representative locality, and southwards into the Cootamundra 1:250 000 map sheet area, where rocks of the unit were named the Currumburrama Volcanics by Bacchin *et al.* (1999).

*Description*

Strata in the roadbase quarry immediately south of the State Forest mostly consist of a succession of thin-bedded siltstones and mudstones, the latter generally weathered into multicoloured clays (pink and white) and orange-brown ochres. The siltstones are more resistant as they are largely composed of sponge spicules, which provide a tightly interlocking meshwork of silica. Fresh examples recently exposed in the quarry are relatively dense and mostly dark grey in colour (Figure 3.24); surficial outcrops of this rock type have been weathered to a lighter biscuit-like texture, of grey-white appearance. The other rock type in the quarry occurs in stratigraphically higher beds, composed of coarser siltstone to fine-grained sandstone, now partly silicified. These strata are distinguished by the high concentration of silicified sponges (predominantly the spheroidal *Hindia*), which are clustered on the surface of beds. Thin maroon-coloured medium- to coarse-grained sandstone layers are rarely interspersed in the siltstone succession towards the basal beds exposed in the working quarry. The metamorphic grade is very low.

Most beds at this locality dip to the east with dip angles variable from nearly zero to about 30 °. Only an estimated 20-30 metres of continuous section is exposed in the floor of the working quarry; the true thickness of the formation is considerably in excess of this, but cannot be measured, or even estimated, as the outcrop represents only a relatively small component of the extent of the formation inferred from the geophysical evidence. Minor faulting and medium-scale folding is well displayed in the walls and floor of the abandoned quarry on the south side of the hill immediately west of 'Bland Farm' homestead.

The Jingerangle Formation is significant in containing the youngest, most diverse, Late Ordovician shelly macrofauna in the region, near the southernmost extent of outcrop of sedimentary rocks associated with the Parkes-Narromine Belt. In this belt, only the lower section of the Cotton Formation, on trend to the north just west of Forbes, appears to be of broadly comparable (Bolindian) age. However, the two formations are distinguished by the inferred presence of interbedded volcanic units in the Jingerangle Formation. The comparatively well-exposed,

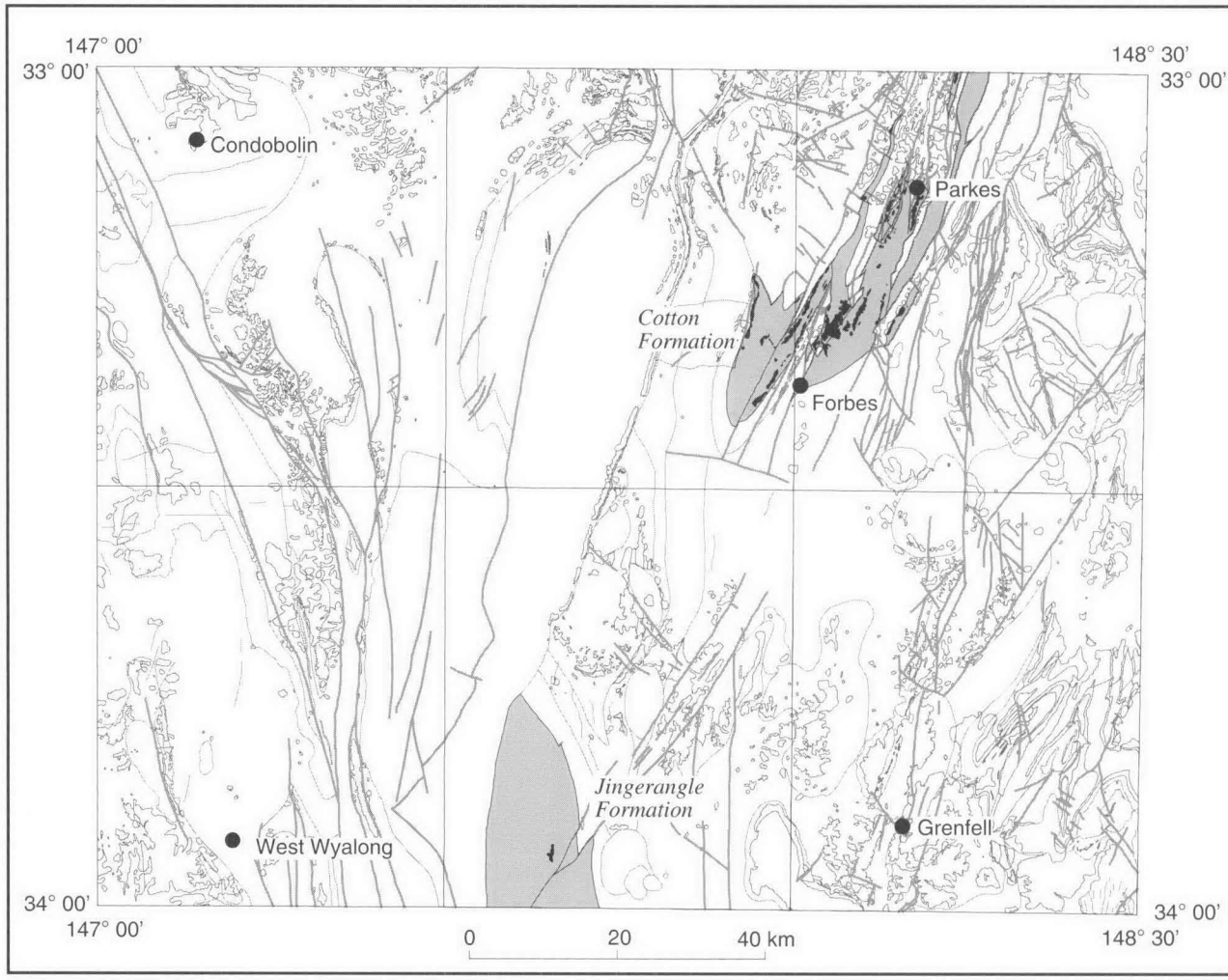



*Figure 3.23. Distribution of the Jingerangle Formation and Cotton Formation in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

lower part of the Cotton Formation shows no sign of contemporaneous volcanic activity.

*Palaeontology, age and depositional environment*

Fossils from the unit were first referred to by Wynn (1961), with this information republished by Moye *et al.* (*in* Packham 1969, p. 98). Subsequent unpublished reports on the faunal assemblage were provided by Sherwin (1982, 1985) and Pickett (1986). Faunal lists from two of these reports were subsequently published in the palaeontological appendix to the Cootamundra 1:250 000 Geological Sheet Explanatory Notes (Warren *et al.* 1995).

The graptolite assemblage includes species ranging in age from middle Eastonian to middle Bolindian (Late Ordovician). Overlap of the published ranges (VandenBerg & Cooper, 1992) suggests an early Bolindian (Bo 2) age is most probable for the formation.

The coiled nautiloids, which are the most spectacular components of the fauna (Figure 3.25), are mostly preserved as external moulds, which do not permit precise identification. A complete list of the faunal assemblage found in the Jingerangle Formation is provided in the Palaeontological Appendix to these Notes.

The association of graptolites, nautiloids of nektic habit (particularly the proliferation of tarphyceratids, which are thought to have been strong swimmers), and lithistid sponges was interpreted by Percival (1999b) to indicate deep water environments at depths typical of Benthic Assemblage 4-5 (perhaps 50-200 m). A somewhat comparable faunal association is present in the basal Malongulli Formation in the Cliefden Caves on the Bathurst 1:250 000 map sheet area (Webby, 1992; Percival & Webby, 1996). Here, a diverse suite of sponges (including Hindia) populated the periplatformal zone, between the shelf edge and the deep basin (Rigby & Webby, 1988). The Malongulli sponge assemblage was subsequently dislodged as debris flows or slumps into the lower slope and basinal sediments. In the case of the Jingerangle Formation, the Hindia-dominated fauna is preserved in laminated sediments that are not slumped and are interpreted to have formed *in situ*. Fauna in the Bolindian section of the Cotton Formation consists only of graptolites, orthoconic nautiloids, ostracodes (Sherwin, 1973) and the lingulate brachiopod Paterula (Percival, 1978); presumably these sediments were deposited at depths slightly greater than that interpreted for the Jingerangle Formation.

*Figure 3.24. Shallow-dipping, siliceous siltstones of the Jingerangle Formation, showing typical flaggy outcrop. (GR 560500 mE 6244240 mN) (O.L. Raymond photograph)*

*Figure 3.25. Coiled nautiloid fossil, ?*Discoceras, *from the Jingerangle Formation. (GR 560500 mE 6244240 mN) (O.L. Raymond photograph)*

*Age and depositional environment*

Nautiloids and climacograptid fossils occur in the laminate beds. Poorly sorted beds contain sponges and corals, and these beds indicate slumping of shallow water sediments.

The Late Ordovician fossil fauna of graptolites, nautiloids (Figure 3.25), brachiopods, sponges, and echinoderms in the Jingerangle Formation is probably Bolindian. The sediments were deposited in a deep marine environment, possibly marginal to a shallow shelf, as suggested by the presence of poorly-sorted slump deposits of spiculitic siltstone.

### **Cotton Formation** (O-Sc) Andrews (1910) modified Sherwin *et al.* (1987)

*Previous nomenclature and type locality*

The 'Cotton Series' was applied by Andrews (1910) to "...indurated and laminated claystones, grey to yellowish-brown in colour..." (p. 25) between Parkes and Forbes. The choice of name implied a type area at Cotton Trigonometrical Station (GR 586800 mE 6313400 mN), about 11 km northwest of Forbes (Figure 3.26). The conglomerate and mudstone immediately west of Forbes, included within the 'Cotton Series' on Andrew's (1910) accompanying map, were detached by Brunker (1972a) as the Forbes Group. The revised stratigraphy of the 'Cotton Beds' was described by Sherwin (1973b) and the status later changed to Cotton Formation (Sherwin *et al.*, 1987). Krynen *et al.* (1990) showed that the Cotton Formation could be recognised north of Parkes and was equivalent to the Tomingley Siltstone (Brunker, 1972b; Bowman *et al.*, 1982) much further to the north in the Narromine 1:250 000 map sheet area. Thin chert beds are present in the type area of the Cotton Formation (Sherwin, 1973b) and tend to be more common in the north easterly outcrops near Parkes — as well as being more obvious because of their comparative greater resistance to erosion.

*Distribution and outcrop*

The Cotton Formation, except for the cherty beds, does not produce good outcrops, although it produces distinctive low ridges, which can be traced many kilometres, especially their traces on aerial photographs. The surface of these ridges is covered with varying amounts of float and angular fragments of vein quartz. Recognition otherwise depends upon favourably sited road or rail cuttings and gravel scrapes. Most of the outcrop is on the limbs of the Forbes Anticline, especially on the eastern limb, which passes through Parkes (Figure 3.23). The Jingerangle Formation, which crops out 70 km southwest from the nearest undoubted Cotton Formation outcrops, is closely comparable both in age and lithology. Sherwin (1996) described the Cotton Formation north of Parkes in the Narromine 1:250 000 map sheet area.

*Description*

Most of the sedimentary layers in the Cotton Formation are well-bedded laminated siltstones, which readily part along bedding planes. Chert beds, much more common in the lower part of the formation, have a very hackly fracture. Sandstone, some of it exhibiting graded bedding, is a minor component. The apparent dominance of coarser sandstone and chert, especially in the line of outcrop passing through Parkes, is because they produce more resistant outcrops.

*Figure 3.26. Shallow-dipping laminated siltstones at the type locality of the Cotton Formation at the quarry on Cottons Hill. (GR 586800 mE 6313400 mN) (O.L. Raymond photograph)*

Quartz veining is locally common, especially near some faults. Outcrops, and all but the deeper quarry exposures, are leached to off-white to buff. The floor of the quarry (GR 587840 mE 6304050 mN) has been excavated into fresh, dark grey rock containing contrasting white tuffaceous bands. Many of these bands show soft sediment slumping.

In thin section (T64489, GR 589980 mE 6312680 mN) the cherty siltstone in the lower part of the Cotton Formation consists of irregularly bedded to laminated, red, spicular, radiolarian tuffaceous chert. Other detritus includes sericite and magnetite. The siltstone from the upper part of the Cotton Formation (T64481, GR 587840 mE 6304050 mN) consists of black, slump-disrupted, and laminated, calcareous, silty mudstone with grains of quartz, feldspar, and magnetite.

*Thickness*

The thickness of the Cotton Formation is difficult to determine for want of an undoubted complete section. Krynen *et al.* (1990) reported an estimated thickness of 1500 m, based on a constant easterly dip of 60° on the eastern limb of the Forbes Anticline, and allowing for some concealed strata across three strike ridges (Sherwin, 1973b).

*Environment of deposition*

Krynen *et al.* (1990) suggested "... a variety of environments of deposition ranging from full-marine [sic] shelf conditions to a shallow littoral facies ..." (p. 44). The presence of thin- to thick-bedded, fine- to medium-grained sandstone, especially in the vicinity of Parkes and east of the Newell Highway south of Parkes, was "... considered to be part of a deep submarine fan depositional system" (p. 45). The environment was mostly calm but periodic slumping and disruption of part consolidated sediment is demonstrated by flaky intraformational conglomerates in drill cores from Calarie, on the northern outskirts of Forbes.

*Boundary relationships and age*

Most of the boundaries of the Cotton Formation are obscured by surficial deposits.

At Bald Hill, just north of Forbes, the Cotton Formation rests, with apparent conformity, on the Parkes Volcanics (Krynen *et al.*, 1990). Some tuffaceous matter is visible in thin sections but it is uncertain if this is fallout from contemporaneous volcanism or fine-grained erosional products from volcanic terrains, presumably weathered Northparkes Volcanic Group. The exposures at Cotton Trigonometrical Station dip below the basal Bocobidgle Conglomerate of the Forbes Group (Wenlock, or mid-Silurian age), suggesting an unconformable contact (Sherwin, 1973b). At Parkes, the Cotton Formation overlies the Nash Hill Volcanics with an inferred conformity. Northwest of Parkes the contact between the upper part of the Cotton Formation (Early Silurian, based on graptolite fauna) and the Parkes Volcanics is within an area of no outcrop.

The Cotton Formation contains a graptolite fauna ranging in age from Bolindian (late Late Ordovician) to late Llandovery (Early Silurian) (Sherwin, 1973b, 1974).

### **Mugincoble Chert** (Omc) Bowman (1977a), modified after Brunker (1972)

*Nomenclature and previous work*

The Mugincoble Chert was originally mapped as the 'Mugincoble Beds' (Brunker, 1972; Bowman, 1976), and was named after the locality of Mugincoble, about 7 km southeast of Parkes. Krynen *et al.* (1990) described the unit in some detail. Sherwin (1996) considered that much of the Mugincoble Chert was variably silicified beds of the Cotton Formation.

*Distribution, type section and thickness*

The Mugincoble Chert crops out in a two subparallel belts with a north-northeast trend, each less than 1 km wide, from 15 km south of Parkes to just east of Tomingley in the Narromine 1:250 000 map sheet area. The southernmost outcrops mapped by Krynen *et al.* (1990) are included here in the Cotton Formation. Bowman *et al.* (1982) specified a type locality just north of Mugincoble rail siding (GR 614000 mE 6326600 mN) but the best exposures are in the railway cutting (GR 615180 mE 6326280 mN) about a kilometre east of the level crossing at Mugincoble siding.

*Boundary relationships*

The Mugincoble Chert is interpreted to be interbedded with, or possibly in faulted contact with, the Ordovician Kirribilli Formation. These contacts are not exposed. The Mugincoble Chert is most probably faulted against the Ordovician Goobang Volcanics northeast of Parkes. The brecciated and quartz-veined nature of some of the Mugincoble Chert suggest that parts of the unit may have developed by silicification of Kirribilli Formation sedimentary rocks near fault zones.

The Mugincoble Chert exposed in the railway cutting east of Mugincoble siding is in contact with very decomposed or altered igneous rock. The dip of the chert suggests that it overlies the igneous rock but the contact could be faulted or intrusive. The igneous rock is weathered and leached to the extent that no primary textures have been preserved. Hence it is unclear if it represents a weathered basement of Nelungaloo Volcanics or a much younger intrusion. The location of the igneous rock between two chert ridges could be interpreted as interbedding or a sill-like intrusion. However, the inferred strike fault between the ridges at this locality may simply indicate repetition of sequence.

Krynen *et al.* (1990) described outcrops with a conformable relationship with underlying Nash Hill Volcanics. However, these outcrops are now included in the Cotton Formation.

*Description*

The Mugincoble Chert consists of milky white to reddish or brown chert and fine-grained siliceous sedimentary rocks, interbedded with foliated siltstone, shale and fine-grained sandstone similar to the surrounding Kirribilli Formation. The interbedded chert–siltstone units form prominent strike ridges within the low relief of the Kirribilli Formation.

The Mugincoble Chert beds are typically only several centimetres thick. However, thicker, more massive beds occur and they may be brecciated and quartz-veined. The cherts may also be strongly ferruginised and manganiferous, and be dark brown to black, notably around Mugincoble.

The Mugincoble Chert is generally poorly magnetic (magnetic susceptibility $<50 \times 10^{-5}$ SI). However, where ferruginised, the chert beds can have magnetic susceptibilities up to $20\,000 \times 10^{-5}$ SI. Regional aeromagnetic data show strong linear magnetic anomalies coincident with outcrops of the Mugincoble Chert. These anomalies can be correlated with ferruginised chert horizons as narrow as a few centimetres, and may not reflect the magnetic character of the unit as a whole.

*Palaeontology, age and correlation*

Percival (1999a) identified the conodonts *Belodina* (or *Pseudobelodina*) sp., *Panderodus* sp., ?*Periodon* sp., ?*Walliserodus* sp. and *Phragmodus* sp. from chert beds near Mugincoble. The fauna indicates a Middle to Late Ordovician age for the Mugincoble Chert. This age is in agreement with a Darriwilian to Gisbornian age quoted by Sherwin (*in* Lyons & Wallace, 1999) from unpublished conodont identifications of I. Stewart and R. Glen.

The conodont fauna and age of the Mugincoble Chert are similar to cherts within the Girilambone Group and Wagga Group (Percival, 1999a). Both these groups are probably also correlatives of the Kirribilli Formation. Krynen *et al.* (1990) and Sherwin (1996) noted that the Mugincoble Chert resembles the more cherty parts of the Late Ordovician Cotton Formation.

*Environment of deposition*

The association of conodont-bearing cherts and other fine-grained sedimentary rocks indicate that the Mugincoble Chert was deposited in a distal, deep marine environment. However, the occurrence of massive and brecciated silica bodies close to interpreted fault zones in the Kirribilli Formation suggests that some of the chert unit may have developed by remobilisation of silica along faults as young as Carboniferous (Sherwin, 1996).

## **Narragudgil Volcanics** (Orv) *nov*

*Nomenclature*

The Narragudgil Volcanics have previously been considered as part of the Bland Diorite (Wyborn, 1996) or "...most probably the northern continuation of the Gidginbung Volcanics..." (Warren *et al.*, 1995, p. 23). However, the latter authors also noted that some of the rocks show affinities to the Jindalee Group.

*Derivation of name*

The name is derived from the Parish of Narragudgil, in which the known outcrops of the unit are located.

*Distribution and outcrop*

Outcrops of the Narragudgil Volcanics are restricted to areas on and adjacent to Wyalong Hill, on either side of the Mid Western Highway east of the Temora Road junction, and in and around Miller's Quarry, south of Wyalong. The width of a belt showing a high and complex character on aeromagnetic images indicates that the unit is probably about 6 km wide. The belt is truncated at its northern end, near Wyalong, by intrusion of the Bland Diorite. Aeromagnetic data indicate that the Narragudgil Volcanics extend southwards onto the Cootamundra 1:250 000 map sheet area, where the unit appears to be extensively

imbricated. The eastern and western margins are fault-bounded.

*Representative locality*

Poor outcrop precludes nomination of a type section for the Narragudgil Volcanics. However, a representative locality is Miller's Quarry, 3 km south of Wyalong. In quarry exposures, the Narragudgil Volcanics consist of fine-grained metabasalts displaying a highly distinctive deformation style (described below), and are extensively intruded by a swarm of sub-vertical dykes having petrographic and geochemical affinities to the Bland Diorite.

*Description*

The Narragudgil Volcanics consist of fine- to medium-grained metabasalts with minor chert, chlorite schist, and ultramafic rocks. The rocks are pervasively metamorphosed to upper greenschist, or transitional greenschist–amphibolite assemblages, but are locally elevated to amphibolite or hornblende hornfels in proximity to the Bland Diorite and adjacent to larger dykes. The highest metamorphic grades, characterised by total recrystallisation to a granoblastic assemblage of hornblende, plagioclase, quartz, and opaque grains, occur either side of the Mid Western Highway, east of Wyalong, close to the contact with the Bland Diorite. The intermediate grades occur in Miller's Quarry (amphibolite mineral assemblages but ragged disequilibrium textural relationships), and the lowest grades (having igneous textures clearly preserved except in schistose samples from narrow deformation zones) on Wyalong Hill.

In Miller's Quarry exposures, the metabasalts are characterised by a pervasive, sub-vertical structural fabric in the form of anastomosing planes of high strain up to a few centimetres wide, which separate sheets of massive, essentially undeformed metabasalt, typically 20-40 cm across, giving a superficial appearance of a sheeted dyke complex (Figure 3.27). No conclusive evidence of original bedding or flow boundaries has been observed in the Narragudgil Volcanics.

*Age and boundary relationships*

No direct age data are available for the Narragudgil Volcanics. Their minimum age is provided by intrusion of the Early Silurian Bland Diorite (433.7 ± 2.3 Ma; L.P. Black, pers. comm., 1998) and a suite of andesite/diorite dykes geochemically related to the Bland Diorite. A small zircon population from one of the dykes gave a poorly constrained age of 443 ± 10 Ma (L.P. Black, pers. comm., 1998). These later units lack the strong deformation exhibited by the volcanic rocks, suggesting that deformation of the Narragudgil Volcanics may not post–date the Benambran Orogeny. No maximum age constraints are available for the Narragudgil Volcanics. Apparent geochemical affinities with other units in this part of the Lachlan Fold Belt, including the Brangan Volcanics (Wallace, these Notes), and other mafic rocks in the Jindalee Group (Warren *et al.*, 1995), suggest a possible common age with those units, i.e., Middle to Late Ordovician.

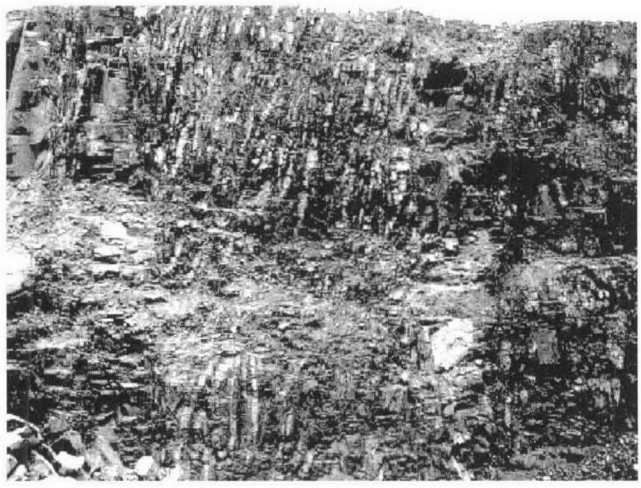


*Figure 3.27. Sub-vertical anastomosing planes of high strain in massive metabasalt of the Narragudgil Volcanics. Massive dykes of andesitic composition (left and centre right) intruded the Narragudgil Volcanics. Width of field approx. 15 m. (GR 522000 mE 6242000 mN) (M.B. Duggan photograph)*

The Narragudgil Volcanics are in fault contact with the Yiddah Formation on the eastern side and with the Wagga Group and Ungarie Granite to the west. The contact with the Bland Diorite appears to be an intrusive relationship. The Narragudgil Volcanics were extensively intruded by a suite of dykes, which may be petrogenetically related to the Bland Diorite.

*Geochemistry*

Four samples of the Narragudgil Volcanics were analysed for major and trace elements. Three samples are basaltic in composition. A fourth (97844057H) is a much more siliceous amphibolite and is believed to represent a basalt or basaltic tuff that has been weathered prior to metamorphism. The basalts are geochemically primitive (Mg-number = 56 to 64) olivine tholeiites with low $K_2O$ and low K/Na ratios. Although it is almost certain that there has been some element mobility during metamorphism, the basaltic rocks have major and trace element characteristics typical of basalts of either normal mid-ocean ridge (N-MORB) or back-arc basin (BAB) tectonic settings including depletion in LILE and flat REE patterns. Element abundances as illustrated on a primordial mantle normalised multi-element diagram (Figure 3.28) show similarities to other volcanic suites in the Lachlan Fold Belt, including basalts from the Jindalee Group (data from Warren *et al.*, 1995) and the Brangan Volcanics (these Notes). It should be noted that the enrichment spikes for U, Th, and Pb evident in the Jindalee Group gabbro sample appear anomalously high, and probably reflect lack of analytical precision or contamination, given that the absolute abundances are in the single digit ppm range. No trace element data are available for basalts from the Jindalee Group.

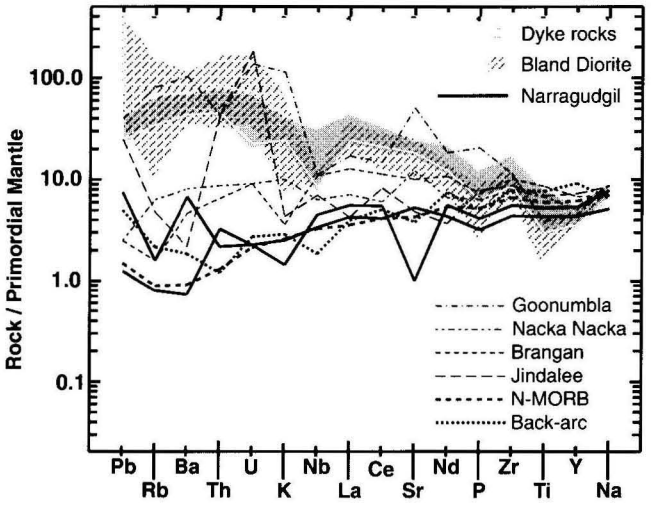



*Figure 3.28. Primordial mantle-normalised multi-element abundance diagram (spidergram) for basalts of the Narragudgil Volcanics and other rocks (from Duggan & Lyons, 1999).*

## Kars Ultramafic Intrusive Complex (Ouk) Jones (*in* Elliott & Martin, 1991)

*Nomenclature, distribution and outcrop*

Jones (*in* Elliott & Martin, 1991) informally named the 'Kars intrusive complex' but did not state whether it was named for the Parish of Kars or Kars Trigonometrical Station (GR 545150 mE 6445520 mN).

The Kars Ultramafic Intrusive Complex, centred at GR 546500 mE 6346600 mN, is the southernmost of several ultramafic complexes, classified as Alaskan type by Elliott & Martin (1991), in a north–south corridor some 200 km in length. With few exceptions, outcrops of these ultramafic intrusions are deeply weathered, with little or no surface expression, so that work on the geochemistry and petrography depends very much on drill core and trench sampling. Also, for that reason, no type locality is given.

The Kars Ultramafic Intrusive Complex was detected because of its strong aeromagnetic anomaly, there being very little surface expression. The aeromagnetic anomaly suggests only one intrusive body is present, although both detailed ground magnetic surveys and drilling show that it is internally complex (Jones, *in* Elliott & Martin, 1991). Unlike some of the other complexes to the north, there is some surface float, possibly even some solid outcrop, but it is difficult to determine how much of this may be the result of disturbance associated with recent mineral exploration, which included several costeans. Agnew (1987) suggested that these ultramafic intrusions may be the source for Ordovician andesitic volcanism in the region. They are of particular interest as a source of platinum mineralisation (Suppel & Barron, 1986), especially in the Fifield district to the north of the Kars Ultramafic Intrusive Complex.

*Description*

Cuttings from auger holes for fence posts (GR 546140 mE 6346800 mN), contained chilled bluish grey, aphanitic basaltic rocks associated with the Girilambone Group. The basaltic rocks have magnetic susceptibilities in the range $800 \times 10^{-5}$ SI to $1000 \times 10^{-5}$ SI, although the rock pile is just west of the strongest part of the Kars intrusion, as indicated by the aeromagnetic anomaly.

Jones (*in* Elliott & Martin, 1991) prepared a geological interpretation of the Kars Ultramafic Intrusive Complex based upon geophysics, supported in the middle part of the complex by drilling and costeaning. The complex appears to be subrectangular, with a long axis of almost a kilometre, although the airborne magnetic image suggests that it might be larger — perhaps up to 10km along a southwest-northeast axis. A detailed ground magnetic survey suggests multiple intrusive phases as have been described from similar complexes to the north. Jones (*in* Elliott & Martin, 1991) described the bulk of the complex as consisting of olivine pyroxenite, cut by a line of minor bodies of wehrlite–dunite and olivine pyroxenite, with dunite dykes and pods. The southern margin of the Kars Ultramafic Intrusive Complex consists of a younger monzonite intrusion, suggested by the presence of thin monzonite dykes enclosing pyroxenite. Olivine-bearing rocks from the upper part of the intrusion have been serpentinised. The highest platinum grades are associated with the wehrlite–dunite rocks.

*Boundary relationships and age*

The associated float suggests that the Kars Ultramafic Intrusive Complex intruded the Ordovician Girilambone Group, in common with similar complexes to the north. However, the linear nature of the south-eastern margin of the complex in aeromagnetic imagery suggests a faulted margin. No internal evidence is available for the age but, by analogy with the Bulbodney Creek Ultramafic Intrusive Complex to the north, it is probable that it is Late Ordovician (Sherwin, 1996, p. 19).

## Unnamed Ordovician ultramafic rocks (Ou)

*Distribution, type locality and relations*

Unnamed ultramafic rocks in fault slivers of the Gilmore Fault Zone were recognised by Burrell (1994a,b; 1995a,b,c) during mapping, drilling, and interpretation of total magnetic intensity images. The ultramafic rocks occur only as scree around a dam beside 'Kookaburragang' homestead at GR 510200 mE 6314500 mN. They have also been intersected in air core drilling at GR 509620 mE 6315320 mN and GR 507790 mE 6320370 mN (Burrell, 1995a,b). Most of the ultramafic rocks are covered by Cainozoic alluvium, but their strong magnetic signatures allow interpretation of their inferred distribution in the subsurface. An elongate magnetic high along a fault at GR 501200 mE 6315900 mN is also interpreted to be caused by the ultramafic rocks. Anderson (*in* Burrell, 1995c) modelled easterly dips for the magnetic highs southeast of the outcrop at 'Kookaburragang' homestead.

Magnetic anomalies with a north-northwest trend, west of the Billys Lookout Granite (GR 530000 mE 6270000 mN), are here interpreted as being caused by ultramafic rocks.

The ultramafic rocks distributed along the Gilmore Fault Zone are interpreted as being faulted against Girilambone Group, Wagga Group, Burcher Greywacke and Manna Conglomerate. The ultramafic rocks west of the Billys Lookout Granite are interpreted as being incorporated within the Girilambone Group, although whether they are part of the group, *per se*, or faulted in is not known (*cf.* description of the Yathella Serpentinite in Sherwin, 1996).

A representative locality for the ultramafic rocks is the only known "outcrop", around a dam beside 'Kookaburragang' homestead at GR 510200 mE 6314500 mN.

*Description*

Rock chips from air core drilling were described by Burrell (1995a, b) as commonly pyroxenite, with possible dunite. The ultramafic rocks are green, and, to a lesser extent, purple; and are strongly foliated and altered, with nontronite clay developed.

*Age*

Stratigraphic relations for ultramafic rocks in the Bathurst 1:250 000 map sheet area (Scott *et al., in* Pogson & Watkins, 1998) and U–Pb age dates for ultramafic intrusive complexes in the Narromine 1:250 000 map sheet area (Sherwin, 1996), suggest a Late Ordovician age for the ultramafic rocks within the Forbes 1:250 000 map sheet area. However, the paucity of data and outcrop do not preclude a younger age.

## Geochemistry of the Ordovician volcanic and intrusive rocks

The Ordovician volcanic and comagmatic intrusive rocks of the Nelungaloo Volcanics, Northparkes Volcanic Group (NPVG) and Lake Cowal Volcanic Complex (LCVC) reflect a period of intermediate to mafic island arc magmatism during the Early to Late Ordovician. On the whole, the volcanic rocks are variably potassic basalts to andesites (~50 wt % to 63 wt% $SiO_2$), which typically range in composition from calc-alkaline to shoshonitic (Figures 3.29 3.30). The rocks have high and variable $Al_2O_3$ concentrations (~14 wt% to 20 wt%), which are also typical of the shoshonitic association. Some of the more felsic trachytes and granodiorites (up to ~69 wt% $SiO_2$) occur in the LCVC. LCVC rocks are also generally less potassic than the those in the NPVG.

$K_2O/Na_2O$ ratios of the Ordovician volcanic rocks range widely up to 1.4, with a few analyses in Goonumbla Volcanics in the Daroobalgie area having strongly shoshonitic ratios ranging up to 1.8. Despite eliminating obviously altered samples from the geochemical dataset, there is considerable scatter from very low to very high $K_2O$ compositions (<1 wt% to >6 wt% $K_2O$) in the NPVG, suggesting significant mobility of potassium during regional metamorphism, shearing and hydrothermal alteration, especially within the Parkes Fault Zone.

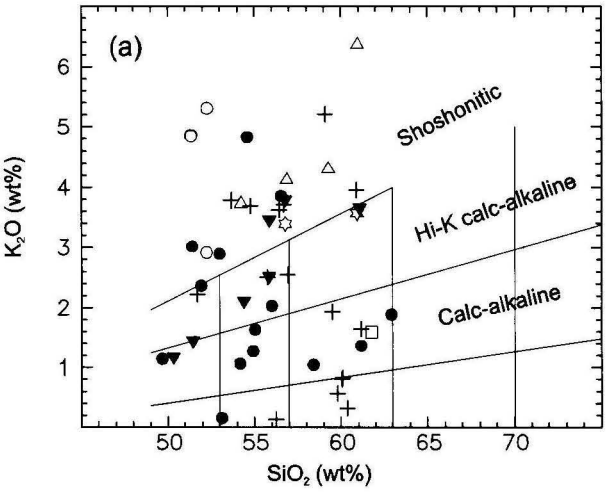



*Figure 3.29. $K_2O$ versus $SiO_2$ plot of volcanic and intrusive rocks of the Northparkes Volcanic Group and the Nelungaloo Volcanics. The wide range of $K_2O$ values implies significant mobility of potassium during regional metamorphism, shearing and hydrothermal alteration. Symbols: Cross – Goonumbla and Parkes Volcanics, open circle – Goonumbla Volcanics in the Daroobalgie area, filled circle – Nash Hill Volcanics, square – Goobang Volcanics, open triangle – Wombin Volcanics, filled triangle – monzonite intrusions, star – Nelungaloo Volcanics.*

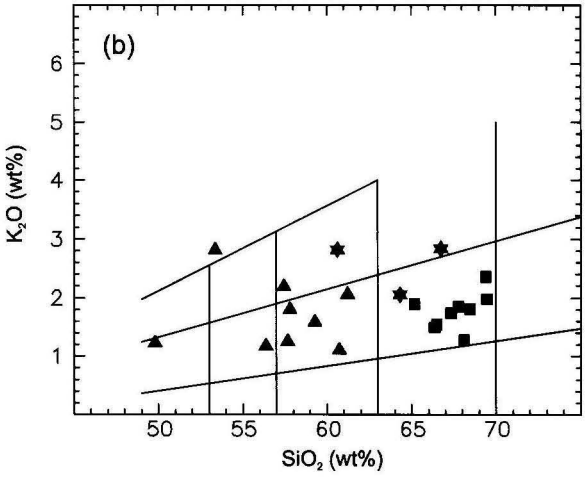



*Figure 3.30. $K_2O$ versus $SiO_2$ plot of volcanic and intrusive rocks of the Lake Cowal Volcanic Complex. Symbols: Triangle - basalt/andesite, star - trachyte, square - granodiorite.*

The Ordovician volcanic and intrusive rocks have low Mg-numbers — all less than 60, with many as low as 40 — suggesting that the rocks were derived from evolved magmas. Bivariate plots of CaO *versus* MgO suggest clinopyroxene and plagioclase fractionation. MORB-normalised multi-element diagrams show typical calc-alkaline patterns of LILE enrichment (e.g., Ba up to 2600 ppm, and Sr typically up to 2100 ppm), and relative depletion in HFSE (e.g., typically less than 0.9 wt% $TiO_2$) and in LREE (e.g., typically less than 50 ppm La) (Figure 3.31, 3.32). The multi-element diagrams show pronounced negative anomalies in Nb and Ta (Figure 3.31, 3.32), which are characteristic of subduction-related magmas (Briqueu *et al.*, 1984; Muller *et al*, 1992). The median compositions of the NPVG rocks are broadly

similar to median compositions of Ordovician volcanic rocks of the Molong High (Figure 3.31). The LCVC andesites and basalts show similar multi-element patterns to NPVG rocks (Figure 3.32), and are even closer in composition to the volcanic rocks of the Molong High.

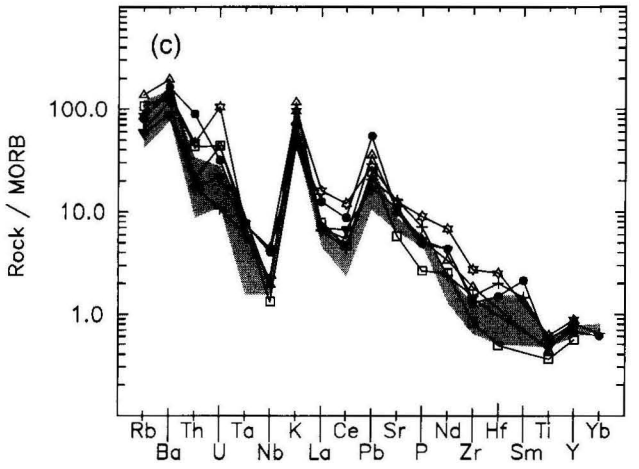



*Figure 3.31. MORB-normalised multi-element spidergram for the Northparkes Volcanic Group and the Nelungaloo Volcanics, compared to average compositions for Ordovician volcanic rocks of the Molong High (shaded area). Symbols as for Figure 3.29.*

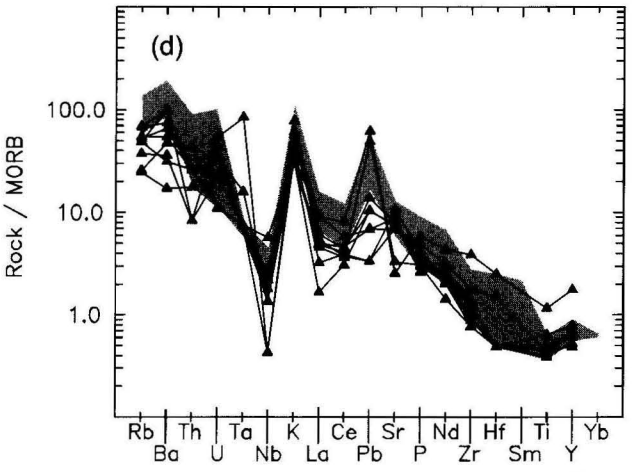



*Figure 3.32. MORB-normalised multi-element spidergram for andesites of the Lake Cowal Volcanic Complex compared to average compositions for the Northparkes Volcanic Group (shaded area).*

The low-$TiO_2$ composition of the Ordovician volcanic rocks contrasts strongly with the much higher $TiO_2$ content of most Silurian and Tertiary mafic volcanic rocks of the northeastern Lachlan Fold Belt (Raymond & Sun, 1998). The Ordovician volcanic rocks also have characteristically high, mantle-like εNd isotopic ratios (+6.1 to 8.0; Wyborn & Sun, 1993), which contrast with the typically negative εNd values of younger igneous rocks of the Lachlan Fold Belt. However, these discriminants are not conclusive, as some Early Devonian rocks, such as the Cuga Burga Volcanics, have similar chemical compositions and εNd values to the Ordovician rocks (Raymond & Sun, 1998; Morgan & Meakin, 1999).

Although the overall compositions of volcanic units in the NPVG are similar, some notable differences exist between units. Most notable are the higher Th and LREE concentrations in the Nash Hill Volcanics (Fig. 3.33). The relatively high Th composition results in a distinctive radiometric signature for outcrops of the Nash Hill Volcanics. The Nash Hill Volcanics also typically have higher $K_2O/Na_2O$ ratios than the rest of the NPVG. Krynen *et al.* (1990) considered the Wombin Volcanics to be more fractionated than the rest of the NPVG. They are the uppermost rocks of the NPVG and are among the most potassic, but there is a great deal of overlap in the compositions of the Wombin Volcanics and the rest of the NPVG. The typical red colour of the Wombin Volcanics may indicate derivation from a more oxidised magma.

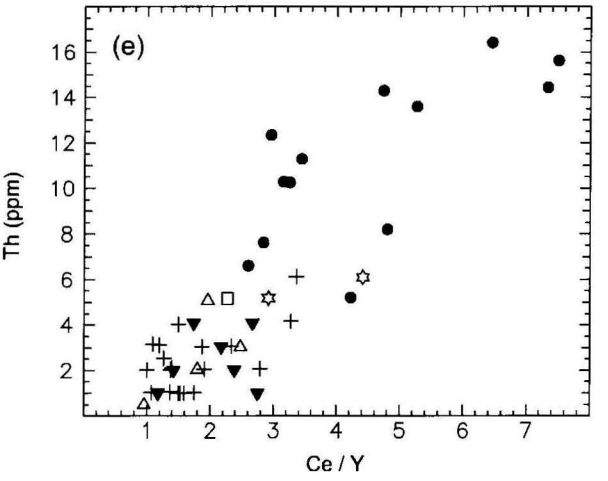



*Figure 3.33. Th* versus *Ce/Y plot for volcanic rocks of the Northparkes Volcanic Group and the Nelungaloo Volcanics, showing the high Th and LREE-enriched compositions of the Nash Hill Volcanics relative to other Ordovician volcanic rocks.*

Based on the geochemical discriminants described above, the NPVG and LCVC are most likely related to "late oceanic arc" subduction (Muller *et al.*, 1992, 1994). Muller *et al.* (1992) considered the "late oceanic arc" tectonic setting to be the last stage of arc development above the site of subduction of one oceanic plate beneath another, with magmatism derived from partial melting of a fluid-metasomatised mantle wedge enriched in LILE such as K, Ba and Sr. Although the strong negative Nb and Ta anomalies of the Ordovician volcanic and intrusive rocks are not completely diagnostic of subduction-related magmas, the very low HFSE concentrations of the NPVG and LCVC rocks most probably preclude a within-plate tectonic setting for the magmatism (Muller *et al.*, 1992).

# 4. EARLY SILURIAN

## **Forbes Group** (Sf) Brunker (1972a), modified Sherwin (1973b), Krynen *et al.* (1990)

*Previous nomenclature*

The 'Forbes Beds' were named by Brunker (1972a) without a formal description, other than a brief summary of the rock types in the map legend of the Forbes 1:250 000 geological map sheet (first edition). Sherwin (1973b) provided a detailed description of the Forbes Group and divided it into a lower unit, the Mumbidgle Formation, and an upper unit, the Calarie Sandstone. Later mapping and fossil discoveries showed that these two units were separated by a low angle unconformity and the Calarie Sandstone was removed from the Forbes Group (Krynen *et al.*, 1990). The conglomerate member at the base of the Mumbidgle Formation was later named the Bocobidgle Conglomerate (Sherwin *et al.*, 1987; Krynen *et al.*, 1990). The Forbes Group is folded into a tight syncline north of Parkes, but to the west of Parkes the deformation is such that the constituent formations cannot always be recognised with confidence. Most of the Forbes Group north of Parkes was described previously as the 'Trewilga Beds' (Bowman, 1977a,b). The distribution of the Forbes Group is shown in Figure 4.1.

## **Bocobidgle Conglomerate** (Sfb) Sherwin *et al.* (1987)

*Type area, distribution and outcrop*

The type locality for the Bocobidgle Conglomerate is on 'Bimbadeen', north of Forbes, where there is an excellent exposure in a shallow quarry (GR 594650 mE 6314050 mN). This formation is recognisable north of Parkes beyond the boundary of the Forbes map sheet area. The conglomerate forms distinctive rounded hills that provide useful marker beds in aerial photograph interpretation, as the outline of the structure presents as chains of low rounded hills.

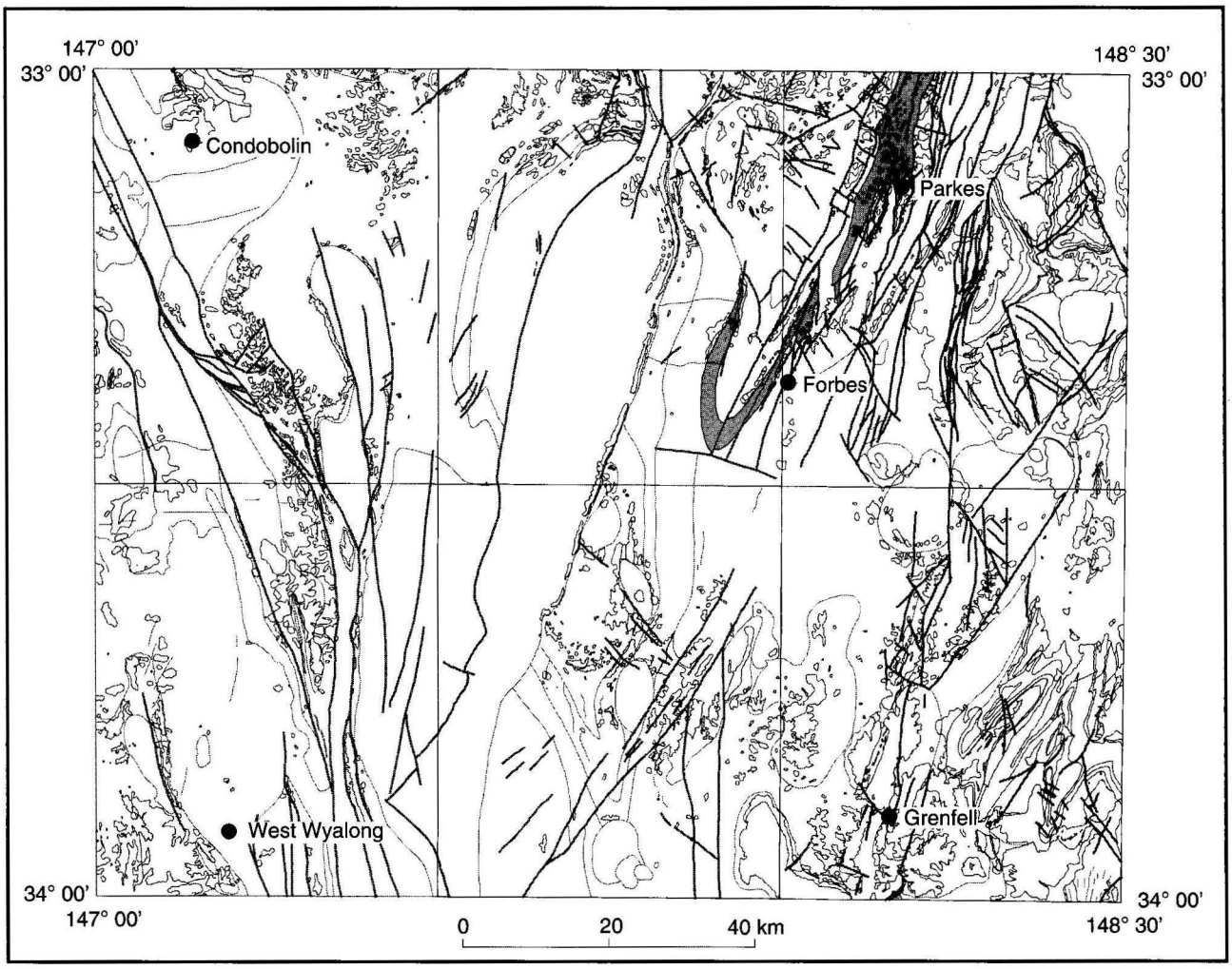



*Figure 4.1. Distribution of the Forbes Group in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

*Description*

The lithology of the Bocobidgle Conglomerate varies from very coarse conglomerate to medium-grained sandstone, the rounded cobbles being as much as 20 cm in diameter. At the type locality, the cobbles are supported in a very calcareous sandy matrix (Figure 4.2). The colour of the rock at 'Bimbadeen' is dark grey, in contrast to the less-terrigenous red limestone matrix just west of Cottons Hill (GR 586800 mE 6313500 mN). The red limestone is composed largely of fossil debris, much of it broken coral and stromatoporoid colonies. The debris, whether the variably sized cobbles or the sandy matrix, is almost wholly derived from the Northparkes Volcanic Group, including the monzonitic intrusions. Quartzite and chert pebbles are also common, especially in comparison with outcrops to the north of Parkes (Sherwin, 1996). The chert pebbles may be from the Cotton Formation, but other potential sources include the Mugincoble Chert and, possibly, the more distant Girilambone Group, which is also a possible source of the quartzite.

The bedding in the Bocobidgle Conglomerate is massive, as much as several metres thick for some of the coarsest conglomerate horizons. The volcanic debris, whether cobbles, pebbles, or even the angular to subangular feldspar grains in the groundmass, are comparable in the degree of alteration with the source volcanic units.

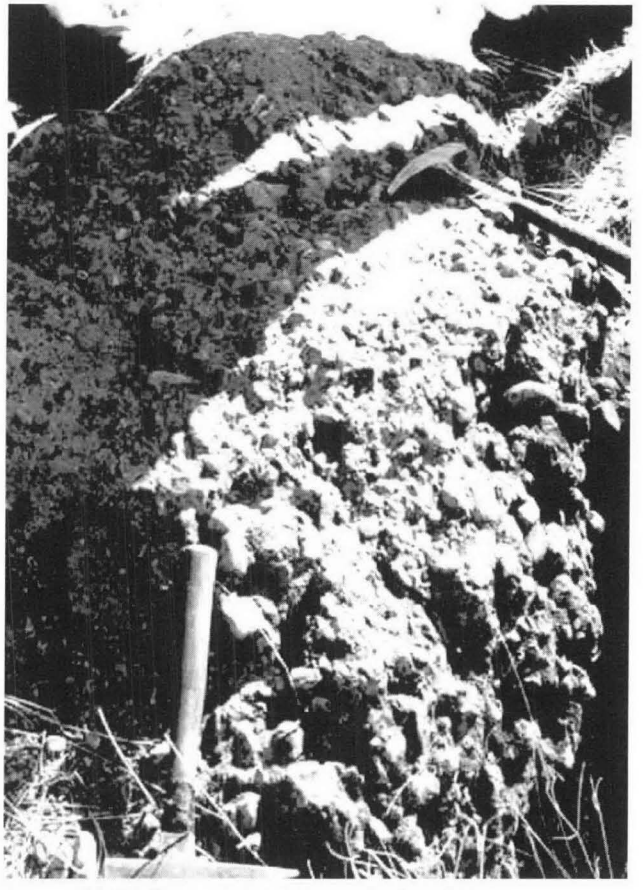


*Figure 4.2. Well-rounded cobbles in the Bocobidgle Conglomerate on 'Bimbadeen'. (GR 594720 mE 6314060 mN) (O. Raymond photograph)*

*Thickness*

Sherwin (1973b) quoted a thickness of 160 m for the Bocobidgle Conglomerate at the type section north of Forbes. To the north of Parkes the outcrops are poor but measurement of mapped outcrop suggests that the thickness may be as much as 300 m.

*Environment of deposition*

The close spatial and lithological association of the Bocobidgle Conglomerate with the Late Ordovician Northparkes Volcanic Group indicates that it formed a flanking blanket deposit around a dormant volcanic high. The red colour of some of the limestone matrix and algal blocks indicates a shallow, well-aerated and, possibly, a nearshore environment. The conglomerates are closely packed in places but not as thoroughly winnowed as might be expected on a beach or flanking shoreline deposit. The change from coarse conglomerates into finer-grained sands of the overlying Mumbidgle Formation may indicate lowering of the source by erosion or subsidence.

*Boundary relationships and age*

The Bocobidgle Conglomerate overlies the Cotton Formation at 'Bimbadeen' and at Cottons Hill, the lines of outcrop having comparable trends. At both localities the Cotton Formation is notably friable at the contact. West and north of Parkes, the boundary with the underlying units is obscured by faulting and strong cleavage, although there is some indication that the conglomerate rests upon the Northparkes Volcanic Group. The Bocobidgle Conglomerate grades upwards into the overlying Mumbidgle Formation.

Corals (*Heliolites daintreei, Acanthohalosites australis, Favosites spp., Aulopora sp., ?Syringopora sp., ?Thamnopora sp.*) in the limestone of the Bocobidgle Conglomerate at Cottons Hill indicate a Wenlock to Ludlow age (Vandyke & Byrnes, 1975). The presence of late Wenlock graptolites (see under Mumbidgle Formation) in the base of the conformably overlying Mumbidgle Formation (Sherwin, 1975) rules out the Ludlow age. The most likely age is early to mid-Wenlock (late Early Silurian).

## **Mumbidgle Formation** (Sfm) Sherwin (1973b), modified Krynen *et al.* (1990)

*Type locality, distribution and outcrop*

The best outcrops of the Mumbidgle Formation are at the type locality (GR 591300 mE 6305750 mN) on the western side of Forbes. However, outcrops of the unit are generally quite poor, and north of Parkes the cleavage in a tight syncline sometimes makes it difficult to distinguish weathered outcrops from those of the Cotton Formation. The strongly cleaved outcrops west and north of Parkes were mapped in part using the distinctive gamma ray spectrometric signature. The attribution of these sedimentary units to the Mumbidgle Formation is supported by the few fossil occurrences.

*Description*

The Mumbidgle Formation consists of olive green to brown and minor grey mudstone and siltstone with a small proportion of lithic sandstone. Even when cleaved and weathered the Mumbidgle Formation has a "dirty" appearance in comparison with the Cotton Formation. The bedding is thick, in some exposures in the order of a metre or more, and usually massive.

The road sections along the Newell Highway north of Parkes consist mostly of siltstone and mudstone, the laminae being masked to some extent by cleavage. The sandy beds are more common near the base, suggesting a gradational boundary with the underlying Bocobidgle Conglomerate. Unlike the Bocobidgle Conglomerate, the sorting in the Mumbidgle Formation is generally very good. The recognisable debris in the siltstones is fine subangular quartz The matrix is unrecognisable in thin section but probably represents degraded volcanic material. In the type section there are thin calcareous bands with tabulate coral colonies, mostly *Favosites* sp., although these are believed to be slump fossil debris bands. The best of these fossiliferous beds, described by Sherwin (1973a), were from a quarry that was buried as part of improvements to the area and the beds are now inaccessible.

*Thickness*

In the type section Sherwin (1973b) estimated the thickness of the Mumbidgle Formation to be 280 m. Exact thicknesses north of the type area are difficult to measure because of the poor outcrop and structural uncertainties. However, in the vicinity of Parkes the thickness is unlikely to be much less than 1000 m.

*Environment of deposition*

The Mumbidgle Formation represents a more distal style of sedimentation, compared to the Bocobidgle Conglomerate. This is a likely continuation of subsidence or continued erosion of the of the volcanic source area to such a level that stream gradients in the source area were no longer sufficient to transport large cobbles. The presence of lamellibranchs indicates burrowing in soft sediment. However, their disarticulated condition indicates posthumous reworking, possibly within debris flows, as suggested by segregation of most shelly fossils into discrete bands.

*Boundary relationships and age*

As noted above, the Mumbidgle Formation has a gradational contact with the underlying Bocobidgle Conglomerate, marked by a change from coarse- to fine-grained clastic detritus. In the vicinity of Forbes, the Mumbidgle Formation is overlain, with a possibly scoured contact, by the Late Silurian Calarie Sandstone. At Cottons Hill the contact with the Calarie Sandstone is a low angle unconformity whereas, at 'Bimbadeen' the contact is paraconformable. In the vicinity of Parkes there are no overlying units other than thin Cainozoic cover.

Fossils are common in the less-cleaved parts of the Mumbidgle Formation, the best localities being rubble along a telephone cable at the type section. This is also the type locality for the late Wenlock (late Early Silurian) graptolite species, *Monograptus sherrardae* (Sherwin, 1975). This graptolite horizon is well-below the top of the Mumbidgle Formation and it is likely that the top of the Mumbidgle Formation extends into the early part of the Ludlow (Late Silurian).

## **Douro Group** (Sd) Pogson & Baker (1974)

The Douro Group crops out extensively in the areas of the Goulburn and Canberra 1:250 000 map sheets where it consists predominantly of felsic S-type volcanic rocks with minor clastic sedimentary horizons and limestone. L. Sherwin & J.G. Byrnes (pers. comm. *in* Basden *et al.*, 1978) suggested the Illunie Volcanics (formerly 'Illunie Rhyolite') could be correlated with the Douro Group. The Illunie Volcanics and Glenisla Volcanics are here formally included in the Douro Group due to their similar age and lithology to Douro Group rocks to the southeast of the Forbes 1:250 000 map sheet area.

The SHRIMP U–Pb zircon age obtained for the Douro Group in the Forbes 1:250 000 map sheet area (Glenisla Volcanics, 432.2 ± 2.8 Ma) is within analytical error of the age of the Young Granodiorite (428.8 ± 1.9 Ma). This closeness in age, combined with the similar chemical compositions of the granodiorite and volcanic rocks of the Douro Group, suggest that the Douro Group volcanic rocks are the extrusive equivalent of the Young Granodiorite.

### **Illunie Volcanics** (Sdi) *nov* modified after Stevens (1955)

*Nomenclature, distribution and contact relationships*

The name Illunie Volcanics, first used by Jones (1984) in an unpublished thesis, replaces the name 'Illunie Rhyolite'. It is named after Illunie Creek (Goulburn 1:250 000 map sheet area), as initially proposed by Stevens (1955). The new name better represents the unit, which includes rhyodacitic ignimbrites, volcaniclastic sedimentary horizons, and limestones.

A major revision of the unit previously mapped as the 'Illunie Rhyolite' (Brunker & Offenberg, 1970; Brunker, 1972a; Bowman, 1976; Warren *et al.*, 1996) is proposed here. Recent mapping and U–Pb dating has shown that the previously described Illunie Rhyolite includes three distinct volcanic units of differing ages. The oldest of these units, the redefined Illunie Volcanics, crops out in two belts. In the Goulburn 1:250 000 map sheet area, the Illunie Volcanics occur along the northeastern margin of the Douro Group volcanic rocks (Brunker & Offenberg, 1970), although the boundary between the two volcanic units is only tentative (Offenberg, 1974). In the Forbes 1:250 000 map sheet area, the Illunie Volcanics occur around Bumbaldry and in the core of the Broula Anticline, northeast of Bumbaldry. The Illunie Volcanics in that area

were intruded along their southern and eastern margins by the Silurian Young Granodiorite.

Unconformably overlying the Illunie Volcanics, and occupying much of the area shown by Brunker & Offenberg (1970) as 'Illunie Rhyolite', west of Bumbaldry, are the Middle Devonian Warrumba Volcanics. East of Greenthorpe, several authors (e.g., Brunker & Offenberg, 1970; Colwell, 1974; Bowman, 1976; Warren *et al.*, 1996) applied the name 'Illunie Rhyolite' to andesitic to rhyolitic volcanic units that are now assigned to the Early Devonian Warrangong Volcanics.

*Type area*

The Illunie Volcanics are well exposed in the area east of Tyagong Creek in the Broula Anticline, although they are weathered and altered in part. Better exposures may occur on the Goulburn 1:250 000 map sheet area.

*Description*

*Quartz–plagioclase–biotite-phyric rhyodacite* (Sdi). The Illunie Volcanics consist predominantly of coarse-grained quartz–plagioclase–biotite-phyric rhyodacite, with minor fine-grained quartz- ± feldspar–phyric ash tuffs, and epiclastic sedimentary horizons and breccias. The dominant rhyodacite is texturally similar to the Canowindra Volcanics (Bathurst 1:250 000 map sheet area), and contains up to 50% phenocrysts. Rounded and fractured quartz phenocrysts, up to 7 mm in diameter (average 3 mm), are ubiquitous, and display a similar morphology to quartz phenocrysts in the adjacent Young Granodiorite. Plagioclase and biotite (average 2 mm to 3 mm) are also common in the rhyodacite, but are usually altered to sericite and/or chlorite. Smith (1985) reported hornblende phenocrysts up to 4 mm in subsurface drill core taken near the Broula King mine. However, hornblende has not been observed during the current study.

Devitrification and alteration of the rhyodacite groundmass prevents identification of any volcaniclastic textures, but the high concentration of phenocrysts and fragmentation of some quartz phenocrysts suggests that the Illunie Volcanics rhyodacites were deposited primarily as ash flows. Narrow lenses of epiclastic sandstone, conglomerate, and breccia contain felsic volcanic detritus derived from erosion of the rhyodacite. The magnetic susceptibilities of the Illunie Volcanics are very low ($5 \times 10^{-5}$ SI to $40 \times 10^{-5}$ SI).

The Illunie Volcanics in the Forbes 1:250 000 map sheet area are almost invariably strongly altered and highly weathered (Figure 4.3). While most of the alteration appears to be hydrothermal, it is clear that the current level of erosion of the Illunie Volcanics is very close to the Late Devonian erosion surface and the Illunie Volcanics may have been extensively weathered during that time. Fresh Illunie Volcanics are very rare. In most cases, the volcanic units are at least partially altered to sericite, chlorite and/or clay, and may be strongly silicified and recrystallised.

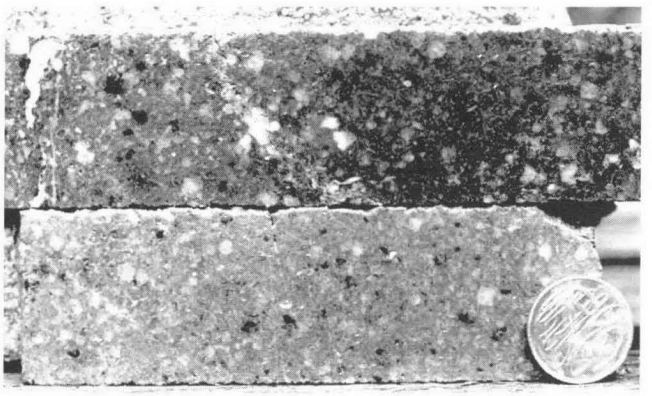


*Figure 4.3. Silicified and sericitised quartz–plagioclase–biotite porphyritic rhyodacite of the Illunie Volcanics, Broula King gold mine, Bumbaldry. (GR 632940 mE 6246030 mN) (O.L. Raymond photograph)*

*Limestone* (Sdil). Several lenses of white to yellow, biomicrite to biolithite limestone crop out in the Illunie Volcanics near Bumbaldry. The limestones contain vugs filled with red terrigenous sedimentary material (Jones, 1984). Some of the limestones have been recrystallised. Unrecrystallised limestones sometimes contain algal and stromatoporoid laminations and commonly include fragments of tabulate and rugose corals, brachiopods, nautiloids and dense ostracod accumulations (Jones, 1984). Smaller limestone outcrops with similar fossil assemblages occur in the Coomaloo Ignimbrite Member of the Middle Devonian Warrumba Volcanics. However, those are allochthonous blocks probably sourced from the underlying Illunie Volcanics.

*Quartzo-feldspathic sandstone* (Sdis). Lenses of quartzo-felspathic sandstone, a few metres to 300 m wide (Smith, 1985), are interbedded with the primary volcanic horizons of the Illunie Volcanics near the Broula King gold deposit at Bumbaldry. There are also other lenses further north in the Broula Anticline. The sandstones are fine- to very coarse-grained, moderately sorted, grain-supported, massive sandstones comprised predominantly of angular to rounded volcanic quartz grains, with up to 15% plagioclase and minor lithic grains. Rare conglomerate and siltstone horizons also occur. The sandstones are commonly silicified and, where grain boundaries are substantially recrystallised, they may look granitic in hand specimen. Trace amounts of quartz veining and disseminated limonite (after pyrite) also occur in the sandstones around Broula King.

*Geochemistry*

Wyborn *et al.* (1987) and Chappell *et al.* (1991) included the 'Illunie Rhyolite' in their Boggy Plain Supersuite. However, it is clear that they were referring to the A-type Middle Devonian Warrumba Volcanics that are now separated from the Silurian Illunie Volcanics. There is only one available analysis of the Illunie Volcanics proper (from the Goulburn 1:250 000 map sheet area), and it is a typical S-type rhyodacite (e.g., ASI >1.1; low Sr, 66 ppm) with trace element patterns very similar to the Silurian S-type Canowindra Volcanics and Hawkins Volcanics.

*Mineralisation and alteration*

The Bumbaldry mining district contains more than ten mineral occurrences, mostly hosted in the Illunie Volcanics. These include the Broula King mine and Cowfell mine, as well as the smaller Boori, Woods prospect, Balston and Tyagong Creek occurrences. At the Broula King mine, six quartz reefs, hosted in altered porphyritic rhyodacite, and up to 1.5 m thick, were mined between 1901 and 1930. They produced over 87 kg of gold at an average grade of 15 g/t Au. The shallow-dipping reefs (~40°) of braided quartz veins up to 30 cm thick, were stoped to depths between 6 m and 50 m (Figure 4.4). Both shear-related and stockwork veins are present (Smith, 1985). Recent exploration has indicated a remaining resource of 226 000 t @ 3.15 g/t Au. Wallrock alteration at Broula King is dominated by pervasive silicification with variable development of sericite, chlorite, kaolinite, minor epidote and widely disseminated pyrite, galena, and arsenopyrite. Smith (1985) considered much of the chlorite and epidote to be related to regional metamorphism rather than hydrothermal alteration. However, silicification, massive white quartz veins, and disseminated limonite after fine-grained disseminated sulphides, are widespread in the Illunie Volcanics. This widespread alteration is a possible low grade alteration halo developed around the Broula King gold mineralisation at Bumbaldry.

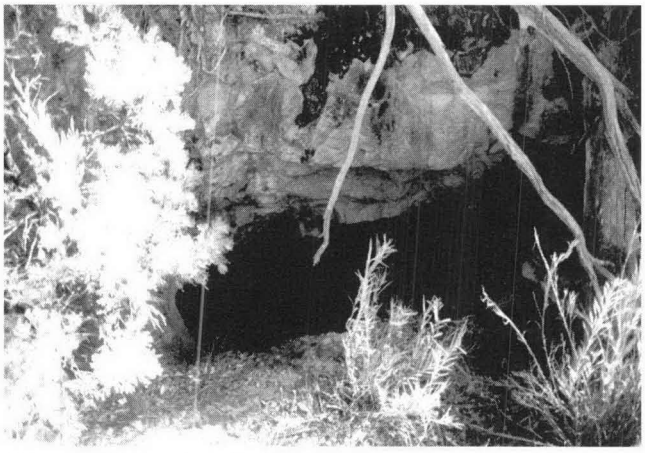


*Figure 4.4. Abandoned inclined stope up to one metre high driven along a mineralised quartz reef, Broula King gold mine, Bumbaldry. (GR 632940 mE 6246030 mN) (O.L. Raymond photograph)*

Secondary copper carbonates, some copper sulphides, and minor gold and silver mineralisation were mined from the Cowfell mine between 1903 and 1912, producing 20 t of copper from ore having an average grade of 7 wt% Cu. Mineralised quartz veins were present in a narrow lens of porphyritic rhyodacite within a larger body of quartzo-feldspathic sandstone.

Intensely kaolinised and sericitised Illunie Volcanics occur at the contact with the overlying Warrumba Volcanics at a quarry called The Claypit (GR 631100 mE 6247000 mN). Quartz phenocrysts, and occasional ghosts of altered feldspar phenocrysts, are commonly the only primary features preserved in the volcanic rocks.

*Palaeontology, age and correlation*

An Early Devonian age was initially assigned to the 'Illunie Rhyolite' in the Goulburn 1:250 000 map sheet area, based on contact relationships with surrounding rock units (Stevens, 1955; Brunker & Offenberg, 1970; Offenberg, 1974). However, Bowman (1976) assigned a Late Silurian age based on fossils from limestones, first noted by Carne & Jones (1919) near Bumbaldry, and described by Adamson (1960) and Sherwin & Byrnes (*in* Basden *et al.*, 1978).

Most recently, Jones (1984) described the Bumbaldry fauna including the corals *Heliolites* sp., *Halysites bellulus*, *Schedohalysites* sp. *cf. S. kikakamiensis*, *Tryplasma lonsdalei*, *Striatopora* sp. and a pachyporid form similar to *Cladopora*; the pentamerid brachiopod genera *Conchidium* and *Kirkidium*; and the conodonts *Belodella* sp., *Ozarkodina* sp., *Panderodus panderi* and *P. simplex*. Adamson (1960) also reported *Conchidium knightii* and Byrnes (*in* Pickett, 1982) reported probable *Halysites chillagoensis* or *H. yarrangobillyensis*. The Bumbaldry fauna is similar to that from the Bango Limestone Member of the Douro Group near Yass (Sherwin, *in* Pickett, 1982). A late Wenlock to early Ludlow age for the Illunie Volcanics is suggested by the coral assemblage.

The Illunie Volcanics are also correlated with the Canowindra Volcanics of the Cudal Group (Bathurst 1:250 000 map sheet area) and Glenisla Volcanics of the Douro Group. Both these volcanic units are texturally, mineralogically and geochemically similar to the Illunie Volcanics. The Canowindra Volcanics have a similar Wenlock age based on fossil evidence from the Bathurst 1:250 000 sheet area (Krynen *in* Pogson & Watkins, 1998). Both the Canowindra and Glenisla Volcanics have Early Silurian U-Pb SHRIMP zircon ages of 432 ± 7 Ma and 432 ± 2.8 Ma (Krynen *in* Pogson & Watkins, 1998; these Notes). However, these zircon U-Pb dates are too old for a Wenlock volcanic age based on the currently accepted range for the Wenlock period (424 to 428 Ma; see discussion of timescale, page vi of these Notes). Therefore, the zircon populations in the volcanics are interpreted as being inherited from a slightly older magma source.

*Depositional environment*

The presence of apparently *in situ* limestone lenses within the Illunie Volcanics suggest a shallow marine depositional environment for the volcanic rocks.

## **Glenisla Volcanics** (Sdg) *nov*

*Nomenclature*

The Glenisla Volcanics are named after 'Glenisla' about 14 km west-northwest of Eugowra.

*Distribution and previous nomenclature*

The Glenisla Volcanics crop out in small areas up to 2.5 km wide sporadically located along the Coolac–Narromine Fault Zone between Grenfell and the northern border of the Forbes 1:250 000 map sheet area. A small inlier (~1 km$^2$)

of Glenisla Volcanics crops out at the northern margin of the Forbes 1:250 000 map sheet area, about 25 km northeast of Parkes.

The Glenisla Volcanics on the northern border of the map sheet area were previously included in the Dulladerry Volcanics (Brunker, 1972; Bowman, 1976; Sherwin, 1997).

*Relationships*

The Glenisla Volcanics unconformably overlie the Ordovician Kirribilli Formation and have been intruded by Devonian granites, notably the Grenfell Granite and Eugowra Granite. The unit is bounded by the Coolac–Narromine Fault Zone on its western edge. Otherwise, the Glenisla Volcanics are unconformably overlain by the Middle Devonian Dulladerry Volcanics.

*Type locality*

The type locality for the Glenisla Volcanics is a road cutting (GR 617990 mE 6308670 mN) on the Parkes–Eugowra road.

*Description*

The Glenisla Volcanics consist of a massive, garnetiferous quartz–feldspar rhyodacitic porphyry compositionally identical to the Canowindra Volcanics described in Pogson & Watkins (1998). At the northern border of the Forbes 1:250 000 map sheet area, the Glenisla Volcanics consist of coarse-grained, immature, felsic volcanic sandstones. The sandstones consist primarily of abundant (≤50%) poorly sorted quartz, plagioclase, and biotite crystals, all up to 4 mm, in an altered, fine-grained, sandy matrix of felsic volcanic lithic fragments and crystal fragments (Figure 4.5). Accessory garnet crystals, up to 7 mm, also occur in the sandstones. Quartz crystals are commonly fractured, but not fragmented. The degree of rounding of the crystal phenocrysts ranges from very well-rounded to angular. Many of the crystals are euhedra with rounded corners.

The sandstones are typically strongly overprinted by lower greenschist metamorphism, and with weathering. The feldspars are strongly sericitised and biotite is almost completely chloritised. The matrix contains abundant recrystallised quartz, chlorite, sericite, and ?pumpellyite.

The sandstones of the Glenisla Volcanics have a very low magnetic susceptibility (~$20 \times 10^{-5}$ SI).

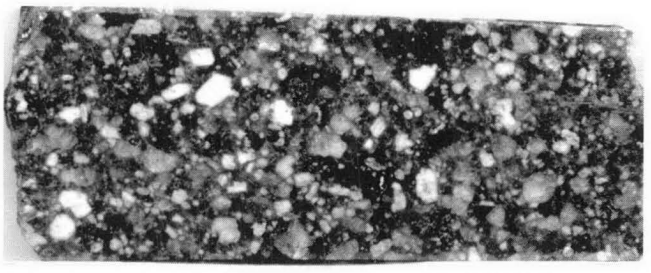


*Figure 4.5. Crystal-rich, garnetiferous, quartz–plagioclase–biotite volcaniclastic sandstone of the Glenisla Volcanics. The sample is approximately 60 mm long. (GR 629950 mE 6347130 mN) (O.L. Raymond photograph)*

In hand specimen, the volcanic sandstones of the Glenisla Volcanics may superficially resemble ash flow deposits or lava flows. However, the abundance of crystals suggests concentration by sedimentary processes with a very proximal volcanic source.

*Geochemistry*

The Glenisla and Illunie Volcanics are both primarily rhyodacitic ignimbrites, and volcanic sandstones, with abundant coarse-grained phenocrysts of quartz, plagioclase and biotite. Garnet and cordierite also occur, but the cordierite is generally completely altered. The presence of limestone and sedimentary lenses within the Illunie Volcanics indicates they were erupted in a submarine environment. In general, alteration of the Illunie Volcanics precludes geochemical analysis. However, the less-altered Glenisla Volcanics are an unfractionated S-type volcanic rocks, with high ASI, low Sr, and they are weakly to moderately oxidised (see Figure 16.1).

*Thickness*

The thickness of the Glenisla Volcanics is unknown as the outcrops are too sporadic. In the type area of the Canowindra Volcanics various thicknesses from 600 m to1000 m have been estimated (Pogson & Watkins, 1998).

*Environment of formation*

Pogson & Watkins (1998) described ignimbrites in the compositionally equivalent Canowindra Volcanics, so a subaerial environment may be possible for part of the Glenisla Volcanics. The Canowindra Volcanics have been interpreted as an ignimbrite deposited in a shallow marine to subaerial environment (Pogson & Watkins, 1998). The occurrence of immature, coarse-grained, volcanic sandstones suggests shallow marine deposition.

*Age*

Recent U–Pb data (L.P. Black, pers. comm., 1999) on a sample from Grenfell yield a Silurian age of 432 ± 2.8 Ma, which is closely comparable to a SHRIMP U–Pb age of 432 ± 7 Ma from the Canowindra Volcanics (Pogson & Watkins, 1998).

## Ungrouped Early Silurian Units

### **Ugalong Dacite** (Su) Kemezys (1976)

*Nomenclature, derivation, distribution and outcrop*

Kemezys (1976) named the Ugalong Dacite after Ugalong Trigonometrical Station (GR 502860 mE 6287180 mN) and the unit was formally defined by the New South Wales Stratigraphic Nomenclature Subcommittee, Geological Society of Australia (1978).

Sparsely porphyritic dacite crops out strongly along a low north–south hill, including Ugalong Trigonometrical Station, west of the Ungarie–Condobolin road and northeast of Ungarie. Immediately east of the ridge, and at one locality west of the ridge, poor and discontinuous

outcrops of porphyritic dacite occur as small whalebacks and tors. The Ugalong Dacite also crops out as a northwest–southeast ridge beside 'Belleforest' homestead and farm buildings at GR 502400 mE 6294100 mN.

*Representative localities*

Kemezys (1976) designated a type section westward from the Burcher–Ungarie road, 17 km west of Burcher, but there is little or no outcrop west from the road. Outcrop of the porphyritic variant does occur at that point, which is a representative locality for the unit. Another locality, representing the sparsely porphyritic variant, is Ugalong Trigonometrical Station.

*Description*

The Ugalong Dacite is a dark grey, sparsely to strongly porphyritic dacite. The sparsely porphyritic variant contains scattered small phenocrysts of plagioclase to 1.5 mm and small clots of biotite granules in a strongly recrystallised groundmass of quartz, feldspar ($An_{30}$ to $An_{40}$), biotite, and muscovite. Accessory minerals include magnetite, apatite, and zircon. Strongly porphyritic variants have abundant euhedral quartz (often partially resorbed) and zoned plagioclase phenocrysts, apatite microphenocrysts, and biotite clots in a similar groundmass. Both types display a distinct foliation, with alignment of plagioclase and groundmass biotite and stretching of biotite clots, which were probably formed during regional compression and metamorphism. A subsequent lower grade retrogressive metamorphic event formed non-aligned sericite, clinozoisite and chlorite.

Strongly porphyritic Ugalong Dacite from one locality (GR 501500 mE 6289000 mN), 2.5 km northwest of Ugalong Trigonometrical Station, is less recrystallised. It contains phenocrysts of quartz, plagioclase, brown biotite, and orthopyroxene in a fine-grained groundmass of quartz, feldspar, and brown biotite. The orthopyroxene occurs as relict cores mantled by actinolite and cummingtonite, which is, in turn, mantled by fine-grained, dark green mica.

Evidence of a pyroclastic origin is not clear. Very subtle ghostly outlines of possible shards, observed in the least-recrystallised samples, are consistent with a pyroclastic origin, and Barron (1998) described the Ugalong Dacite outcrops near 'Belleforest' homestead as welded crystal vitric tuff.

The Ugalong Dacite has relatively high magnetic susceptibility, around $500 \times 10^{-5}$ SI. Moderate K and Th gamma ray spectrometric count rates are reflected in deep pink hues on RGB images.

*Age and boundary relationships*

A K–Ar age determined by A.W. Webb is recalculated using 1977 decay constants as 425 ± 6 Ma (Pogson & Hilyard, 1981). U–Pb SHRIMP ages have been determined from zircons from two samples of the Ugalong Dacite. Zircons from porphyritic dacite near the junction of the Ungarie–Condobolin road and the Burcher road (GR 507020 mE 6292500 mN) and from sparsely porphyritic dacite from near Ugalong Trigonometrical Station gave essentially identical ages of 433.4 ± 3.1 Ma and 432.9 ± 1.8 Ma, respectively (L.P. Black, pers. comm., 1998). This is indistinguishable from the age of the Ungarie Granite.

Contact relationships of the Ugalong Dacite with other (basement) units are not exposed. The Ugalong Dacite is overlain unconformably by Cainozoic colluvium and alluvium, which conceal contacts with the Wagga Group and the intrusive Currah Granite and a Carboniferous mafic dyke. The nature of the contact with the underlying Humbug Sandstone of the Wagga Group is uncertain, but is interpreted to be an angular discordant unconformity. Around Ugalong Trigonometrical Station, the dacite was intruded by dykes of granite and pegmatite, and outcrops of Ungarie Granite occur within 1 km of the southernmost outcrops of the unit. The general field relationships; the observation that the Ugalong Dacite has been extensively recrystallised subsequent to eruption and deposition; and is partly surrounded by the Ungarie Granite (which appears to intrude it) suggests that eruption of the Ugalong Dacite was an early surface manifestation of intrusion of the Ungarie Granite. The Ungarie Granite apparently intruded and partly subsumed its own volcanic pile.

*Geochemistry*

The Ugalong Dacite is an S-type, felsic volcanic unit. In most respects, it is very similar to the Ungarie Granite, but there are subtle differences in their geochemical variation. Notably, the Ugalong Dacite has lower MgO, Sr, and Cr overall, and higher $Al_2O_3$, CaO, and $Na_2O$ in the less siliceous rocks. It is possible that these differences may be produced by crystal accumulation or depletion in the dacite, either by crystal fractionation prior to eruption, or by crystal concentration or depletion by pyroclastic eruptive processes.

## **Ina Volcanics** (Sn) Kemezys (1976)

*Nomenclature, distribution, relationships and type locality*

Kemezys (1976) named the Ina Volcanics. Although he did not explain the basis for the name, it is probably after the Parish of Ina, within which the unit is located. He identified the Ina Volcanics as a 2000 m thick sequence of andesitic and rhyolitic volcaniclastic units, shales, sandstones, and carbonates. However, current mapping by several geologists only identified rhyolitic ignimbrite. Kemezys' (1976) 'Cowal Member', which he identified as a massive rhyolitic porphyry, has been discontinued as a separate unit, as it is merely a slightly sheared equivalent of the ignimbrite. Rocks of the Ina Volcanics crop out in limited areas from about 3 km west of Nerang Cowal to about 10 km due north of Burcher.

Although no contacts are exposed, the Ina Volcanics probably lie unconformably over the Ordovician Girilambone Group, and are unconformably overlain by the Siluro-Devonian Ootha Group. The best exposures are in the Nerang Cowal State Forest, around GR 528200 mE 6292700 mN, and on a hill (GR 531200 mE 6289500 mN),

about 7 km east of Burcher, where it is slightly sheared due to movement of the Gilmore Fault Zone.

*Description*

The ignimbrite of the Ina Volcanics crops out as a grey to pinkish grey, massive, medium-grained quartz–feldspar-phyric rhyolite (Figure 4.6). In places it is highly weathered, and in the vicinity of the Nerang Cowal gold prospect, hydrothermal alteration has contributed to accelerated weathering. Quartz phenocrysts make up about 50% of the rock and vary from angular to rounded and embayed, and are commonly fractured. Feldspar phenocrysts, both microcline and plagioclase, are less common. The quartz and the feldspar grains are generally about 1 mm to 2 mm across, but up to 5 mm is common. They are set in a devitrified, probably sericitic groundmass containing abundant fine-grained quartz and relict shards and pumice fragments, which are only slightly flattened, indicating that welding was at a low temperature. Lithic fragments, of phyllite and chert, and apparently derived from the Girilambone Group, are common in the Ina Volcanics. The shear fabric in the Ina Volcanics is developed in parts of the ignimbrite that are closer to the Booberoi Shear Zone — they are upright, and with a north-northwest trend. Because the fabric is weakly developed, there are no certain kinematic indicators.

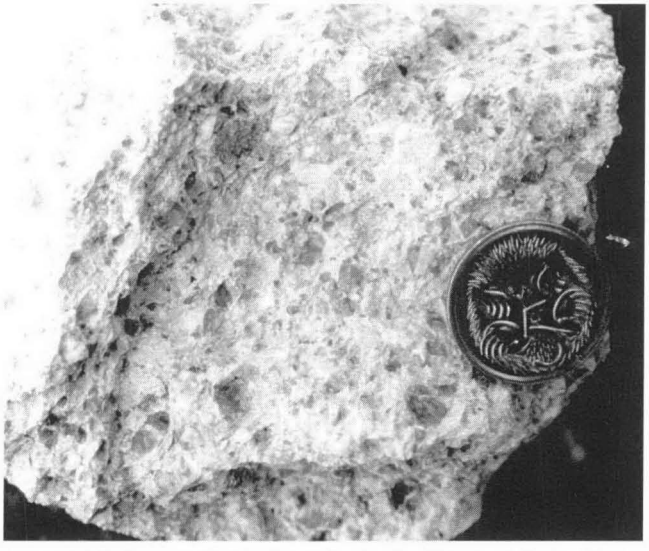


*Figure 4.6. Quartz–plagioclase-phyric rhyolitic ignimbrite of the Ina Volcanics. (GR 525800 mE 6301250 mN). (O.L. Raymond photograph)*

*Age*

Zircons obtained from the Ina Volcanics gave a SHRIMP U–Pb age of 426.1 ± 3.2 Ma (L.P. Black pers. comm., 1998). All 38 zircon grains analysed for the Ina Volcanics gave the same age, suggesting the age represents that of eruption, with no evidence of inheritance.

*Geochemistry and origin*

The Ina Volcanics have a fractionated, reduced, S-type (75 wt% $SiO_2$), composition. This composition is similar to that of the Billys Lookout Granite. Because the age of the Ina Volcanics is comparable to the Billys Lookout Granite (427.0 ± 2.2 Ma, these Notes), and the units are within 20 km of each other, it is possible that the Ina Volcanics were comagmatic with the Billys Lookout Granite.

## **Burcher Greywacke** (Sb) Kemezys (1976)

*Nomenclature, distribution and type locality*

Kemezys (1976) named the Burcher Greywacke after the village of Burcher, in the centre of the western third of the Forbes 1:250 000 map sheet area, 45 km north of West Wyalong.

The bulk of the outcrop of the Burcher Greywacke occupies an area extending north-northwest from the road north of Billys Lookout to about 2 km north of Burcher (Figure 4.7). An isolated occurrence (GR 509700 mE 6314500 mN) forms a hill beside Humbug Creek, about 25 km northwest of Burcher.

Only the massive greywacke of the Burcher Greywacke is well-exposed. The extent of the finer-grained sedimentary rocks is poorly known because of poor outcrop. This precludes the establishment of a type section. A type locality, of massive sandstones, may be observed at a road cutting about half a kilometre north of Lake View State Forest (GR 524200 mE 6282500 mN). It is not known if the deeply-weathered unexposed parts of the Burcher Greywacke are more pelitic units.

*Constituent unit*

A conglomerate lens has been identified as a unit within the Burcher Greywacke and is named the Blow Clear Member.

*Description*

In almost all outcrops, the Burcher Greywacke is a fine- to coarse-grained, massive, dark grey (when fresh) quartz–feldspar–lithic sandstone with thin silty lenses and shaly rip-up clasts. It displays occasional graded bedding. Grains were supported in a muddy matrix, now recrystallised to muscovite and biotite. Rare recrystallised calcite, perhaps derived from crinoid stems reported by Kemezys (1976), is visible in thin section. Structural fabrics are well-developed in the silty layers but poor to non-existent in the greywackes.

The greywacke contains poorly sorted, angular to rounded quartz, feldspar, and lithic grains up to 0.5 mm. The lithic grains are both igneous (intermediate volcanic and granodioritic) and (meta-)sedimentary. The proportions of the clast types vary: quartz from 15% to 80%; feldspar from trace to 30%; and lithic clasts from trace to 20%, including up to 20% of the total rock as chert. Grains are supported in a muddy matrix recrystallised to muscovite and biotite, although some detrital muscovite occurs. The biotite is usually about 5% to 10% of the rock and the muscovite fraction varies between 1% and 10%. Recrystallised carbonate may be up to 5% but its distribution is very irregular. Zircon and tourmaline are the common accessory minerals, and brookite has been

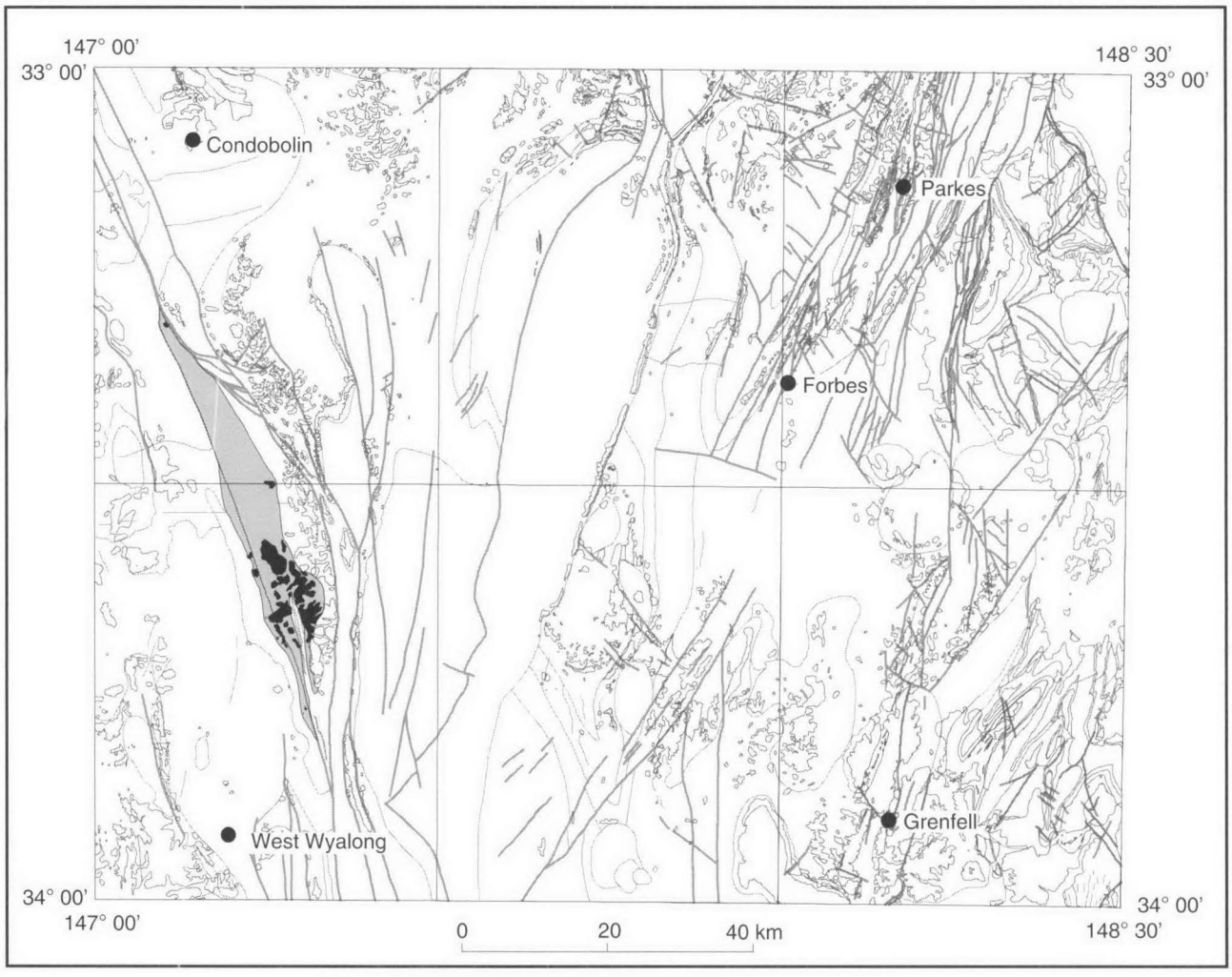



*Figure 4.7. Distribution of the Burcher Greywacke in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

identified as an accessory mineral in the northernmost outcrops, near Humbug Creek (Barron, 1998).

Although the Burcher Greywacke has been folded, the massive sandstones exhibit varying degrees of preferred orientation and cleavage development, which in turn depends on the shape of the grains and the proportion of clay in the original matrix; elongate grains in a clayey matrix are better able to rotate their long axes (viewed in two dimensions) into a high angle to the local stress field. Therefore, cleavage is only developed in silty lenses and clay-rich sandstones. It is near vertical, and generally trends about 340°.

The shaly and silty lenses in the Burcher Greywacke consist of very fine-grained quartz and mica showing a well-formed penetrative cleavage, which is almost slaty. Syn-deformational pyrite grains (no pressure shadows), euhedral and up to 1 mm across, are sometimes present.

At the western margin of outcrop, the Burcher Greywacke becomes more siliceous. Further, where exposed in some gravel pits (e.g., GR 519200 mE 6289800 mN), about 5 km west-southwest of Burcher, some very fine-grained, cherty boulders occur. These may be cherts proper, or very silicified siltstone. In thin section they are composed of exceedingly fine-grained quartz and minor mica, generally 1 μm or 2 μm, the rock containing an extensive network of quartz veins about 0.1 mm to 0.3 mm wide. This part of the Burcher Greywacke contains abundant vein quartz float and coincides with a splay of the Gilmore Fault Zone. Kemezys (1976) identified the rocks there as the Devonian Sandal Formation and reported the presence of shelly fossils in a sandstone horizon, near 'Glenview', at about GR 520000 mE 6287000 mN. No fossils were found there during this mapping of the Forbes 1:250 000 map sheet area.

The magnetic susceptibility of the Burcher Greywacke is very low, generally about $5 \times 10^{-5}$ SI to $20 \times 10^{-5}$ SI. On RGB gamma ray spectrometric images, the Burcher Greywacke shows as pink to white. It is magnetically and spectrometrically indistinguishable from the adjacent Ordovician Girilambone Group.

*Geochemistry*

Three samples of the massive greywacke from the Burcher Greywacke have a composition similar to granodiorite or dacite, although silica contents are higher at about 70 wt%.

This suggests deposition close to its source rocks, which presumably had felsic to intermediate compositions. Conventionally, this composition indicates deposition on an active margin, but the limited areal extent of the Burcher Greywacke, and the possible non-representative nature of its outcrop, mean that such interpretations must be made with caution.

*Thickness*

The consistent parallelism of cleavage and bedding in the Burcher Greywacke indicates tight to isoclinal folding but with the absence of marker beds in the generally massive sandstones it is not possible to determine whether folding has been strain partitioned or not. Kemezys (1976) estimated a thickness of about 4000 m, but that figure remains uncertain.

*Environment of deposition*

The turbidite character of the Burcher Greywacke indicates deposition in a deep marine environment. The restricted extent of the formation suggests a small submarine fan, or localised deep water basin.

*Boundary relationships and age*

The boundary of the Burcher Greywacke with the underlying Girilambone Group is not exposed, although it is constrained by mapping in the southern part of its distribution. Fragments of both Burcher Greywacke and Girilambone Group rocks from a single locality (GR 530860 mE 6275770 mN), unearthed during trenching for the high-pressure gas pipeline, show no evidence of shearing or faulting and this suggests that the contact between the two units is unconformable. The western margin of the Burcher Greywacke is covered by Cainozoic deposits so the relation between the Greywacke and the interpreted Ordovician volcanic rocks there is unknown. The Burcher Greywacke was intruded by the Silurian Billys Lookout Granite.

Given the lack of datable fossils, Kemezys (1976) assigned a broad Silurian age, based on stratigraphic position. Sherwin (*in* Pickett, 1982) considered the Burcher Greywacke to be part of the Siluro-Devonian 'Ootha Formation'. A minimum age is given by the mid-Silurian Billys Lookout Granite (427 ± 2.2 Ma; these Notes), which intruded the Burcher Greywacke. SHRIMP U–Pb dating of detrital zircons gave a bimodal distribution, 440 Ma and 432 Ma (L.P. Black, pers. comm., 1998). Thus the maximum age for the Burcher Greywacke is no more than mid-Early Silurian. The younger zircon population has both morphologies and spread of ages identical to zircons crystallised in the Silurian Ugalong Dacite (these Notes). Therefore, the Ugalong Dacite is suggested as a source rock for the Burcher Greywacke.

## **Blow Clear Member** (Sbc) Kemezys (1976)

*Nomenclature*

Kemezys (1976) applied the name Blow Clear Member to conglomerate and hill-forming sandstone immediately west of 'Lakeview' homestead (GR 528000 mE 6277600 mN). However, the sandstone is included here in the undifferentiated Burcher Greywacke.

*Derivation of name*

The Blow Clear Member is named after Blow Clear Trigonometrical Station (Kemezys, 1976).

*Distribution and outcrop*

The Blow Clear Member crops out about a kilometre west of 'Lakeview' homestead and extends along strike, either as outcrop or abundant float, for about 5 km.

*Type locality*

Good outcrops of conglomerate of the Blow Clear Member are found at GR 527380 mE 6277900 mN.

*Description*

The Blow Clear Member consists of poorly sorted, polymict, pebble and cobble matrix-supported conglomerate, with minor sandy and silty layers. Clasts consist of rounded quartzite and vein quartz, and angular siltstone, which may be autochthonous. The clasts have a preferred orientation parallel to bedding, which dips steeply towards 245°. It is not certain whether the preferred orientation is imbrication or was produced during folding. The matrix is identical to gritty sandstone of the Burcher Greywacke, albeit quartz- and lithic-rich. The Blow Clear Member grades into sandstone and siltstone at the southern end of the unit.

*Thickness*

Where the true thickness of the Blow Clear Member is measurable, it does not exceed 200 m. However, aerial photograph interpretation suggests that it may be up to 500 m thick near its southern end.

*Boundary relationships*

The Blow Clear Member is bedded within the Burcher Greywacke although contacts are not exposed.

# 5. EARLY SILURIAN INTRUSIONS

## Ungarie Suite

**Ungarie Granite** (Sug) modified from Griffin (1960)

*Nomenclature, derivation and distribution*

The name Ungarie Granite now includes granitoid rocks formerly mapped as the 'Wyalong Granite' (Brunker, 1968, 1972a) and 'Wyalong Granodiorite' (Bowman, 1976,1977a; Pogson & Hilyard, 1981; Suppel *et al.*, 1986). The name was first used by Griffin (1960) for granite mapped in the Cargelligo 1:250 000 map sheet area. Pickett (1982) noted the continuity of the Ungarie Granite and 'Wyalong Granite', and Chappell *et al.* (1991) extended the definition of the Ungarie Granite to include both units. The Ungarie Granite is named after the village of Ungarie, near the eastern edge of the Cargelligo 1:250 000 map sheet area.

The Ungarie Granite is a widespread unit extending in a northwesterly direction from just south of the southern boundary of the Forbes 1:250 000 map sheet area into the area of the Cargelligo 1:250 000 map sheet at Ungarie (Figure 5.1). Outcrop is generally poor except for a few areas where the granite crops out well as large tors, whalebacks, and rock pavements. These areas of outcrop show very clearly on ternary (K–Th–U) gamma ray spectrometric images as areas with a very high potassium signature, in contrast to the attenuated signal from areas of deep weathering and regolith cover. The size and highly irregular shape of the Ungarie Granite, consisting of individual broadly lobate components centred roughly on Ungarie, Hiawatha, and northeast of Girral, strongly suggest that the pluton is multiphase. While this remains a likely interpretation, the aeromagnetic data do not show any internal structure of the pluton.

*Representative locality*

A representative locality for the Ungarie Granite is Tullabung Hill, 24 km north-northwest of West Wyalong (GR 509800 mE 6267800 mN) and approximately central to the total outcrop extent of the granite.

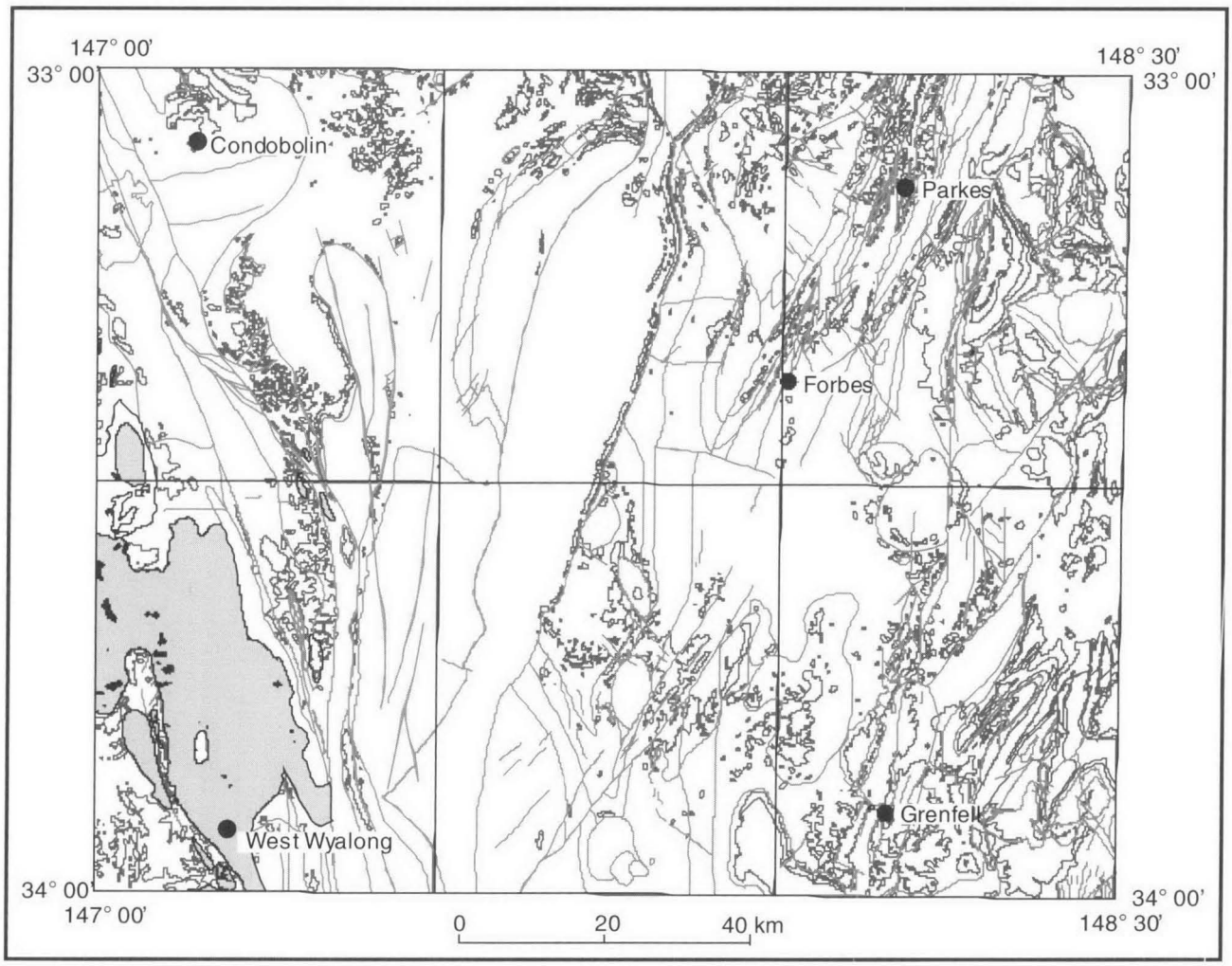



*Figure 5.1. Distribution of the Ungarie Suite in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

*Description*

The principal rock type in the Ungarie Granite is a grey, medium-grained, equigranular biotite–muscovite granite or granodiorite. The granite is generally massive and unfoliated but, near the margins, and in some zones within the pluton, the rock is strongly foliated with alignment of micas, fracturing and flattening of quartz grains, and fracturing of feldspars. The unfoliated rocks are typically hypidiomorphic granular, containing subhedral biotite, muscovite, and zoned plagioclase, and anhedral quartz and perthitic orthoclase, with trace amounts of ilmenite, apatite, and zircon (Figure 5.2). The abundance of orthoclase is variable so that the samples show a spread from granite to granodiorite compositions. In rare instances, samples of the Ungarie Granite are hornblende-bearing.

Xenoliths, usually less than 10 cm in diameter, are common throughout the pluton, typically comprising between 1% and 5% of the rock. The xenoliths include a spectrum of textural types ranging from strongly foliated biotite–cordierite–(sillimanite) schists through to totally recrystallised, unfoliated mica-rich dioritic rocks.

*Figure 5.2. Photomicrograph of muscovite–biotite granite of the Ungarie Granite. Width of field of view 10 mm. (M.B. Duggan photograph)*

*Age and boundary relationships*

New U–Pb SHRIMP zircon dating of four samples of the Ungarie Granite have yielded ages that are identical, within experimental error, at 433 ± 2 Ma (L.P. Black, pers. comm., 1998). This is significantly older than indicated by earlier K–Ar data on hornblende (417 ± 8 Ma) and biotite (410 ± 10 Ma) (Pogson & Hilyard, 1981) Some of this discrepancy may result from lower closure temperatures for the K–Ar system than for the U–Pb system, but it appears likely that the K–Ar ages also reflect some argon loss. The age is also identical to other spatially associated intrusive and extrusive units including the Bland Diorite and the Ugalong Dacite.

The contacts with country rocks are largely concealed. A mixed contact, resembling migmatite, is exposed in a creek near GR 509800 mE 6258800 mN, where abundant high-grade metasedimentary xenoliths of the Wagga Group occur in the granite. The presence of mylonite on the west side of a low hill, about 9 km west-northwest of West Wyalong, indicates that the contact there, which is also with rocks of the Wagga Group, is in part faulted.

*Geochemistry*

The Ungarie Granite is, for the most part, a geochemically uniform, typical S-type granite with $SiO_2$ in the range 67 wt% to 70 wt%. Most analysed samples form a tight and coherent group having 2.4 wt% to 2.8 wt% CaO and relatively unfractionated S-type compositions, including relatively high MgO (1.7 wt% to 2.3 wt%), Ba (420 ppm to 630 ppm) and Sr (150 ppm to 300 ppm) and low $Na_2O$ (2.4 wt% to 3.2 wt%), and Rb (177 ppm-234 ppm). Hornblende-bearing samples collected from near Spy Hill and from a small hill west of Wyalong are geochemically distinct with higher CaO (3.7 wt% and 4.3 wt%) and lower Rb (122 ppm and 146 ppm).

## Charcoal Tank Granite (Stg) *nov*

*Nomenclature, derivation and distribution*

The Charcoal Tank Granite is a new name applied to a previously unmapped granite stock. The stock was emplaced into metasedimentary rocks of the Wagga Group, south of Wyalong.

The name is derived from the Charcoal Tank Flora Reserve, which is located adjacent to the Newell Highway, about 8 km south-southwest of West Wyalong, and about 3 km west of the outcrop area of the Charcoal Tank Granite. There are no other named landmarks closer to the outcrop area of the Charcoal Tank Granite.

Outcrop of the Charcoal Tank Granite is poor. However, the extent of the intrusion is readily discernible on aeromagnetic images as an oval body, approximately 3.5 km × 2.5 km with northwest–southeast elongation.

*Representative locality*

A representative locality for the Charcoal Tank Granite is on the eastern side of an unnamed lane, south of West Wyalong (GR 517530 mE, 6240610 mN), where the granite crops out as boulders and small tors.

*Description*

The Charcoal Tank Granite is a cordierite-bearing muscovite–biotite granite. Away from the margins of the intrusion, the granite is massive and unfoliated but, near the margins, it becomes gneissic in character. In hand specimen, the rock is medium-grained, dark grey, and has a saccharoidal texture. In thin section, it contains abundant (~20%) euhedral to subhedral grains of cordierite in an allotriomorphic granular assemblage of quartz, plagioclase, microcline, red–brown biotite, muscovite, and opaque oxides. The cordierite is altered to sericite and chlorite

along a network of irregular fractures. Apatite and zircon, as minute euhedra, are common accessory minerals.

*Age and boundary relationships*

The Charcoal Tank Granite intruded, and is wholly contained within, the Humbug Sandstone of the Wagga Group. Near the contact, there appears to be a complex intermingling of typical hornfelsed metasediments and medium- to coarse-grained gneissic veins and pods that increase in abundance, and become less gneissic, towards the interior of the intrusion. The stock and adjacent metasediments were extensively intruded by veins and dykes of granite pegmatite.

The exact age of the Charcoal Tank Granite has not been determined. It may represent another manifestation of the major igneous event around 433 Ma that produced the Ungarie Granite, Bland Diorite, and Ugalong Dacite, and which post-dated the principal deformation and metamorphism of the Wagga Group. However, its contact relationships, overall syn-metamorphic character and distinctive, exaggerated S-type mineralogy and geochemistry suggest that it may be related to metamorphism of the Wagga Group and somewhat older than the Ungarie Granite.

*Geochemistry*

In keeping with the modal abundance of cordierite, muscovite, and biotite, the granite is strongly corundum-normative and distinctly different from other granitoids in the Wyalong area. It is notably low in $Na_2O$ and CaO and plots well within the quartz field on a Qz–Or–Ab diagram. These features are consistent with derivation from quartz argillites that have previously been extensively weathered.

## Currah Granite (Srg) *nov*

*Nomenclature, derivation, distribution and relations*

The Currah Granite is named after the Parish of Currah, in which it occurs. Based on an aeromagnetic survey and rotary air blast (RAB) drilling, Jones (1985) mapped granite beneath alluvium near the western margin of the Forbes 1:250 000 map sheet area but did not name it. The Currah Granite does not crop out, and the detailed AGSO aeromagnetic survey of 1993 has enabled more accurate mapping of its extent. The Currah Granite intruded the relatively more magnetic Silurian Ugalong Dacite, and was intruded by a highly magnetic (presumed Carboniferous) mafic dyke. The Currah Granite is covered by between 60 m and 75 m of Cainozoic alluvium and colluvium (Jones, 1985). Lack of outcrop and drillcore preclude the designation of a type locality. Jones (1985) observed the Currah Granite in RAB chips, but they are no longer available.

*Description*

Jones (1985) described the RAB chips from the bottom of three drillholes as weakly magnetic granite containing medium grained quartz, feldspar, white mica, and biotite. Based on proximity and similarity to the Ungarie Granite, the Currah Granite is probably part of the unfractionated felsic S-type Ungarie Suite (Chappell *et al.*, 1988).

*Age*

No age data are available on the Currah Granite. However, the intrusion is interpreted, on the basis of aeromagnetic data and identical mineralogy, to be a subvolcanic equivalent of the Ugalong Dacite, for which a Llandovery age has been obtained (these Notes). This age is indistinguishable from that of other granites of the Ungarie Suite.

## Cookaburragong Granodiorite (Skg) *nov*

*Nomenclature, derivation, distribution, type locality and relations*

The Cookaburragong Granodiorite is named after the Parish of Cookaburragong, in which it crops out. Its main outcrop trends north–south and forms a ridge (GR 500000 mE 6311000 mN) on the property 'Recital', along the western boundary of the Forbes 1:250 000 map sheet area, about 25 km west-northwest of Burcher. Another north–south trending felsic intrusive at GR 502340 mE 6307720 mN is included within the Cookaburragong Granodiorite. The margins of the granodiorite are roughly concordant with the surrounding Humbug Sandstone of the Wagga Group

The type locality, which has the best outcrops and contact relations, is on the northern slope of the ridge at GR 500100 mE 6311500 mN.

*Description*

The distribution of outcrops, and contact relationships, indicate that the granodiorites are dykes, or sills, at least 2 km long, and between 200 m and 500 m wide, as its margins are roughly concordant with moderate to steeply east dipping beds of the Humbug Sandstone. The magnetic susceptibility of the granodiorite is low ($\leq 15 \times 10^{-5}$ SI). The granodiorite has high and moderate gamma ray spectrometric count rates for K and Th.

The main outcrop of the Cookaburragong Granodiorite is a grey, medium-grained, flow banded, biotite granodiorite. A thin section of the rock from this outcrop was described by Barron (1998). The modal composition includes 30% quartz, 20% porphyritic biotite, and 45% plagioclase and K-feldspar, with accessory magnetite, apatite, zircon, and tourmaline sprays. Xenoliths include common bedded metasediments, and melamonzodiorite with alkali feldspar, and minor porphyritic quartz melamonzodiorite, which displays a preferred orientation. The other felsic intrusive is a cream-coloured, intrusive rhyolite, with phenocrysts of quartz and altered feldspar up to 3 mm. Barron (1998) identified quartz, altered feldspar and ?biotite, and muscovite as the main minerals. It may also contain altered cordierite. Zircon and magnetite are accessory minerals.

Regional metamorphism and deformation has produced a strong overprint of decussate and subaligned sericite and biotite (Barron, 1998). Alteration around the Laurieston

prospect, at GR 502500mE 6308200mN, produced an overprint of muscovite, tourmaline-quartz veins and brecciation, quartz-muscovite greisen, with minor sulphides and gold, jarosite, limonite, and epidote (Barron, 1998; Palmer, 1998). Due to the narrowness of the unit, contact metamorphic effects on the surrounding country rocks are limited.

*Geochemistry*

The Cookaburragong Granodiorite has a composition bordering on granite, with 70 wt% $SiO_2$, 2.6 wt% $Na_2O$, and 3.2 wt% $K_20$.

The Granodiorite has S-type affinities, as it has biotite-bearing sedimentary xenoliths, moderate alkali contents, a relatively high $K_2O/Na_2O$ ratio of 1.2, an aluminium saturation index (ASI) of 1.2, and low Zr. The granodiorite is unfractionated, as determined from Rb/Sr *versus* $SiO_2$ and Ba *versus* $SiO_2$ plots. The redox state ($FeO/Fe_2O_3$ ratio) of the granodiorite is unclear. The single analysis has abnormally low FeO (0.14 wt%), which suggests either analytical error or alteration.

The composition of the Cookaburragong Granodiorite is similar to the Ugalong Dacite, which may occur as close as 7 km south of the granodiorite. The composition of the Granodiorite lies within the range of these dacitic to rhyolitic volcanic rocks, except for an anomalously low Zr content (77 ppm). This similar chemistry, combined with the similar age of the two units (~433 Ma), suggests that they are closely related and possibly comagmatic.

*Age*

An Early Silurian age of 432.8 ± 3.1 Ma was obtained by the SHRIMP U–Pb zircon method (L.P. Black, pers. comm., 1999). This age indicates that the Cookaburragong Granodiorite is part of the Early Silurian felsic magmatic event, and it is included in the S-type Ungarie Suite of granitoids and volcanic rocks (Chappell *et al.*, 1988, 1991), which also includes the Ungarie Granite and Ugalong Dacite.

## Ungrouped Early Silurian Intrusions

### **Bland Diorite** (Sbd) Bowman, (1977a)

*Nomenclature, derivation, distribution and outcrop*

The Bland Diorite was defined by Bowman (1977a) to include rocks of a diorite intrusion, covering approximately 15 $km^2$, east and northeast of Wyalong. The Bland Diorite is named after the County of Bland.

Scattered outcrops, as tors and small pavements, occur in the area immediately north of Wyalong, and on 'The Laurels', approximately 6 km north-northeast of Wyalong. Aeromagnetic data indicate that the unit actually occupies a roughly triangular area of about 20 $km^2$ to the east and northeast of Wyalong.

*Representative locality*

A representative locality for the Bland Diorite is on 'The Laurels' (GR 525500 mE 6251230 mN).

*Description*

In most outcrops, the Bland Diorite is massive, dark grey, medium-grained, and equigranular, although altered variants are paler grey–green. The rock is variable in its primary mineralogy, which is often partially to completely obscured by subsequent alteration effects, most notably uralitisation, leading to actinolite–epidote–sodic plagioclase–quartz assemblages. Where preserved, the primary rock type varies from a relatively mafic diorite (approaching gabbro) through diorite to a mafic tonalite. The dominant mafic mineral is clinopyroxene. Orthopyroxene or biotite, or both, may be present, and variants rich in primary hornblende also occur. A textural variant, probably representing a petrogenetically related late-stage dyke, is andesitic in character, containing phenocrysts of plagioclase, hornblende, and clinopyroxene in a fine-grained quartzo-feldspathic groundmass.

*Age and boundary relationships*

A U–Pb SHRIMP age of 433.7 ± 2.3 Ma (L.P. Black, pers. comm., 1998) has been obtained on zircon from the Bland Diorite from the representative locality listed above. Pogson & Hilyard (1981) reported a K–Ar age of 450 ± 15 Ma, although in the original report by Rowley (1975) it was noted that there was an "anomalously low potassium content".

Contacts of the Bland Diorite with adjacent units are mostly obscured. On the eastern side, it is faulted against the Yiddah Formation. The northwestern contact, with the Ungarie Granite, is totally obscured and problematic in nature. High-resolution aeromagnetic data show that the contact is sharp and relatively smooth, suggesting that the two plutons may be in fault contact. Zircons from the Ungarie Granite and the Bland Diorite give identical SHRIMP U–Pb ages within analytical error. The southern contact, with the Narragudgil Volcanics, is highly irregular and clearly intrusive. Large blocks of the Ordovician Narragudgil Volcanics are contained within the Bland Diorite, and apophyses of the Bland Diorite extend into the Narragudgil Volcanics. Basalts of the Narragudgil Volcanics are contact-metamorphosed to hornblende hornfels within the irregular contact zone.

*Geochemistry*

The Bland Diorite is an I-type intrusion. The geochemical characteristics, including relative enrichment in incompatible elements (both LIL and HFSE) and small but distinct relative depletions in Nb, P, and Ti, suggest calc-alkaline or shoshonitic affinities.

A suite of dykes, which intruded the Narragudgil Volcanics show similar geochemical characteristics to the rocks of the pluton. These include identical trace element enrichment and depletion patterns at the same $SiO_2$ content. However, they display a smaller overall variation in major and trace elements, lacking the more siliceous compositions reached

by parts of the Bland Diorite. The dykes are believed to be early offshoots from the Bland Diorite, intruded before the diorite magma had undergone substantial fractionation.

## **Young Granodiorite** (Syg) Ashley & Basden (1973), modified after Adamson (1960)

*Nomenclature, distribution and boundary relationships*

Adamson (1960) originally introduced the term 'Young Granite' for this very large intrusion, named after the town of Young (Cootamundra 1:250 000 map sheet area). Ashley & Basden (1973) amended the term to Young Granodiorite, but included, as part of the unit, the Cowra Granodiorite, which is now regarded as a separate body (e.g., Chappell *et al.*, 1991; Wyborn *et al.*, 1991). The Young Granodiorite has been described in some detail by several authors, including Basden *et al.* (1978), Owen & Wyborn (1979), Basden (1990) and Warren *et al.* (1995).

The Young Granodiorite forms a very large, elongate intrusion (~3640 $km^2$) extending south for some 170 km from Bumbaldry. Only the northernmost 130 $km^2$ of the granodiorite is exposed in the southeastern corner of the Forbes 1:250 000 map sheet area. There, the Young Granodiorite was intruded in the east by the Early Devonian Broula Granite and is probably faulted against the Early Devonian Warrangong Volcanics. Along its northern and western boundaries, the granodiorite intruded the mid-Silurian Illunie Volcanics and Ordovician Kirribilli Formation, and is unconformably overlain by the Middle Devonian Warrumba Volcanics, the Late Devonian Hervey Group, and Cainozoic alluvial sediments.

*Type area*

The type area of the Young Granodiorite is around the town of Young in the Cootamundra 1:250 000 map sheet area (Adamson, 1960). Basden (1978) also described exposures of the granodiorite along the Hume Highway near Jugiong, about 55 km south of Young.

*Description*

Although the Young Granodiorite is in general remarkably uniform in composition, the exposure in the Forbes 1:250 000 map sheet area appears to be slightly more felsic than the granodiorite exposed further south — being mainly grey, medium- to coarse-grained, biotite granodiorite to leucogranite. There are equigranular and porphyritic textural variants, as well as minor fine-grained, felsic granite and aplite phases. Plagioclase ($An_{25}$ to $An_{45}$) and K-feldspar comprise 10% to 40% of the rock and quartz, 30% to 45%. Biotite is often tabular and typically makes up around 10% of the rock, although more mafic and felsic variants occur. Mafic restite clots and xenoliths, rich in biotite, also occur.

Quartz, biotite and K-feldspar may occur as phenocrysts up to 6 mm across. Highly weathered samples of porphyritic granodiorite are difficult to distinguish from the adjacent Illunie Volcanics. Accessory minerals include muscovite, apatite, opaque oxides, and zircon. Primary biotite is often recrystallised or altered to chlorite and muscovite, and sometimes epidote. Sericitisation of feldspars is variably weak to strong. Lesser fine-grained felsic granite and aplite phases of the Young Granodiorite in the Forbes 1:250 000 map sheet area are pink to white and composed of equigranular quartz and feldspars (~1 mm) with accessory biotite and muscovite. Less commonly, quartz phenocrysts up to 3 mm or 4 mm occur in the aplites.

The Young Granodiorite is generally weakly magnetic (magnetic susceptibility $<100 \times 10^{-5}$ SI). However, some more mafic phases range between $200 \times 10^{-5}$ SI and $1100 \times 10^{-5}$ SI, and the aplites are typically less than $20 \times 10^{-5}$ SI. A more highly magnetic part of the Young Granodiorite, interpreted from aeromagnetic data, occurs around the Broula Granite. It is not clear whether this region of higher magnetic susceptibility is related to the Young Granodiorite or if it is a subsurface expression of the more strongly magnetic Broula Granite or Warrangong Volcanics. The regional gamma ray spectrometric signature of the Young Granodiorite reflects moderate concentrations of K, U, and Th relative to other granitoids in the Forbes 1:250 000 map sheet area. The spectrometric signature is probably somewhat attenuated by a deep, but *in situ*, soil cover over much of the Young Granodiorite.

The Young Granodiorite has been intruded by numerous thin andesite to rhyodacite dykes. East and south of Greenthorpe, the dykes generally trend north–south, and form the northern extent of a major dyke swarm, which intruded much of the Young Granodiorite south of the Forbes 1:250 000 map sheet area. East of Bumbaldry, several andesite dykes occur in the granodiorite. These dykes trend northwest, parallel to faulting interpreted from aeromagnetic data and are possibly derived from the early Devonian Warrangong Volcanics.

*Geochemistry*

The Young Granodiorite is a typical S-type intrusion, as defined by White & Chappell (1983). The granodiorite is peraluminous (ASI consistently greater than 1.1), and has typically low Sr concentrations (100 ppm to 150 ppm). The granodiorite is an unfractionated and relatively reduced intrusion. Only minor aplitic phases show any signs of fractionation, such as low Ba or elevated Rb and U concentrations. Analyses of the granodiorite from the Forbes 1:250 000 map sheet area show that it is slightly more felsic than average, containing 70 wt% to 71 wt% $SiO_2$ compared to 68 wt% to 69 wt% $SiO_2$ for the batholith as a whole.

The chemical composition of the Young Granodiorite is very similar to volcanic rocks of the Early Silurian Douro Group and Cudal Group. These S-type volcanic rocks include the Illunie and Glenisla Volcanics in the Forbes 1:250 000 map sheet area and the Canowindra, Hawkins, and Laidlaw Volcanics in the Bathurst and Goulburn 1:250 000 map sheet areas. The Hawkins Volcanics and the Young Granodiorite are especially similar.

*Age and correlation*

A sample of the Young Granodiorite, taken 10 km west of Young, has recently been isotopically dated by the SHRIMP zircon U–Pb method (L.P. Black, pers. comm., 1999) at 428.8 ± 1.9 Ma (Early Silurian). Previously, recalculated K–Ar ages of 417 ± 6 Ma (Richards pers. comm. in Basden *et al.*, 1978) and 405 Ma (Pogson & Hilyard, 1981) were obtained from the granodiorite, but both of these most probably dated later thermal or deformational events.

The Young Granodiorite appears to have intruded the Illunie Volcanics, which contain late Wenlock age limestone lenses. This implies that the granodiorite is no older than late Wenlock (~426 Ma), and that although the zircon age is tightly constrained (428.8 ± 1.9 Ma), some degree of inheritance is reflected in the zircon U-Pb age. The similar age and composition of Young Granodiorite and Illunie Volcanics suggest they may have been comagmatic.

## **Bena Monzodiorite** (Sbm) *nov*

*Nomenclature, derivation, distribution, type locality and relations*

The Bena Monzodiorite is a newly recognised unit and is named after the locality Bena, 4 km southeast of its outcrop. The extent of outcrop, and type locality, is only about 200 m across on a hill at GR 510780 mE 6293150 mN, beside 'Miner Lea' homestead and farm buildings, about 20 km west-northwest of Burcher. The Bena Monzodiorite intruded the Clements Formation of the Wagga Group but the contact is not exposed.

*Description*

The Bena Monzodiorite is a medium-grained, speckled, grey to cream to pink, quartz monzodiorite. It is composed of plagioclase ($An_{55}$ to $An_{30}$), glomeroporphyritic or porphyritic biotite (10%), quartz (0.5 mm; 20%), and interstitial K-feldspar (2 mm; 15%) (Barron, 1998). Accessory minerals include magnetite, apatite, and zircon. Other components include more mafic monzodiorite xenoliths containing about 5% quartz and oikocrystic biotite. A low metamorphic grade, with only minor clinozoisite, chlorite, illite, sericite, and titanite, indicates that intrusion of the Bena Monzodiorite postdates the peak regional metamorphism, which is Early Silurian.

The Monzodiorite has low magnetic susceptibility ($15 \times 10^{-5}$ SI), similar to its country rock. Its outcrop extent is too small to give a gamma ray spectrometric response at the resolution of the airborne geophysical survey.

*Age*

The Bena Monzodiorite has not been isotopically dated. As it intruded the Ordovician Wagga Group after the Early Silurian peak regional metamorphism, a maximum age of Early Silurian is suggested. It can be inferred that its age is about mid–Early Silurian because a major magmatic event, including intrusion of the Ungarie Suite of granites, occurred in the region at that time.

## **Billys Lookout Granite** (Sbg) Bowman (1977a)

*Nomenclature and distribution*

Bowman (1977a) named Billys Lookout Granite after Billys Lookout hill. The granite is well exposed as massive, hill-forming outcrop, with a north–south trend, and rises about 130 m above the surrounding plain. The outcrop is about 6 km long and a kilometre wide.

Although the contacts with the country rock are not exposed, it is strongly inferred that the Billys Lookout Granite intruded the Burcher Greywacke and rocks of the Girilambone Group.

*Description*

The Billys Lookout Granite is a grey, generally coarse-grained, equigranular to seriate, felsic granite with quartz (~30%), K-feldspar (~30%), and sericite (~30%) as the dominant minerals. The sericite forms a very fine-grained groundmass produced during cataclasis and alteration. Fine-grained sodic plagioclase ($An_0$ to $An_{10}$) is a minor component. There are trace amounts of muscovite, fluorite, zircon, and iron oxides — all fine-grained. The magnetic susceptibility is very low, around $10 \times 10^{-5}$ SI, and on TMI or vertical derivative magnetic images the granite is indistinguishable from its country rocks. On RGB gamma ray spectrometric images, the granite shows high K count rates. Its distribution is exaggerated in the spectrometric images, as the apron of granitic colluvium, which covers the contact with the country rocks, has a similar spectrometric signature to the parent outcrop.

The Billys Lookout Granite is mildly deformed and displays cataclastic textures in outcrop and thin section. The most obvious manifestations are the fine-grained sericitised matrix and undulose extinction, sub-grain formation, and dynamic recrystallisation in quartz. Steeply dipping, anastomosing shear bands are developed, and indicated in outcrop by iron oxide-stained mica or possibly chlorite. The shear bands are generally not more than a centimetre wide, and trend northwest. A north–south-trending, steeply dipping, fracture set cuts the shear bands. If the fracture set defines the orientation of the $\sigma_1$–$\sigma_2$ plane during deformation then the sense of shear is dextral. The amount of shearing is unknown.

*Geochemistry*

The Billys Lookout Granite is an unoxidised (or possibly reduced), corundum-normative, S-type granite (74 wt% $SiO_2$). It has a $K_2O$ content (5.5 wt%), which may reflect a degree of potassium enrichment due to metasomatism.

*Age*

A late Early Silurian (Wenlock) age of 427 ± 2.2 Ma (L.P. Black, pers. comm., 1998) was obtained for the Billys Lookout Granite by the U–Pb SHRIMP zircon method.

# 6. LATE SILURIAN

## **Goonigal Group** (Sg) Pickett (1982)

The Goonigal Group is a Late Silurian (predominantly Pridoli) group of marine clastic sedimentary rocks, including chert, and andesitic volcanic rocks, which crop out mainly in the area of the Bathurst 1:250 000 map sheet area (Pogson & Watkins, 1998). The only representative of the Goonigal Group in the Forbes 1:250 000 map sheet area is the Moura Formation. In the absence of precise stratigraphic or fossil evidence, Raymond (*in* Pogson & Watkins, 1998) included the Moura Formation in the Goonigal Group, based on lithological similarity.

### **Moura Formation** (Sgm) Raymond (*in* Pogson & Watkins, 1998) after Powell *et al.* (1980)

*Nomenclature, distribution and boundary relationships*

The name Moura Formation was used by Raymond (*in* Pogson & Watkins, 1998) to formalise the term 'Moura Beds' used by Williams (1975) and Powell *et al.* (1980). The name is derived from the 'Moura', near Mount Boulton. The eastern part of the Moura Formation was first mapped by Healey (1961) and Castle (1965). Much of the Moura Formation was mapped as unnamed Early Devonian sedimentary rocks by Brunker (1972a) and Bowman (1976), although some was included in the Dulladerry Volcanics. In the main, the Moura Formation occupies two areas of low ground in the Mandagery and Bindogundra areas (Figure 6.1). Small isolated outcrops of the unit also occur adjacent to the Eugowra Granite and Milandra Granite, 8 km northwest and southwest of Eugowra, respectively.

In the Bindogundra area, about 15 km east of Parkes, most of the Moura Formation is covered by Cainozoic colluvium. The few outcrops show intrusion by the Bindogandri Granite and they are overlain by the Hervey Group. At its northern extremity, the Moura Formation is interpreted to unconformably overlie the Ordovician Kirribilli Formation beneath Cainozoic cover.

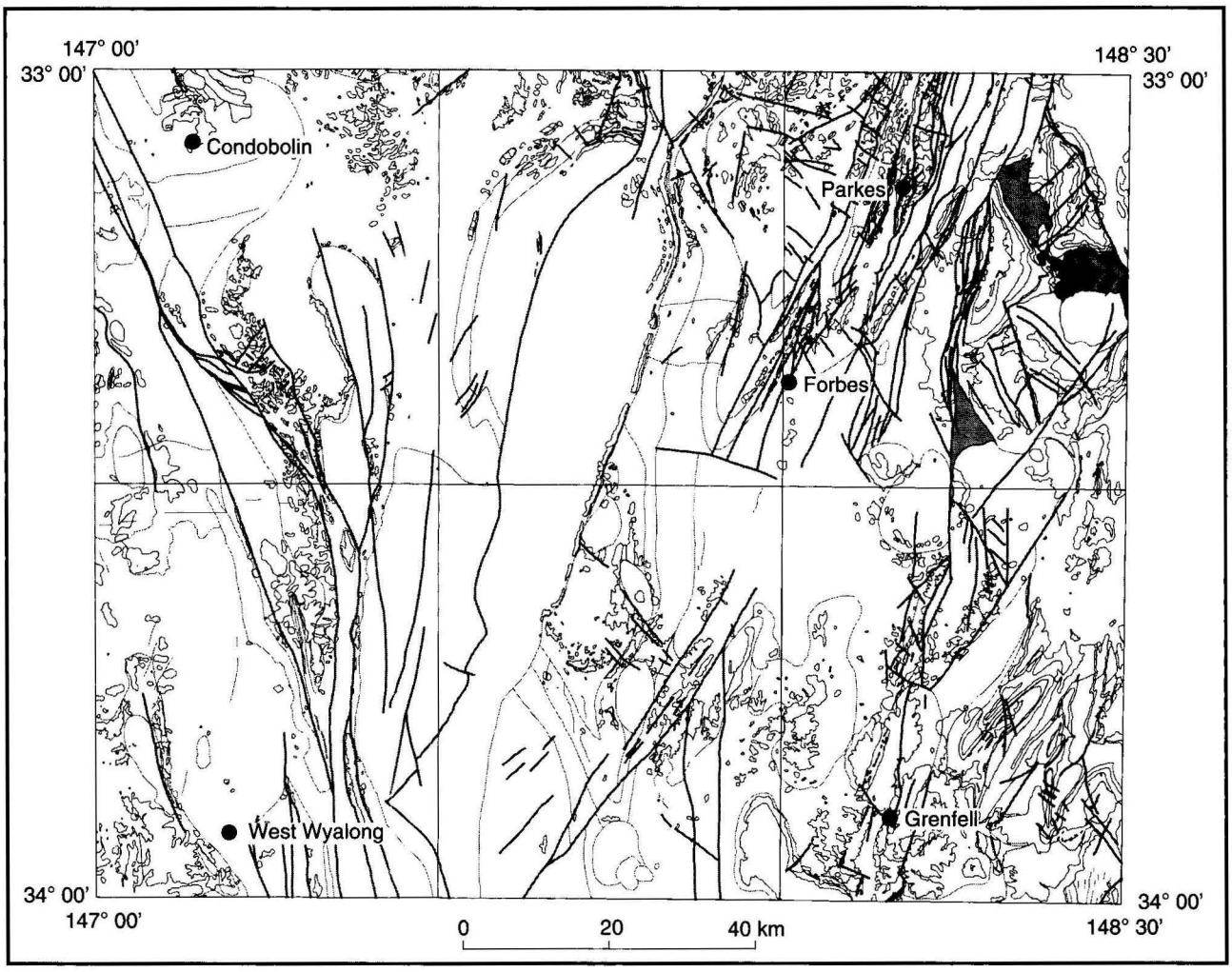



*Figure 6.1. Distribution of the Goonigal Group in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

In the Mandagery area, about 25 km southeast of Parkes, the Moura Formation is folded and was intruded, along its southern margin, by the Early Devonian Lords Granite and Eugowra Granite. It is unconformably overlain by the Late Devonian Hervey Group in the west and north, and is faulted against the Middle Devonian Dulladerry Volcanics in the east, along the Bumberry Fault. An unconformable relationship most probably existed between the Moura Formation and the younger Dulladerry Volcanics. The original unconformity is interpreted to have existed close to the present faulted contact, and little movement is inferred on the fault.

*Description*

The Moura Formation consists of thinly- to very thickly-bedded greywackes and quartzose sandstones, with interbedded shales, siltstones, and minor conglomerate. The sandstones are variably very fine- to very coarse-grained, grey to green, and have massive to graded internal stratification. The sedimentary rocks have generally angular grains, and sorting becomes poorer with increasing grainsize. The sandstones are predominantly feldspathic and lithic in composition. They commonly contain andesitic and felsic volcanic detritus, including plagioclase, quartz, hornblende, and clinopyroxene crystals, and abundant volcanic lithic fragments. Chlorite and epidote, developed during regional greenschist metamorphism, occur in many of the greywackes.

Quartzose sedimentary rocks also occur in the Moura Formation, and some quartzite occurs in the contact metamorphic aureoles of the Bindogandri and Eugowra Granites. Shales are grey to maroon and buff, and may have a penetrative foliation. The shales are often preferentially foliated where they are interbedded with the more competent sandstones (Figure 6.2). Small limestone clasts were observed in one sedimentary breccia just to the east of the Forbes 1:250 000 map sheet area. A conformable, quartz-phyric, flow-banded rhyolite occurs in the same area. It is unclear whether the rhyolite was a thin lava flow, or a sill derived from the younger, nearby Dulladerry Volcanics. Several thin discordant rhyolite dykes occur in the Moura Formation east of Mount Boulton.

The Moura Formation has a low magnetic susceptibilities, averaging $25 \times 10^{-5}$ SI. Horizons rich in volcanic detritus may rarely have magnetic susceptibilities up to $4000 \times 10^{-5}$ SI. The volcaniclastic units have moderate K and low U and Th gamma ray spectrometric count rates, resulting in a magenta colour in a composite RGB gamma ray spectrometric image.

*Age, correlation and depositional environment*

Only rare trace fossils have been found in the Moura Formation. The age of the formation is constrained only by the intrusive contact of the Early Devonian Eugowra Granite, and the interpreted unconformable contact with the Ordovician Kirribilli Formation. Its age is inferred to be Late Silurian (Pridoli), based on a lithological correlation with the Wansey Formation of the Goonigal Group, which crops out about 15 km to the east in the Bathurst 1:250 000 map sheet area. Both of these formations contain significant andesitic volcanic detritus.

The interbedded nature of the sandstones and shales, the presence of minor grading, and the abundance of volcanic detritus suggest that the Moura Formation was deposited in a flysch environment marginal to a volcanic rise. The generally angular nature of grains and preservation of hornblende and clinopyroxene in some greywackes suggests a proximal source.

*Figure 6.2. Interbedded greywackes and shales of the Moura Formation. A steeply dipping foliation is developed only in finer-grained layers. (GR 631670 mE 6322380 mN) (O.L. Raymond photograph)*

## Ungrouped Late Silurian Unit

### Unnamed quartz veins near Condobolin (Sqv)

*Distribution, type localities and relations*

Unnamed quartz veins are hosted in the Girilambone Group, near Condobolin, and contain mineralisation of the Condobolin gold-base metal district (Brunker, 1977; Downes & Burton in Lyons & Wallace, 1999). The veins are relatively undeformed, and postdate the Late-Ordovician–Early Silurian deformation and metamorphism of the Girilambone Group (Scott, 1999). The greatest concentration of veins is associated with an arcuate potassium anomaly in the Girilambone Group, north of Condobolin.

The nominated type localities are the Red Paint, Mascotte, and Julia Reubens mines around GR 511800 mE 6342600 mN.

Clasts of epithermal textured quartz, which are presumably derived from the quartz veins, occur in the basal part of the Manna Conglomerate (Figure 6.3). If these quartz clasts are so derived, the quartz veins must be older than the Late Silurian–Early Devonian Manna Conglomerate.

*Description*

Mineralised quartz veins in the Condobolin gold-base metal district display massive and banded textures, and

have an associated, arcuate, high K radiometric anomaly. The veins commonly strike northeast with a vertical to steep dip to the southeast. They have variable extent due to pinching and swelling along strike and at depth (Hammond, 1893; Jaquet, 1896), but are commonly less than a metre thick. They have been followed to a depth of 120 m in Potters mine (Milne, 1918).

Quartz textures are commonly massive and coloured milky-white, which suggest a mesothermal origin (Figure 6.4). However, banded vein quartz is locally abundant, which suggests an epithermal origin. Other epithermal quartz textures (Dong *et al.*, 1995), including colloform, crustiform, comb, zonal, cockade, and recrystallisation feathery and flamboyant textures are present in the veins at Condobolin, as well as boxwork gossan textures. On mine walls, and visible in mullock dumps, amethyst occurs in some colloform–crustiform banded veins. Quartz vein breccias hosting wallrock fragments are also important rock types hosting mineralisation (Figure 6.5).

*Figure 6.3. Crustiform-colloform banded quartz boulder from the base of the Manna Conglomerate, overlying Girilambone Group rocks north of Condobolin. (GR 511650 mE 6345800 mN) (O.L. Raymond photograph)*

Pyrite is the common sulphide, with galena, sphalerite, chalcopyrite, and bornite being of economic importance in the mines of the Condobolin gold-base metal district. Bismuth, arsenopyrite, and secondary minerals malachite, azurite, pyrolusite, cerussite, and anglesite were reported by Bowman (1977). Barron (1998) recognised limonite, jarosite, ?gummite, and ?corkite/beudantite in thin section. The sulphides occur in cavities between quartz crystal terminations, along with accessory magnetite, hematite, chlorite, calcite, illite, and sericite (Barron, 1998). Wallrock alteration is limited to narrow (<1m) zones of silicification adjacent to veins, despite extensive potassic zones showing on radiometric images.

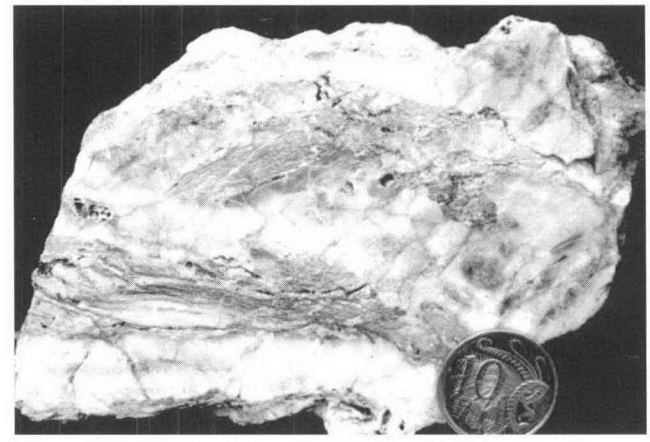


*Figure 6.4. Massive quartz vein rock from the Mascotte mine near Condobolin, containing fragments of Girilambone Group wallrock. (GR 512950 mE 634310 mN) (O.L. Raymond photograph)*

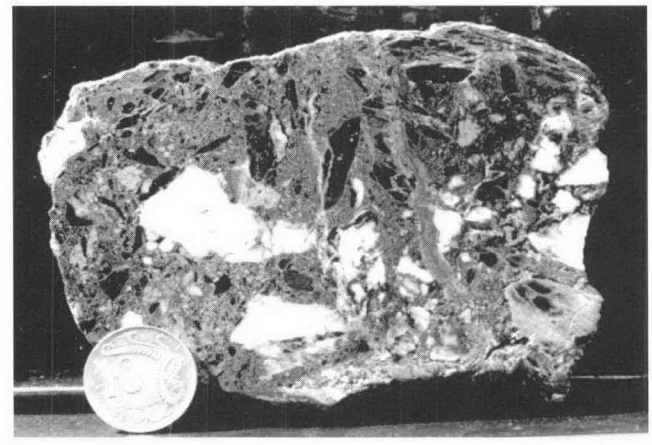


*Figure 6.5. Mineralised breccia containing pyrite, galena and fragments of massive vein quartz and chloritic wall rock, from the Mascotte mine near Condobolin. (GR 512950 mE 6343100 mN) (O.L. Raymond photograph)*

*Geochemistry*

Assays reveal the mineralised quartz veins carry anomalous levels of Au, Cu, Pb, Zn, Ag, As, and Bi.

*Age*

The age of the quartz veins is constrained to being younger than the Late Ordovician-Early Silurian deformation of the Girilambone Group, and older than the Siluro-Devonian Manna Conglomerate. Lead isotope ratios determined from quartz-sulphide veins from the Five Mile Hill prospect and Potters mine are similar to ratios from deposits hosted by the Cobar Supergroup (Dean, 1995), and give a Late Silurian Lachlan Fold Belt model age of approximately 420 Ma (Dean, 1995).

# 7. SILURO-DEVONIAN

## **Ootha Group** (S-Do) Raggatt (1937)

*Previous nomenclature*

The 'Ootha Series' was never formally defined other than by association with the Ootha district. Rose & Brunker (1969) changed the name to Ootha Group but applied the term to sedimentary and volcanic rocks in the Mineral Hill district, well north of both Ootha and the Forbes 1:250 000 map sheet area. Sherwin (1996) used 'Ootha Formation' to describe sedimentary and volcanic rocks in the Narromine 1:250 000 map sheet area, which appeared to be continuous with those at Ootha, but deferred any further changes in status until a re-examination of the strata at Ootha.

*Type locality*

The 'Ootha Series' of Raggatt (1937) implies a type locality around the village of Ootha where there are extensive, if poor, outcrops of sedimentary and volcanic rocks.

*Distribution and outcrop*

The Ootha Group is widespread to the west and southwest of Ootha but largely east of a meridional line through Condobolin (Figure 7.1). With the exception of the basal Manna Conglomerate, the outcrops are poor and mostly strongly cleaved.

*Constituent formations*

The Ootha Group contains the following units:

Mulguthrie Formation (S-Dom);

Yarnel Volcanics (S-Doy);

Yiddah Formation (S-Doh); and

Manna Conglomerate (S-Doa).

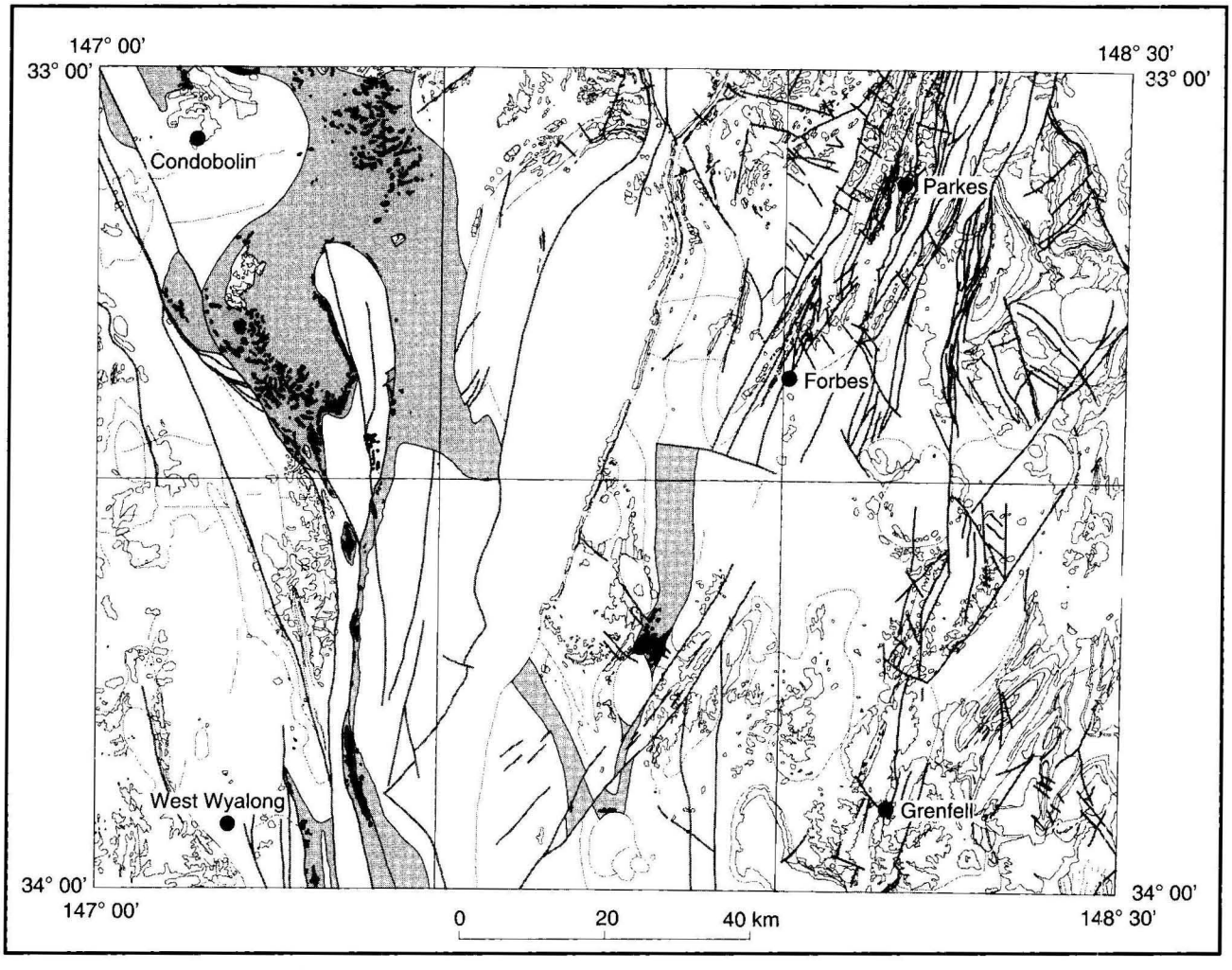



*Figure 7.1. Distribution of the Ootha Group in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

*Boundary relationships and age*

The Ootha Group, like the Derriwong Group, has few exposed basal contacts because of the thick cobble scree surrounding outcrops of the basal Manna Conglomerate. There is a marked angular unconformity with the underlying Ordovician Girilambone Group exposed at several localities north of Condobolin. South of Condobolin the Ootha Group is unconformably overlain by the Darbys Ridge Conglomerate (of the Yarra Yarra Creek Group). Few fossil localities are known from the Ootha Group, and even those few fossil occurrences do not necessarily indicate the total time span of the Ootha Group.

### **Manna Conglomerate** (S-Doa) Kemezys (1976); defined Stratigraphic Nomenclature Subcommittee, NSW (1978)

*Nomenclature, derivation and distribution*

This basal unit of the Ootha Group was named the 'Womboyne Conglomerate' by Brunker (1972a). However, as that name was preoccupied, Kemezys (1976) renamed it the Manna Conglomerate. Conolly (1965a) regarded the outcrops of conglomerate north of Condobolin as Late Devonian and placed them in the now-superseded 'Condobolin Formation' at the base of the Hervey Group. Before the Ootha Group was redefined and its constituent units removed from the Derriwong Group, the outcrops of Manna Conglomerate were regarded as part of the Edols Conglomerate of the Derriwong Group (Scott *in* Lyons & Wallace, 1999; p. 62).

The Manna Conglomerate crops out west and southwest of Ootha and is present in a south-southeast to north-northwest-trending corridor from the Booberoi Hills, which are cut by the Mid Western Highway at GR 530500 mE 6250400 mN, past Lake Cowal to the northern boundary of the sheet area, near Condobolin. This corridor is roughly co-incident with the Gilmore Fault Zone. South-east of Wirrinya, the Manna Conglomerate occurs as a thin (60 m to 100 m thick) conglomerate and sandstone unit, where it forms a low ridge between the relatively recessive Yiddah Formation and Kirribilli Formation.

The Manna Conglomerate generally forms prominent ridges and hills. The type locality at Manna Mountain (GR 531300 mE 6302700 mN) is one of the highest topographic points in the Forbes 1:250 000 map sheet area and stands almost 300 m above the surrounding plain. Because of the poor fertility and minimal soil cover, few of the more extensive outcrops have been cleared for agricultural purposes. Some of the less prominent outcrops, such as those north of Steels Lookout (GR 537900 mE 6294800 mN), consist largely of bouldery mounds in sandy soil.

*Thickness*

The thickness of the Manna Conglomerate is variable and it is likely that the conglomerate is not continuous. Exposures in road cuttings north of Condobolin show thicknesses of only a few metres. In the Mount Tilga area, the Manna Conglomerate attains a maximum thickness of approximately 100 m, with 39 m exposed below Tilga Trigonometrical Station (Raggatt, 1937). The apparent great thickness at Manna Mountain is caused by local folding, although a maximum thickness approaching 1000 m is likely, based upon outcrop width where the dip can be measured reliably (GR 533500 mE 6304350 mN).

*Description*

The Manna Conglomerate consists of very poorly sorted polymict conglomerate and sandstone. Clast types in the conglomerate include quartzite, shale, limestone, granite, and, possibly, mafic volcanic lithic fragments, and quartz and feldspar crystals. Clast size ranges from less than 1 mm up to 30 cm, and are, on average, larger than those of the Edols Conglomerate. The larger clasts, mainly quartzite, are typically very well rounded and the great majority exhibit medium to high sphericity. Angular clasts are common only in the outcrops north of Condobolin and, even there, only at or very near the contact with the underlying Girilambone Group, where fragments derived from the Girilambone Group and colloform quartz vein clasts occur. Sorting is generally poor, except in the finer-grained beds. Erosional bases to beds are common. Load structures may occur where conglomerate beds overlie sandstones.

North of Condobolin, in a cutting on the Cobar Road (GR 510820 mE 6348640 mN), a reddish purple, coarse-grained, lithic, close-packed, conglomeratic base grades upwards into a quartz pebble conglomerate, overlain in turn by a coarse brown grit containing abundant fossil debris dominated by crinoid ossicles. The cobbles and boulders tend to be close packed in most places where the base of the Manna Conglomerate is exposed but matrix support is common in higher beds where there is a gradual decrease in average grainsize.

The Manna Conglomerate is generally medium-bedded to very thick-bedded, as much as 3 m or 4 m where there is sufficient exposure (GR 530790 mE 6303580 mN), and internally massive. Some indication of bedding in less conglomeratic horizons is provided by localised pebble concentrations or imbrication of tabular clasts (GR 531420 mE 6303550 mN). The sandstone matrix is typically a medium- to coarse-grained, poorly sorted quartz-lithic sandstone, with a sparse clayey matrix. In addition to lithic grains, of the same rock types as the cobbles, there are minor amounts of perthite, muscovite, tourmaline, magnetite, apatite, zircon, rutile, and magnetite.

The gamma ray spectrometric signature of the line of outcrop south of the Lachlan River differs from the other outcrops of either Manna Conglomerate or Edols Conglomerate in having a high K content at the base. The most intense part of the anomaly, south of Manna Mountain at Kerribrew Ridge (GR 529300 mE 6299000 mN), is associated with an unusually arkosic part of the Manna Conglomerate, which has a superficial resemblance to granite, possibly derived from underlying, but unexposed

volcanic rocks. The coarse-grained ferruginous sandstones at Bogeys Island (GR 537600 mE 6289900 mN) contain what appear to be flattened pumice shards and a population of broken zircon grains yielding a minimum age of 452.2 ± 2.0 Ma (L.P. Black, pers. comm., 1998), which suggests that the volcanic input was from rocks not younger than Late Ordovician.

South of Manna Mountain the Manna Conglomerate has a strong shear fabric where it has been caught up in the Booberoi Shear Zone (Ingpen, 1995), although there are some undeformed parts, as the strain was partitioned (Figure 7.2). The clasts are notably elongated and the matrix has changed to a fine-grained quartz–mica (mainly white mica and chlorite) foliation. The sense of movement is clearly visible in outcrop: west side up in the Booberoi Hills; and sinistral near Nerang Cowal (GR 532030 mE 6290960 mN). Away from the Booberoi Shear Zone, deformation is confined to one period of folding, and later brittle faulting, with dips no more than about 50° about north- to northwest-trending fold hinges. In finer-grained rocks, such as sandstones, an upright, meridional, spaced cleavage ($S_1$) is developed. In thin section it is a weak, anastomosing foliation defined by very fine-grained micas and a preferred orientation of quartz and lithic grains.

*Figure 7.2. Quartzite pebble in sheared Manna Conglomerate in the Booberoi Shear Zone showing asymetrical tails indicating sinistral movement. The pencil points due north. (GR 532030 mE 6290960 mN) (P. Lyons photograph)*

*Environment of deposition*

The Manna Conglomerate was probably laid down in a deepwater basin where sediments of the Muguthrie Formation and Yiddah Formation were being deposited, and attained a greater thickness than the Edols Conglomerate. Only north of Condobolin does the Manna Conglomerate exhibit any features diagnostic of shallow conditions, including reasonably intact corals. It is possible that extensive longitudinal faults in the Condobolin–Wyalong district provided the escarpments that would be a source for the conglomerates.

*Boundary relationships and age*

As the basal unit of the Ootha Group, the Manna Conglomerate does not differ significantly from the Edols Conglomerate of the Derriwong Group, both being basal conglomerates containing debris eroded from a Girilambone Group terrain. The Manna Conglomerate unconformably overlies the Ordovician Girilambone Group and Kirribilli Formation, and the Silurian Ina Volcanics. Raggatt (1937) described the unconformity at the base of the unit at Mount Tilga (GR 512600 mE 6345700 mN), where he recognised angular discordance and metamorphic grade changes across the contact between the Manna Conglomerate and the Girilambone Group. The unconformity is also exposed west of Gulgo Trigonometrical Station (GR 500100 mE 6345200 mN), and in roadbase quarries at GR 511650 mE 6346960 mN and GR 511650 mE 6345800 mN.

On the Cobar Road there are reasonably clear scraped surfaces on some crests (e.g., GR 510820 mE 6348640 mN) where it is possible to see the conglomerate, here at its thinnest, grade up into fine lithic sands at the base of the overlying Mulguthrie Formation in a space of less than 25 m. The K-rich base of the conglomerate outcrops south of the Lachlan River, indicated by a gamma ray spectrometric anomaly, may indicate erosion of the underlying Ordovician shoshonitic volcanic rocks of the Lake Cowal Volcanic Complex, although no contacts are exposed.

Higher in its sequence, in contrast to the Edols Conglomerate, the Manna Conglomerate is interbedded with the overlying deepwater Mulguthrie Formation. The conglomerate forming the prominent Berewombenia Hill (GR 537300 mE 6335500 mN), just west of Ootha, exhibits features consistent with the Manna Conglomerate. Field inspection shows that it is two superimposed conglomerate lenses, wholly within the Mulguthrie Formation and not a basal conglomerate. The comparatively narrow width of these lenses suggests a late erosion of the source area providing channel fills rather than a conglomerate blanket as elsewhere. Isolated conglomerate outcrops several kilometres west of Manna Mountain, which on trends appear to be within, rather than at the base of the Mulguthrie Formation, may also represent later, more restricted deposition.

The Manna Conglomerate is conformably overlain by the Yiddah Formation or may be, in part, laterally equivalent to that unit. However, the contact with the overlying Yarnel Volcanics is not exposed.

In many places, the Manna Conglomerate is unconformably overlain by Cainozoic alluvium, and Quaternary colluvium around hilly outcrops. Interpreted faults of the Gilmore Fault Zone are inferred to offset the unit against Ordovician ultramafic rocks west of Blue Ridge (GR 511300 mE 6316000 mN).

Fossils, including the brachiopod *Retziella* (formerly *Molongia*) and the coral *Mucophyllum*, in the upper part of the Manna Conglomerate, north of Condobolin, indicate a Late Silurian to Early Devonian age (Sherwin, 1981). Broken crinoid stems and disarticulated brachiopods occur

in sandstones just above the basal unconformity at GR 511700 mE 6347700 mN (*cf.* Brooke, 1980).

## **Yarnel Volcanics** (S-Doy) *nov*

*Previous nomenclature*

Although previous authors have recorded rhyolitic volcanic rocks in the Ootha Group (Raggatt, 1937; Kemezys, 1976; Sherwin, 1996), those units have never been differentiated as a separate named unit. The Bogandillon Chert Member in the Weelah Formation of Kemezys (1976) is a rhyolitic vitric tuff within the Yarnel Volcanics. It is recommended that the name Bogandillon Chert Member name be retained in the event that a more refined subdivision of the Yarnel Volcanics becomes possible.

*Distribution, outcrop and type localities*

In common with the closely associated Mulguthrie Formation, the outcrops of Yarnel Volcanics are distributed around Ootha and to the west of Manna Mountain, although they occur more sporadically. The volcanic rocks are typically aphanitic to glassy rhyolitic vitric tuffs, with fine-grained spherulites (Figure 7.3). North of Ootha, they are crystal-rich and interbedded with sandstones. A hill (GR 528820 mE 6333000 mN), 12 km west-southwest of Ootha, is an isolated outcrop of volcanic sandstone The outcrops of the tuff are very blocky, tending to resist the regional cleavage, and form slightly more prominent rises than the surrounding Mulguthrie Formation.

*Figure 7.3. Fine grained spherulites developed in a glassy, rhyolitic vitric ash tuff of the Yarnel Volcanics. (GR 522340 mE 6315050 mN) (O.L. Raymond photograph)*

A lack of outcrop precludes the construction of a type section. The best exposures of the tuff serve as type localities. They are on the Condobolin–Burcher road (GR 522350 mE 6315050 mN), on the western side of Bogandillon Swamp, and on the hill (GR 541100 mE 6334730 mN) immediately to the south of Ootha railway siding. The 'Bogandillon Member' is well-exposed where it crops out (GR 525060 mE 6308660 mN) beside the Condobolin–Burcher. The felsic volcaniclastic sandstone is best exposed along the ridge north of Murda State Forest (GR 518100 mE 6348300 mN).

*Description*

The Yarnel Volcanics are aphanitic and crystal tuffs. The former are typically aphanitic to glassy rhyolitic vitric ash tuffs, commonly with fine-grained spherulites (Figure 7.3). The fresh tuff is dark grey to black, and develops a dull white weathering rind. The aphanitic texture has a superficial resemblance to chert. Where the rhyolite has been cleaved, the weathered material is very difficult to differentiate from the associated Mulguthrie Formation. The vitric rhyolitic tuff contains minor (<5%) quartz and feldspar phenocrysts (<1 mm) in a groundmass of unwelded shards, compacted pumice, and accessory magnetite, apatite and zircon. The compaction-bedded, medial, vitric rhyolitic tuff is autosilicified and contains minor quartz and feldspar, unwelded shards, compacted pumice, and accessory magnetite, apatite and zircon, with ankerite spots and traces of sericite.

The crystal tuff in the Yarnel Volcanics contains crystals of quartz and feldspar chips, and zircon. Shards and sparse ?pumice fragments form a compaction banding. Some 40% to 45% of a representative sample stained positive for potassium, which is strong in some feldspar phenocrysts and in the matrix. Its associated sandstone contains sorted subangular ?volcanic quartz, with accessory tourmaline, biotite, muscovite, magnetite, apatite, zircon and rutile.

Deformation and very low-grade metamorphism have produced a vague quartz–sericite cleavage, with stars of bladed ankerite, patchy calcite, brown clay, trace rutile/brookite, pyrite and chlorite, and multiple quartz veinlets.

The Yarnel Volcanics have very low magnetic susceptibilities ($5 \times 10^{-5}$ SI to $30 \times 10^{-5}$ SI) but show high K and Th count rates on gamma ray spectrometric images.

*Geochemistry*

The Yarnel Volcanics consist of highly siliceous (76.4 wt% to 80 wt% $SiO_2$), normal to high-K rhyolites. At least the two most siliceous of the five samples analysed are probably silicified and have not been considered in analysis of the geochemical data. Although categorising such siliceous rocks is difficult, the rhyolites are most probably I-type, having ASI values not greater than 1.04. They are also highly oxidised and are unfractionated. There is a weak fractionation trend in Ba, but not in the Rb/Sr ratio.

*Thickness*

Despite the lack of type a section, the measurable outcrops indicate remaining thicknesses between 200 m and 400 m.

*Environment of deposition*

The lateral extent of the Yarnel Volcanics, and their pumice and shard content, suggest that they are pyroclastic deposits derived from explosive fragmentation of vesiculating magma. Identifiable layering in the tuff shows it is probably conformable with the Mulguthrie Formation and the two are probably interbedded. Rare lithic fragments suggest there has been minimal epiclastic reworking of the volcanic detritus in the Condobolin–Burcher area. A

fragment of a brachiopod found in the volcanic sandstone (at GR 528820 mE 6333000 mN) could indicate a near-shore marine environment.

*Boundary relationships and age*

No contacts between the Yarnel Volcanics and the surrounding Mulguthrie Formation have been observed, although interbedding may be inferred (see above). If so, it implies that the Yarnel Volcanics are also Late Silurian–Early Devonian.

Where outcrop allows stratigraphic relationships to be determined, the Yarnel Volcanics conformably overlie the Manna Conglomerate. Cainozoic alluvial cover north of the Murda State Forest makes it uncertain whether the Yarnel Volcanics overlie Manna Conglomerate or lie directly on Girilambone Group rocks. The unit overlying the Yarnel Volcanics is not exposed in this area, although elsewhere in the Forbes 1:250 000 map sheet area they are overlain by the Mulguthrie Formation, and an equivalent unit in the Narromine 1:250 000 map sheet area (Sherwin, 1996). Outcrop of the Yarnel Volcanics is limited by unconformably overlying Cainozoic alluvium, and by a fault trending north-northwest at GR 511000 mE 6348000 mN.

## **Yiddah Formation** (S-Doh) Warren *et al.* (1995)

*Distribution, type locality and nomenclature*

Outcrops of the Yiddah Formation extend north from the Cootamundra 1:250 000 map sheet area (Warren *et al.*, 1995) to an area southeast of Wyalong. The unit crops out strongly along the line of hills that include Narragudgil Trigonometrical Station, south of Yiddah Creek, but only poorly and sporadically further north. A further area of outcrop now assigned to the Yiddah Formation is located immediately east and south of Wirrinya in the central part of the Forbes 1:250 000 map sheet area.

Well-bedded siltstones, with lesser fine-grained sandstone and shale, crop out well in the area around and south of Wirrinya (GR 575000 mE 6274000 mN). Similar rocks occur in isolated outcrops about 6 km south of Caragabal (GR 570000 mE 6248500 mN). They occur along strike from sedimentary rocks of the Derriwong Group to the north, near the Lachlan River, and appear to be the same age. However, the rocks at Wirrinya are interpreted to have been deposited in a deepwater environment, and are included in the Yiddah Formation of the Ootha Group, which represents the deepwater facies equivalent of the Derriwong Group. These sedimentary rocks at Wirrinya occur at least 50 km from the nearest outcrops of similar rocks. However, they are very similar to other fine-grained rocks of the Ootha Group, which occur about 50 km to the southwest (Yiddah Formation) and 70 km to the northwest (Mulguthrie Formation).

Type localities for the Yiddah Formation have been given by Warren *et al.* (1995). A representative locality on the Forbes 1:250 000 map sheet area is the roadbase quarry immediately east of Narragudgil Trigonometrical Station (GR 530050 mE 6238840 mN).

The Yiddah Formation was first named and defined by Warren *et al.* (1995) as a large area of previously unnamed and undifferentiated sedimentary and minor volcanic rocks in the northern part of the Cootamundra 1:250 000 map sheet area. It is considered to be the northern equivalent of the Combaning Formation in the southern part of the Cootamundra 1:250 000 map sheet area. The name is for the locality of Yiddah (Cootamundra 1:250 000 map sheet area GR 529400 mE 6233600 mN).

*Description*

In the area east of Wyalong, the Yiddah Formation typically consists of well-sorted fine- to medium-grained quartz-rich sandstone or lithic quartz sandstone and some siltstone with pebbly sandstone and conglomerate lenses. A coarse conglomerate horizon within the unit occurs on a low hill (GR 525860 mE 6253560 mN) 10 km northeast of West Wyalong. No evidence has been found in the Forbes 1:250 000 map sheet area for occurrences of acid volcanic rocks within the unit as described by Warren *et al.* (1995) in the Cootamundra 1:250 000 map sheet area. The sandstones may be purplish when fresh but are often bleached white. Near Wirrinya, the Yiddah Formation consists predominantly of weakly to moderately foliated, laminated to thick-bedded siltstone and lesser fine-grained sandstone and shale. They range from pale grey and buff to maroon. Very minor, small-scale cross-bedding is preserved and trace erosional bases to sandstone beds have been reported (P. Lennox, pers. comm., 1999). The smooth, rounded weathering faces of the siltstone outcrops are also similar to the Mulguthrie Formation and Yiddah Formation in their type areas.

Foliation in the Yiddah Formation is generally parallel or subparallel to bedding. Both bedding and foliation have steep to vertical dips, and strike northeast–southwest, parallel to the Parkes Fault Zone, which is about 2 km to the east of the base of the Yiddah Formation. Evidence for both east- and west-directed younging can be observed (rarely) in cross-bedding. Although no fold closures or shallow-dipping beds have been observed, the younging evidence suggests isoclinal folding.

Near Wirrinya, parts of the Yiddah Formation occur in the contact metamorphic aureoles of two unexposed granites, the Wirrinya Granite, 5 km south of Wirrinya, and the Berendebba Granite, about 6 km south of Caragabal. Andalusite spotting occurs in siltstones up to 750 m from the inferred contact of the Wirrinya Granite. A quartz–andalusite hornfels is developed in a sandstone 250 m from the inferred Wirrinya Granite contact, at GR 575020 mE 6268740 mN. South of Caragabal, exposures of well-bedded siltstones grade into strongly andalusite-spotted slates over about 200 m, adjacent to the inferred contact with the Berendebba Granite (Figure 7.4).

*Figure 7.4. Strong andalusite spotting of fine-grained sedimentary rocks of the Yiddah Formation in the contact aureole of the Berendebba Granite. (GR 570230 mE 6247900 mN) (O.L. Raymond photograph)*

*Environment of deposition*

The Yiddah Formation is laterally equivalent to the Cookeys Plains Formation, around Bogan Gate, but it does not contain the limestone lenses and shallow-water fossil fauna of the latter. This suggests a facies change from a shallow-water environment around Bogan Gate to a deeper water environment, similar to the transition from Cookeys Plains Formation to the deeper-water Mulguthrie Formation west of Bogan Gate (Warren *et al.*, 1995).

*Boundary relationships and age*

The Yiddah Formation, near Wirrinya, conformably overlies a conglomerate unit, interpreted to be the Manna Conglomerate, containing Siluro-Devonian conodonts. East of Wyalong, the boundary relationship is not exposed but is interpreted to be an east-dipping unit overlying the Manna Conglomerate, and to be faulted against the Narragudgil Volcanics and Bland Diorite.

Sherwin (1973a) described Late Silurian to Early Devonian fossils from rocks now mapped as Yiddah Formation at a locality, 10 km northeast of Wyalong (GR 525800 mE 6253700 mN. More recently, he also described fossils of a similar age from a locality in the Cootamundra 1:250 000 sheet area (Sherwin (1993a).

## **Mulguthrie Formation** (S-Dom) *nov*

*Type locality*

The Mulguthrie Formation is named after the Parish of Mulguthrie, a few kilometres south of Ootha. As well as being close to Ootha, the inferred type area for the 'Ootha Series' of Raggatt (1937), this area has good quarry exposures and probably the best preserved fossils in the Mulguthrie Formation.

*Previous nomenclature*

The Mulguthrie Formation was previously an undifferentiated unit within the 'Ootha Formation' (Sherwin, 1996). The outcrops northwest of Manna Mountain were called the 'Weelah Formation' by Kemezys (1976), who remarked upon their similarity to the "Ootha Beds east of Condobolin". However, the type locality for the 'Weelah Formation' is comparatively structurally complex and has not been reliably dated. It possibly includes fault slices of otherwise unrelated formations. For these reasons, the name 'Weelah Formation' is no longer used.

*Distribution and outcrop*

Interbedded mudstones, siltstones, and fine-grained sandstones of the Mulguthrie Formation are widely distributed around Ootha, between the Lachlan River and the northern boundary of the Forbes 1:250 000 map sheet area. There is a comparable area of outcrop to the northwest of Manna Mountain. The outcrops are everywhere poor, and associated with low rolling hills. Useful natural exposures are very rare and the Mulguthrie Formation can only be studied effectively in quarries and road gutters. The mapped distribution of the unit is based, in part, upon the use of gamma ray spectrometric images. The best exposures are in the western part of Ootha rubbish tip, the deepest part of the pit being in a rather structureless mass of altered sedimentary and probable volcanic rocks. There is a variety of the sedimentary rock types exposed in a quarry (GR 537500 mE 6327900 mN) near Mulguthrie station.

*Description*

The Mulguthrie Formation consists of interbedded mudstone, siltstone and fine-grained sandstone, olive-grey when fresh, weathering to reddish or yellowish brown. Both areas of significant outcrop (i.e., Ootha and Manna Mountain) have a well-developed penetrative cleavage, which, in weathered fine-grained rocks, can obscure the bedding. Even the sandstone units cannot be traced for any significant distance, so the overall structure of the Mulguthrie Formation is quite unclear.

The cleavage in the Mulguthrie Formation also obscures the bedding and masks fine internal sedimentary structures, such as laminae. The sandstone beds vary in thickness from 10 cm to 100 cm, and in some road gutters (e.g., GR 534810 mE 6342450 mN) exhibit both graded and massive bedding. In massive, medium-grained sandstones (GR 531830 mE 6341010 mN) the muddy quartz lithic detritus is typically well-sorted and consists of subangular clasts of quartz, crenulated meta-pelites, and minor quantities of muscovite, magnetite, tourmaline, apatite, zircon, and rutile. There is minor white mica defining the cleavage. At some localities (e.g., GR 540900 mE 6337300 mN) the detritus includes slump-disrupted lenticles/pellets of mudstone and siltstone.

*Thickness*

Because of complexities of deformation, no reliable estimates of thickness are available for the Mulguthrie Formation. If the dips north of Ootha, generally in the range of 60° to 80°, are consistent for more than a few kilometres, the measurement across strike indicates a minimum thickness of 1500 m. Kemezys (1976) reported a

thickness of 10 000 m for the succession west of Manna Mountain, based on the assumption that the rocks there have a uniform dip to the west and represent a single formation. Recent mapping has demonstrated that this succession includes at least one major fold and has almost certainly been disrupted by strike faults.

*Environment of deposition*

The Mulguthrie Formation probably represents a deeper environment than its time equivalent unit to the east, the Cookeys Plains Formation. There are no indicators of shallow-water sedimentation, with the possible exception of the corals north of Condobolin at the very base of the Mulguthrie Formation. The graded bedding and slumped mass-flow conglomerates, of the type at Berewombenia Hill (GR 537350 mE 6335500 mN), are consistent with a deep marine environment. The deepwater environment of the Mulguthrie Formation is also thought to be represented by the Yiddah Formation, which crops out around 50 km to the south of the southern limit of the Mulguthrie Formation.

*Boundary relationships and age*

In a road cutting (GR 510800 mE 6348700 mN) north of Condobolin, there is a conformable transition within a few metres from the Manna Conglomerate into the overlying lithic sandstone of the Mulguthrie Formation. The relationship of the associated Yarnel Volcanics is uncertain, but could be both interbedded and intrusive. Volcanic rocks appear to occur at several horizons within the Mulguthrie Formation. There is no sign of a gradational boundary with the overlying Yarra Yarra Creek Group at Mulguthrie Mountain, where there is an abrupt change from cleaved mudstones of the Mulguthrie Formation to coarse lithic quartz sandstone of the Yarra Yarra Creek Group. The contact is exposed in a small gully (GR 541300 mE 6326000 mN), although for the sake of clarity the extent of the exposure is somewhat exaggerated on the geological map.

The presence of the brachiopod *Notanoplia* cf. *pherista*, at several localities within the Mulguthrie Formation, indicates a Late Silurian, or more likely, very Early Devonian age (Sherwin, 1981; 1992).

## **Derriwong Group** (S-Dd) Mulholland (1940), modified by Sherwin (1996)

*Previous nomenclature*

Sherwin (1980a; 1996) subdivided the Derriwong Group into several formations, including the 'Ootha Formation'. The latter was deposited in a somewhat deeper-water environment than the remaining Derriwong Group units and is now separated as the Ootha Group (these Notes). The subdivision of the Derriwong Group used by Sherwin (1996) for the Trundle district, in the Narromine 1:250 000 map sheet area, can be applied to the area immediately south from Botfields (at the northern boundary of the Forbes 1:250 000 map sheet are), to Forbes.

*Constituent formations*

In the Forbes 1:250 000 map sheet area (Figure 7.5), five formations have been mapped within the Derriwong Group

Yarrabandai Formation (S-Ddy)

Cookeys Plains Formation (S-Ddp, S-Ddpl, S-Ddps)

Byong Volcanics (includes former 'Milpose Volcanics') (S-Ddb)

Calarie Sandstone (S-Ddc, S-Ddcs)

Edols Conglomerate (S-Dde)

*Boundary relationships and age*

Wherever the base of the Derriwong Group can be observed, it rests unconformably on older units. The group is overlain, with at least a minor disconformity, by the Early Devonian Trundle Group. The Derriwong Group is laterally equivalent to the Ootha Group, with an inferred facies change from a predominantly shallow marine setting to a deep marine environment.

Fossils within the Derriwong Group indicate an age range from Pridoli, possibly as early as Ludlow (Late Silurian), to Lochkovian (early Early Devonian).

### **Edols Conglomerate** (S-Dde) Brunker (1972a)

*Previous nomenclature*

Brunker (1972a) named the Edols Conglomerate the 'Edols Sandstone', with Edols Trigonometrical Station (GR 557250 mE 6344200 mN) in the Black Range as the implied type locality — but he did not provide any description other than that in the map legend. Sherwin (1996) changed the name to Edols Conglomerate, reflecting the dominant lithology.

The Edols Conglomerate does not differ significantly from the Manna Conglomerate to the west, outcrops of the latter having been detached because they mark the base of the Ootha Group. In applying this new restricted definition of Edols Conglomerate, the outcrops at Derriwong Hill (Sherwin, 1996), which just extend into the northern margin of the Forbes 1:250 000 map sheet area, are now assigned to the Manna Conglomerate. Some very isolated outcrops, such as that in the Lachlan River alluvial plain 42 km west-southwest of Forbes (GR 552980 mE 6293360 mN), could be assigned to either the Edols Conglomerate or Manna Conglomerate in the absence of any definitive overlying sedimentary rocks of the Mulguthrie Formation or Cookeys Plains Formation, respectively.

*Type locality, distribution and outcrop*

The Edols Conglomerate forms prominent hills to the northwest of Bogan Gate, the most prominent being the Black Range type locality where the Edols Trigonometrical Station is almost 200 m above the surrounding plains. The patchy distribution of these outcrops is believed to reflect, at least in part, lateral discontinuity of the conglomerate beds, some outcrops having a distinctly lenticular profile.

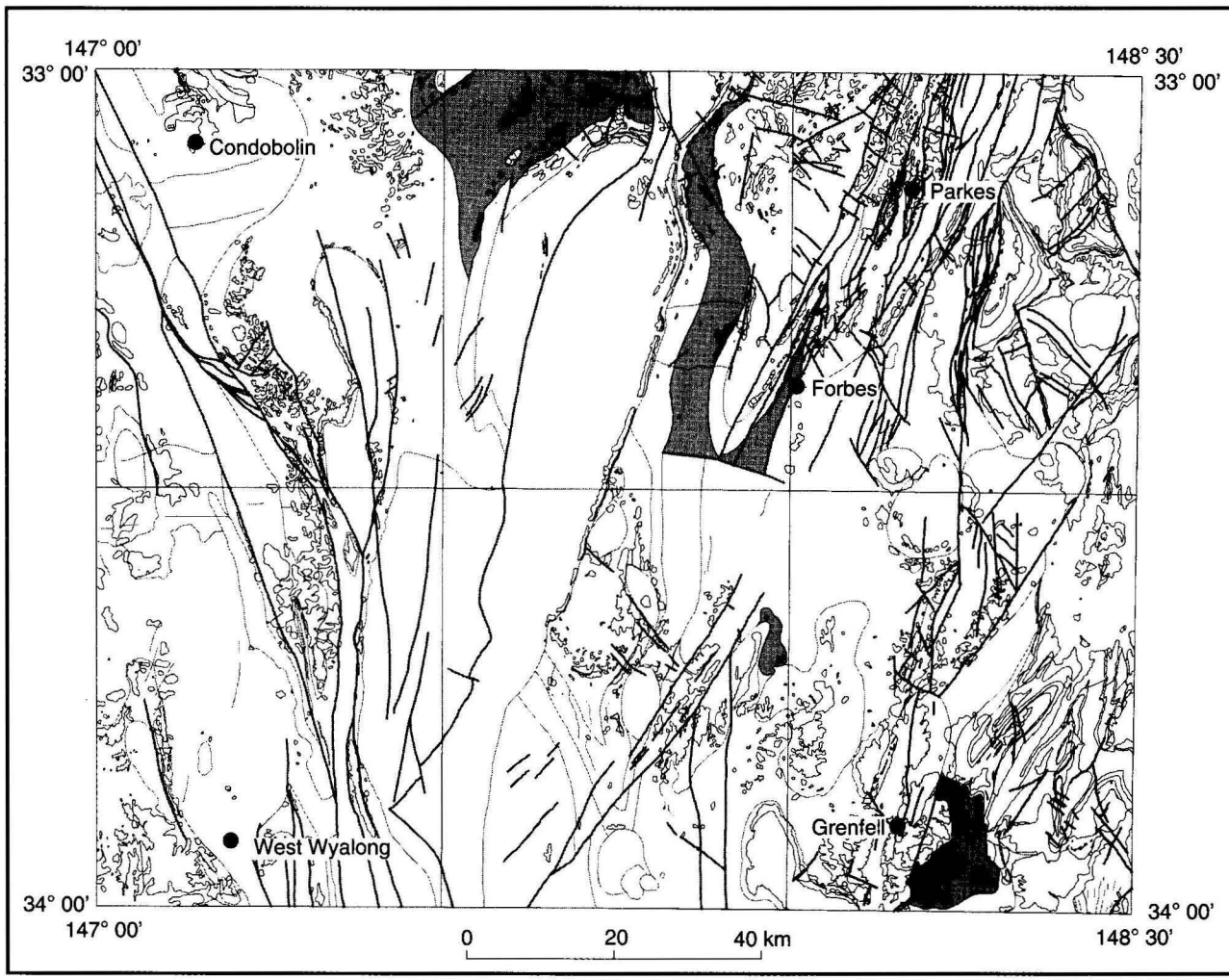



*Figure 7.5. Distribution of the Derriwong Group in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

The Black Range has an escarpment formed by almost horizontal strata on its western margin. The gently dipping eastern slope is the exhumed bedding surface. Other outcrops, such as that at Kars Trigonometrical Station (GR 545050 mE 6345200 mN), are surrounded by a thick scree of cobbles and pebbles, released by weathering, with comparatively little solid outcrop exposed.

The best outcrops of the Edols Conglomerate are in the Black Range where there are several access roads. Because the ridges are very stony and infertile, they tend to remain uncleared. Ironbarks are among the more common trees growing on the associated sandy, pebbly soil.

*Description*

The Edols Conglomerate consists almost wholly of interbedded cobble to pebble conglomerate and sandstone. Some gravel quarries (e.g., GR 552980 mE 6293360 mN) expose thick beds, about 2 to 3 m, of an underlying massive to indistinctly bedded, reddish purple to pale purple mudstone with abundant marine fossils. Blocks of this mudstone disintegrate within a few years of being exposed, so that natural outcrops of it are unlikely. The conglomerate has a very sharp ?erosional boundary with the underlying mudstone.

At the type locality the Edols Conglomeratic beds are massive, some being over 3 m thick. The cobbles are essentially supported by the medium-grained sandy matrix but, locally, the cobbles are sometimes closely packed. At some localities, such as that about 200 m east-northeast of Kars Trigonometrical Station (GR 545020 mE 6345200 mN), bedding is somewhat indistinct and suggested by variation in pebble size and packing, as well as imbrication of ovoid clasts. The pebbles include vein quartz, chert, and quartzite, the proportions varying according to the local basement rocks, usually the Girilambone Group. Some cobbles are as much as 22 cm in diameter but most are less than 15 cm. All cobbles are well-rounded but smaller quartz pebbles in the 1 cm to 5 cm range may be angular to subangular.

The medium-grained sandstone matrix of the Edols Conglomerate varies from off-white to reddish brown, although in some localities (e.g., gravel pits at GR 549620 mE 6346300 mN) it is quite reddish. The deeper (reddish) colour is believed to represent derivation from a reddish source rock rather than diagenetic oxidation.

Many of the older volcanic rocks and ultramafic intrusions weather to very ferruginous deep red soils.

Where the sandstone of the Edols Conglomerate does not contain any pebbles or coarser material it can be bedded in layers as thin as 5 cm (GR 549620 mE 6346300 mN), but otherwise it is internally structureless. In thin section, the more thinly-bedded sandstone shows better sorting (T64724, GR 549620 mE 6346300 mN) than coarser, more thickly-bedded sandstone (T65651, GR 545050 mE 6345180 mN). The latter is poorly sorted, with subangular grains of quartz and feldspar, and with fragments of veined mudstone, quartzite, chert, and crenulated phyllite. Other detrital minerals include tourmaline, magnetite, muscovite, zircon, apatite, and rutile. The grains show deformation by compaction, with minor recrystallisation and new growth of sericite and quartz. Some fractures have been healed by limonite after pyrite.

*Thickness*

The maximum thickness for the Edols Conglomerate is at the type area in the Black Range where the Conglomerate is almost flat-lying. The thickness there is, thus, at least as much as the topographic relief, which at Edols Trigonometrical Station is almost 200 m.

*Environment of deposition*

The coarse-grained and well-rounded cobbles in the conglomerate indicate rapid erosion of the source terrain, possibly even from a fault escarpment. The coarser parts of the conglomerate appear fluvial, especially the imbricated ovoid cobbles. However, the generally poor sorting is more characteristic of mass-flow deposits, and a marine environment is indicated by brachiopods and trilobites in the rare outcrops of the underlying interbedded mudstone. The abrupt boundary between the mudstone and overlying conglomerate indicates some quiescent periods between rapidly emplaced mass flows.

*Boundary relationships and age*

The thick pebble scree surrounding outcrops of the Edols Conglomerate tends to conceal the underlying formation. The thick conglomerate implies rapid erosion of older strata and the clast types suggest derivation from the Girilambone Group. The Edols Conglomerate is conformably overlain by thinly bedded siltstone of the Cookeys Plains Formation. East of Black Range there is an outcrop gap of nearly 600 m but the local dip is so slight that very little of the actual section is missing. The Edols Conglomerate is laterally equivalent to the Calarie Sandstone, which forms the base of the Derriwong Group east of Bogan Gate.

Fossils are not known to occur within the conglomerate beds, nor is it likely that many fossils would be preserved in what was undoubtedly a high energy, grinding environment. The underlying mudstone in the quarry at GR 552980 mE 6293360 mN contains a brachiopod and trilobite fauna, including the trilobite *Encrinurus*. Foldvary (1969) and Nazer (1972) reported a similar fauna from reddish siltstone near the southern end of the Black Range. Based on those faunas, the most likely age is Ludlow–Pridoli (latest Silurian).

### **Calarie Sandstone** (S-Ddc, S-Ddcs) Sherwin, (1973b), modified in Krynen *et al.* (1990)

*Previous nomenclature*

Sherwin (1973b), following Brunker (1972a), described the Calarie Sandstone as the upper unit of the Silurian Forbes Group, but it was later recognised as being unconformable upon the Forbes Group. Krynen *et al.* (1990) placed the Calarie Sandstone at the base of the 'Wallingalair Group', a poorly dated unit with little outcrop. Later work has shown that the 'Wallingalair Group' is equivalent to the better defined Derriwong and Trundle Groups. The 'Wallingalair' Group is now considered redundant and the Calarie Sandstone has been reassigned as the basal formation of the Derriwong Group in the area east of Bogan Gate (Sherwin, 1996).

*Type section, distribution and outcrop*

The Calarie Sandstone forms an obvious ridge on either side of the Forbes Anticline to the immediate north and west of Forbes. At the type section (GR 594700 mE 6314300 mN), on Bimbadeen station, just north of Calarie, this formation produces some of the most prominent topographic features in the Forbes district. North and south of Gunningbland the outcrops are more or less continuous, if lower in relief. North of these outcrops, the Calarie Sandstone is either faulted out or was never present. Further north, in the Narromine 1:250 000 map sheet area, the Calarie Sandstone persists for a few kilometres as low rubbly outcrops (Sherwin, 1996). Between the more obvious outcrops at Gunningbland and Forbes there are some small isolated outcrops in the Goobang Creek alluvial plain.

*Description*

The Calarie Sandstone is a medium- to coarse-grained, pebbly in part, quartz–lithic sandstone. The bedding is mostly thick, 3 m to 4 m in the more prominent outcrops, and includes both cross-bedded and massive units. Its colour varies from off-white to buff, although some of the more friable beds are deep reddish brown. North of Cottons Hill there is a quarry (GR 587200 mE 6318700 mN) exposing the lower part of the Calarie Sandstone. The base is thick-bedded and massive, but up-sequence the sandstone becomes flaggy. There is some cross-bedding in the coarser-grained, more thickly bedded section. This quarry was the source of the sandstone used for many buildings built in Forbes during the late nineteenth century.

At Avalon station (GR 584000 mE 6313000 mN) the bedding in the Calarie Sandstone is mostly between 10 cm and 50 cm thick, but some beds are as much as 1 m thick. The thickest bed shows indistinct cross-bedded units about 30 cm thick, the other beds being the more usual massive ones. The reddish sandstone is fine- to medium-grained, reasonably well-sorted, with some rare flakes of reddish

phyllite. In thin section (T64484, GR 584090 mE 6312780 mN) the red ferruginous lithic–quartz sandstone contains 2 mm to 4 mm pellets of ankeritic mudstone, rounded fragments of mudstone, phyllite, metamorphic vein quartz, quartzite, and abundant grains of magnetite, apatite, tourmaline, zircon, and mica.

The most easterly outcrops of the Calarie Sandstone, exposed on the side of Allens Road (GR 596400 mE 6316900 mN), have abundant small quartz pebbles. This line of outcrop is associated with a distinct aeromagnetic anomaly, although field inspection failed to find any outcrops with any correspondingly magnetised rock.

*Thickness*

Sherwin (1973b) determined, directly from aerial photographs, a thickness of 300 m at the type section of the Calarie Sandstone.

*Environment of deposition*

The clean, washed, cross-bedded, coarse sandstones of the Calarie Sandstone are possibly fluviatile, probably deposited as outwash from erosion of the newly uplifted Silurian, and older, siliceous basement, with at least one marine incursion indicated by a fossiliferous band.

*Boundary relationships and age*

The outcrops of Calarie Sandstone on the eastern limb of the Forbes Anticline rest paraconformably on the late Early Silurian (Wenlock) Mumbidgle Formation, in the upper part of the Forbes Group. On the western limb, at the quarry site north of Cottons Hill, the Calarie Sandstone sits directly on the late Early Silurian (Wenlock) Bocobidgle Conglomerate, near the base of the Forbes Group. Near Gunningbland the Calarie Sandstone overlies volcanic rocks of the Ordovician Northparkes Volcanic Group, the sandstone outcrop (GR 584090 mE 6312780 mN) on the Monumea Gap Road being more lithic than usual for the Calarie Sandstone, with rare weathered volcanic pebbles. The Calarie Sandstone is overlain, with presumed conformity, by the Cookeys Plains Formation (see below), a unit with very poor outcrop and, hence, unclear boundaries.

The position of the Calarie Sandstone at the base of the Derriwong Group makes it the eastern equivalent of the Ludlow–Pridoli (latest Silurian) Edols Conglomerate, with due allowance made for the probable diachronous base of the two transgressive formations. The Calarie Sandstone shows more features of shallow deposition, having clean cross-bedded sandstones in contrast with the polymict mass flows of the Edols Conglomerate. Both formations also have at least one indicator of comparatively quiescent marine sedimentation, i.e., a fine-grained sandstone with marine fossils.

### Unnamed marine sandstone member of the Calarie Sandstone (S-Ddcs)

*Distribution and outcrop*

Where the Calarie Sandstone is best developed, there is a mappable fine sandstone (S-Ddcs) bed between the more prominent coarse sandstone and conglomerate. The finer-grained beds are represented by a topographic low and can be examined only in excavations.

*Description*

Just west of Forbes the friable sandstone (S-Ddcs) is thin- to medium-bedded and contains common rhynchonellid brachiopods, and lamellibranchs with strongly incurved beaks, possibly referable to *Kochia* sp. Near Gunningbland there is similar thin-bedded, almost laminate, white sandstone exposed in a quarry (GR 582800 mE 6333500 mN) between two ridges of the more resistant sandstone. This contains a similar brachiopod and lamellibranch fauna. These sandstones are more quartzose than the coarser confining beds, although the exposures near Gunningbland do contain detrital mica.

*Environment of deposition*

The softer, laminated sandstones (S-Ddcs) containing marine fossils indicate a shallow marine environment. The lamellibranchs were possibly near-surface burrowers but all specimens observed are disarticulated, implying that any confining sediments were not sufficient to prevent the characteristic posthumous gape of lamellibranchs. The rhynchonellids are also disarticulated, although these belong to a group, which requires some agitation for posthumous disarticulation.

### Byong Volcanics (S-Ddb) Brunker *et al.* (1970)

*Type locality*

Brunker *et al.* (1970) did not specify a type area for the Byong Volcanics which were shown as a name in a map legend. However, the choice of "Byong" as a stratigraphic name implies selection of the Byong Hills, 14 km west-northwest of Bogan Gate, as the type locality.

*Previous nomenclature*

Sherwin (1980a) gave some thicknesses for the Byong Volcanics and referred to the lithology as "...very weathered porphyries and tuffs within the Derriwong Group...". Bowman (1977a) created a new unit, the 'Milpose Volcanics', with a type locality at Milpose Creek, 15 km northeast of Bogan Gate. The type localities for these two volcanic units are on opposite sides of the Tullamore Syncline. However, on the Forbes metallogenic map (Bowman, 1976) the Byong Volcanics were included in the 'Milpose Volcanics' despite the former being the senior terminology. Krynen *et al.* (1990) recommended that, pending more research on the respective ages of the two units, the term Byong Volcanics be retained for the silicic volcanic rocks west of Bogan Gate. Clarke (1990) noted the compositional similarity of the Byong Volcanics

and outcrops of the 'Milpose Volcanics' at Amys Lookout. Because of this similarity, and approximate age equivalence it is recommended that these two areas of Siluro-Devonian siliceous volcanic rocks be included in a single unit, the name Byong Volcanics having priority. Bowman (1977a) also included the siliceous volcanic units between Wirrinya and Bundaburrah within the 'Milpose Volcanics' but these southern outcrops are Devonian and now named the Carawandool Volcanics.

*Distribution and outcrop.*

The Byong Volcanics form prominent hills in the type area and at Amys Lookout to the southeast of Bogan Gate. At Milpose Creek the volcanic rocks are interbedded with sedimentary rocks and form rather more subdued slopes. All the outcrops have been altered to some extent, the freshest being the ridges crossing the Yarrabandai Road northwest of Bogan Gate. The outcrops are surrounded by generally blocky, angular float.

*Description*

Brunker *et al.* (1970) described the Byong Volcanics as being comprised of "... dacite, rhyolite and andesite with minor occurrences of limestone and tuffaceous sediments ...". The most common rock type is a pinkish-brown feldspar porphyry. The magnetic susceptibility is quite variable, ranging from $180 \times 10^{-5}$ SI to $500 \times 10^{-5}$ SI (even within a single sample). Further north in the Trundle district Sherwin (1996) observed that the Byong Volcanics are almost unmagnetised.

*Geochemistry*

The Byong Volcanics comprise predominantly strongly oxidised, unfractionated, normal to high-K, I-type rhyolites. The rhyolites have distinctly low Th (3 ppm to 10 ppm) and Rb (mainly 20 ppm to 60 ppm) for Lachlan Fold Belt felsic rocks, a characteristic shared by other volcanic rocks of the Jemalong Trough such as the Carawandool Volcanics and the Kadungle Volcanics of the Trundle Group. The Byong Volcanics typically also have low U (up to 3.6 ppm), and moderately high levels of HFSE (e.g., Zr, Ti). The geochemical features of the Byong Volcanics, such as low levels of incompatible elements, are consistent with derivation by partial melting of underlying Ordovician mafic volcanic rocks.

*Thickness*

Sherwin (1980a) estimated the maximum thickness to be about 1000 m, based upon measurement across Byong Hills using aerial photographs.

*Boundary relationships and age*

Outcrops of the Byong Volcanics in the type area form prominent hills having no clear relationship with the nearby sedimentary units. About 8 km north of Bogan Gate (GR 572600 mE 6344750 mN) there is a thin, fossiliferous layer interbedded with the Byong Volcanics. Clarke (1990) thought a shallow intrusive origin likely for the massive volcanic rocks in both the type area and at Amys Lookout (GR 581400 mE 6332800 mN). In both of those localities the volcanic units are wholly within the Derriwong Group, specifically within the Cookeys Plains Formation. At "North Gunning" (GR 58300 mE 6341750 mN) the volcanic rocks are interbedded with several horizons of limestone and fine siltstone in the Cookeys Plains Formation. This close association of the Byong Volcanics with well-dated sediments indicates a very Late Silurian, possibly Pridolian, age for the Byong Volcanics (Sherwin, 1992).

## **Cookeys Plains Formation** (S-Ddp, S-Ddpl, S-Ddps) Sherwin (1980a)

*Previous nomenclature*

The Cookeys Plains Formation was described in detail (Sherwin, 1996) from outcrops that cross the boundary between the Narromine 1:250 000 and Forbes 1:250 000 map sheet areas. This formation includes a variety of sedimentary rock types but no units have been named formally because of the difficulty in tracing any for more than a few kilometres.

*Distribution, outcrop and type area*

The best outcrops of the Cookeys Plains Formation are north of the main road between Yarrabandai and Bogan Gate and in a more restricted area north of Gunningbland. There are some widely scattered poor outcrops northwest of Forbes. Outcrops, except for some limestones and resistant sandstones, are more or less confined to cuttings and farm dams. The topography developed on this formation consists of low, gently sloped hills. In some localities, such as west of Cottons Hill, there is little positive expression above the alluvial plain.

Sherwin (1980) did not specify a type section for the Cookeys Plains Formation because of the poor outcrop. The designated type area is between Black Range and Byong Hills, about 16 km west northwest of Bogan Gate. Those outcrops are in the Parish of Cookeys Plains.

*Description*

The dominant rock types of the Cookeys Plains Formation are mudstone and siltstone, with the best outcrops being on the Yarrabandai to Trundle road near the northern boundary of the map area, just east of the Black Range, and in scrapes on the low hill just north east of Yarrabandai. The dark to light brown fine-grained sediments are thin- to medium-bedded and, locally, very fossiliferous. The fossils are generally fragmentary (Figure 7.6), in the case of bryozoa; or disarticulated, in the case of brachiopods and trilobites. In thin section (T64496, GR 554160 mE 6334720 mN), the siltstone contains mostly angular quartz and fragments of mudstone and meta-mudstone, with minor magnetite, feldspar, mica, tourmaline, zircon, and apatite.

Some boulders of massive mudstone (thought to be of the Cookeys Plains Formation) overlying the Calarie Sandstone, west of Cottons Hill, have been unearthed by ploughing (GR 584000 mE 6313390 mN), there being no obvious sign of outcrop. The mudstone boulders are so packed with large rhynchonellids as to approach a coquina.

A nearby fine-grained, muddy sandstone (T64485, GR 584200 mE 6313400 mN) contains recognisable grains of K-feldspar and plagioclase ($An_{30}$), possibly reflecting greater proximity to the Ordovician volcanic rocks.

Fawn to olive-green mudstone and shale are also common, although exposures are largely restricted to scraped roadsides and some dams. Even so, these exposures are friable to splintery. There are typical exposures of these rocks alongside scaped surfaces and gutters on the Yarrabandai Road (GR 562340 mE 6344470 mN).

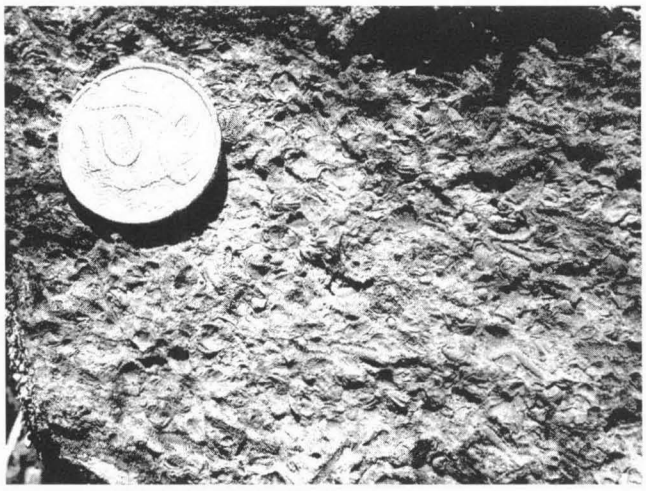


*Figure 7.6. Disarticulated brachiopod shells and bryozoa fragments in siltstone of the Cookeys Plains Formation. (GR 554160 mE 6334720 mN) (O.L. Raymond photograph)*

*S-Ddps* Sandstones low in the Cookeys Plains Formation are present along the northern edge of the Forbes 1:250 000 map sheet area, west of Botfields. They are clearly derived from volcanic sources, possibly the contemporaneous Byong Volcanics. A ?zeolite-altered banded crystal ash tuff occurs about 13 km northwest of Bogan Gate (T64710, GR 569700 mE 6347040 mN).

*S-Ddpl* The most extensive limestone outcrops within the Cookeys Plains Formation are alongside the Bogan Gate to Trundle road, about 13 km north of Bogan Gate. The limestone is reddish and grades laterally into a reddish marl. Tabulate corals and stromatoporoids are particularly abundant (Figures 7.7, 7.8). The limestone on Charleroi station (GR 562810 mE 6345680 mN) is interbedded with the olive-green mudstone and siltstone. The limestone is grey and contains abundant fossils, verging in part on a crinoidal coquina, although the fragmentary condition of the stromatoporoids and corals indicates an environment quite different from that represented in the Trundle Road outcrops. Limestone on Avalon station (GR 583740 mE 6313470 mN), near Forbes, does not protrude above the level ground surface but is sufficiently thick to have developed a sinkhole several metres deep. This limestone is massive and consists largely of fossil debris, especially favositid corals and crinoid ossicles, in a terrigenous matrix.

The limestone lenses at North Gunning (GR 583700 mE 6342200 mN) and Mount Pleasant (GR 583300 mE 6344300 mN) are similarly bioclastic, though with less crinoidal debris, and have poor outcrops. A small skarn containing copper mineralisation, associated with the Mount Pleasant outcrop, is believed to be a block-faulted Ordovician body and not an indicator of post-Early Devonian mineralisation.

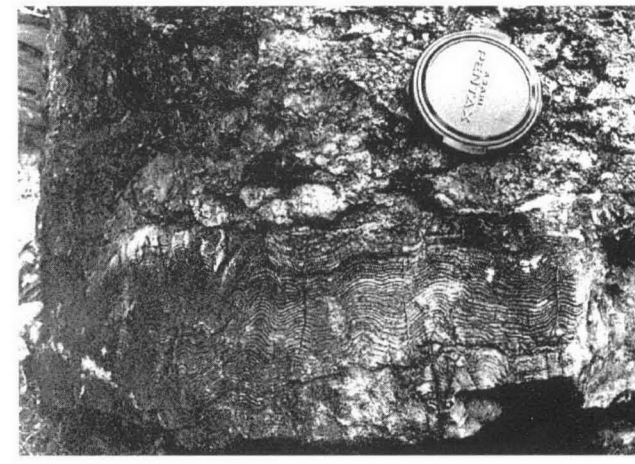


*Figure 7.7. Stromatoporoid layering in a limestone lens of the Cookeys Plains Formation. (GR 572470 mE 6346470 mN) (O.L. Raymond photograph)*

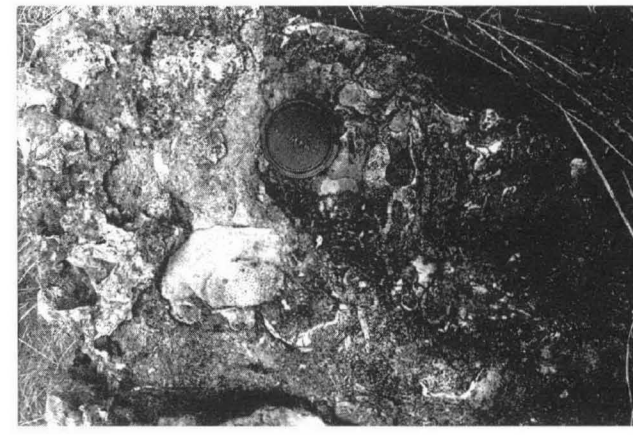


*Figure 7.8. Tabulate coral fragments in a limestone lens of the Cookeys Plains Formation. (GR 572470 mE 6346470 mN) (O.L. Raymond photograph)*

*Thickness*

Estimates of thickness for the Cookeys Plains Formation are necessarily speculative because of the poor outcrop and the possibility of undetected faults resulting in repeated sections. In the type area, east of Black Range, Sherwin (1980a) estimated the thickness at approximately 1200 m, determined using aerial photographs.

*Environment of deposition*

The various sedimentary rock types in the Cookeys Plains Formation imply varied depositional environments. The limestones are probably separated concentrations of calcareous fossil debris deposited on a muddy to sandy sea floor. Limestone, with *in situ* fossils, as on the Trundle Road, may have formed below normal wave base. The large stromatoporoid colonies at that site are partly

interbedded with the surrounding marls and were probably more resistant to disruption by wave action, including storm surges. At least some of the limestone lenses contain algae, indicative of photic conditions. The concentration of the limestones in the lower part of the Cookeys Plains Formation suggests a possible subsidence or increasing turbidity during its deposition.

*Boundary relationships and age*

The Cookeys Plains Formation is believed to rest conformably on the Edols Conglomerate, both formations having comparable trends, and on the Calarie Sandstone. Limestones and clastic units of the formation interfinger with the contemporaneous Byong Volcanics about 10 km northeast of Bogan Gate. There is a gradational boundary with the overlying Yarrabandai Formation in the few places where the contact is exposed. North of Bogan Gate, at the foot of a slope (GR 573720 mE 6341520 mN) formed by the Yarrabandai Formation, there is poor outcrop of the Cookeys Plains Formation almost obscured by coarser-grained float of Yarrabandai Formation.

The Cookeys Plains Formation is locally very fossiliferous. The low hill just to the northeast of Yarrabandai contains abundant bryozoan debris and small brachiopods. In the type area, just above the Edols Conglomerate, there is a rich trilobite and brachiopod fauna, including species diagnostic of the Late Silurian–Early Devonian *Encrinurus–Retziella* (formerly Molongia) fauna (Sherwin, 1992). Pickett & Ingpen (1990) itemised the coral–stromatoporoid faunas from limestones along the Bogan Gate to Trundle road, about 12 km north of Bogan Gate, which indicated a Late Silurian age. Conodonts indicate an age ranging from latest Silurian (Pickett, 1978; Pickett & Ingpen, 1990) to Early Devonian (Pickett, 1975).

## **Yarrabandai Formation** (S-Ddy) Sherwin (1980a)

*Type locality*

The type locality for the Yarrabandai Formation is designated as the fine-grained sandstones forming Bogan Hill (GR 571100 mE 6343200 mN), which is about 8 km northwest of Bogan Gate, and is a prominent feature on the Yarrabandai road. The name is derived from the Yarrabandai district where the best outcrops of this formation are found.

*Previous nomenclature*

Sherwin (1980a) named the Yarrabandai Formation following an unpublished description by Foldvary (1969) but did not specify a type section. The outcrops between Forbes and the Jemalong–Coradgery Range were formerly mapped as unnamed members of the 'Wallingalair beds'.

*Distribution and outcrop*

The Yarrabandai Formation forms a line of hills southwest from the type locality almost as far as the Parkes–Broken Hill railway line. South of Gunningbland the outcrops are more scattered and subdued, as well as being obscured by float from overlying Trundle Group sandstone. The float has a characteristic flaggy appearance.

*Description*

The Yarrabandai Formation consists of brown to brownish grey, fine- to medium-grained, generally well-sorted quartz sandstones, which part very readily along bedding planes. In some outcrops this ready parting is facilitated by an abundance of detrital mica. Bedding thickness is up to 20 cm but is mainly from 5 cm to 15 cm and internally laminate. Some bedding planes exhibit a variety of trace fossils, in many cases on bedding surfaces that also display symmetrical ripple marks.

Some beds of the Yarrabandai Formation are very fossiliferous, although most of the fauna consists of very small specimens. The tentaculitids and beyrichiid ostracodes are, naturally, small, but the associated brachiopods and echinoderm debris are also small even though the brachiopod *Iridistrophia* is capable of growing much larger. Considerable posthumous sorting of shelly debris is indicated. Associated lamellibranchs show less obvious sorting, if any. It is possible that the lamellibranchs have been preserved in their living environment, whereas all other fossils have been sorted and transported. The lithology is remarkably consistent throughout the distribution of the Yarrabandai Formation, the flaggy float and tentaculid fauna being very distinctive.

In thin section (T64729, GR 569200 mE 6342560 mN), sandstone of the Yarrabandai Formation shows a strong compaction fabric associated with suturing and overgrowths, but no matrix. Detrital minerals include sericite and rounded magnetite, apatite, tourmaline, zircon, rutile, biotite, and muscovite. Angular lithic fragments, including mudstone, quartzite, chert, and possible felsic volcanic clasts make up to 10% of the detrital material, including minerals.

*Thickness*

Sherwin (1980a) did not quote a thickness for the Yarrabandai Formation but reference to his measured sections, based upon measurements of outcrop on aerial photographs, indicates that it has a maximum thickness of about 900 m.

*Environment of deposition*

The Yarrabandai Formation marks a distinct change from the mudstones and siltstones that dominate the immediately underlying Cookeys Plains Formation. The coarser grainsize is a possible indicator of closer proximity to the source area and the symmetrical ripple marks are indicators of shallower conditions. Some of the fossiliferous beds, especially those with abundant tentaculitids, resemble strandline deposits. The faunal variations in different beds may reflect the differing environments that are possible in a nearshore area.

*Boundary relationships and age*

The base of the Yarrabandai Formation is best exposed on 'The Grange', 5 km north of Bogan Gate, where there is an

obvious coarsening in grainsize from the underlying silty and muddy Cookeys Plains Formation (GR 573720 mE 6341520 mN). The Yarrabandai Formation is overlain at several localities by the coarse Coonardoo Sandstone of the Trundle Group. Over short distances, of a few hundred metres, the Yarrabandai Formation and Coonardoo Sandstone appear to be paraconformable. However, north of Gunningbland the Coonardoo Sandstone lies directly on the Cookeys Plains Formation and Byong Volcanics, implying a low-angle unconformity between the Yarrabandai Formation and Coonardoo Sandstone.

Where the coarse marker is not developed it can be difficult to distinguish the Yarrabandai Formation from some of the flaggy beds of the overlying Euchabil Gap Formation of the Trundle Group.

The age of the Yarrabandai Formation is early Lochkovian (Early Devonian), based upon the "*Podolella* fauna", which is a characteristic of this unit (Sherwin, 1992).

# 8. EARLY DEVONIAN

## Black Range Group (Db) Best *et al.* (1964), modified after Brown (1941)

The Black Range Group occurs mainly in the Goulburn and Canberra 1:250 000 map sheet areas, where the group consists mainly of rhyolitic to andesitic volcanic rocks with lesser shale and volcaniclastic sedimentary rocks. Previously, the northern limit of the Group had been mapped near the boundary of the Cootamundra and Goulburn 1:250 000 map sheet areas, about 20 km northeast of Young. However, the Warrangong Volcanics, a new unit previously included as part of the 'Illunie Rhyolite' (Brunker & Offenberg, 1970; Warren *et al.*, 1995, 1996), is now mapped as part of the Black Range Group in the Forbes 1:250 000 map sheet area.

## Warrangong Volcanics (Dbw) Bacchin *et al.* (1999)

*Nomenclature and distribution*

The Warrangong Volcanics cover about 4 km$^2$ of the southeastern corner of the Forbes 1:250 000 map sheet area (Figure 8.1) and extend south and east into areas of the Bathurst, Goulburn, and Cootamundra 1:250 000 map sheet areas. A swarm of andesitic dykes, which intruded into the Young Granodiorite and Illunie Volcanics to the west and north of the Warrangong Volcanics, may be comagmatic. The name was first used by Bacchin *et al.* (1999) on a geophysical interpretation map of the Cootamundra 1:250 000 map sheet area. The name is derived from the Warrangong Hills and Parish of Warrangong, where the Warrangong Volcanics are well-exposed. The Warrangong Volcanics were not previously recognised in the Forbes and

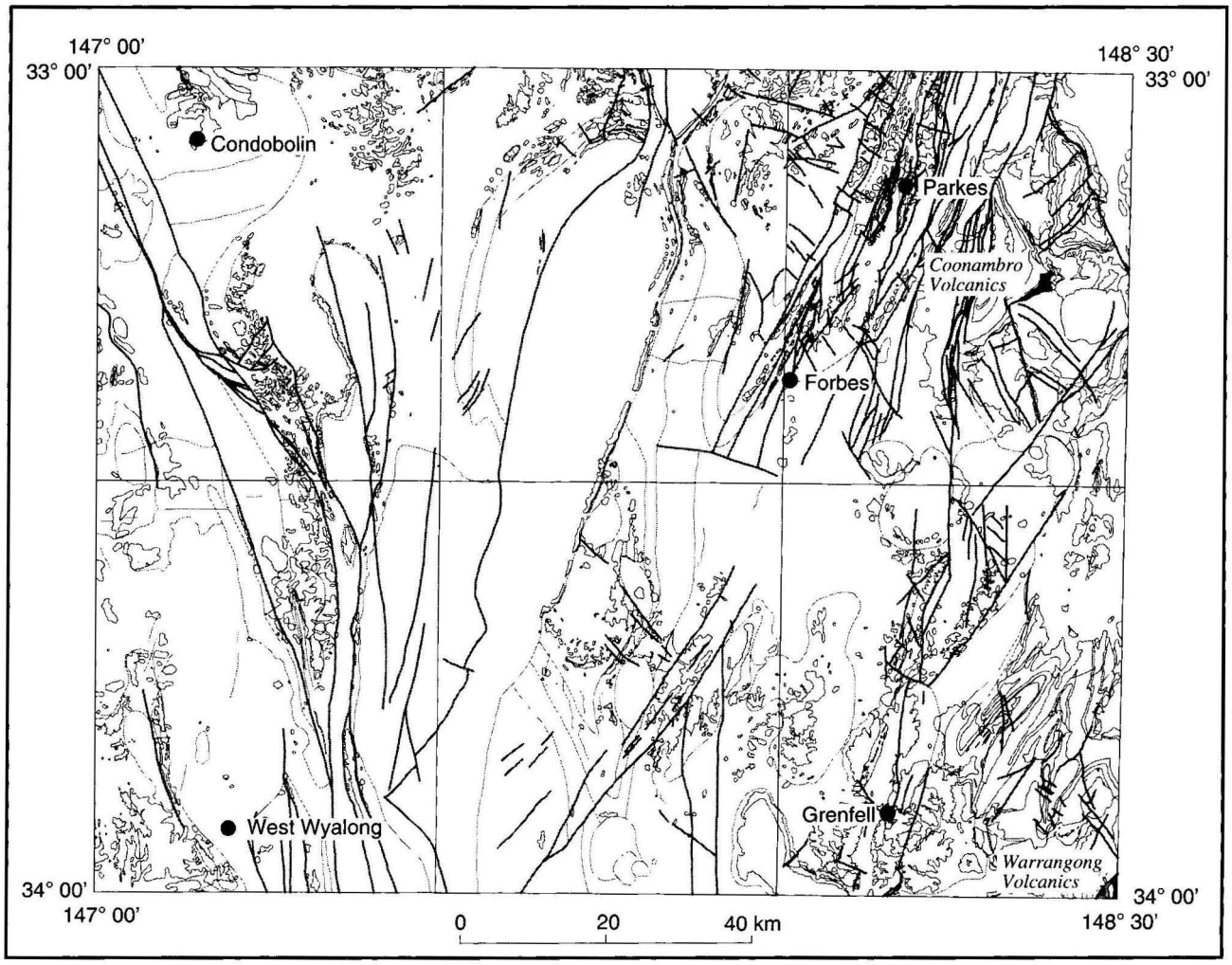



*Figure 8.1. Distribution of the Warrangong Volcanics (Black Range Group) and Coonambro Volcanics in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

Bathurst 1:250 000 map sheet areas (Brunker, 1972; Raymond *et al.*, 1998) and were included in the 'Illunie Rhyolite' on the Cootamundra and Goulburn 1:250 000 geological map sheets (Brunker & Offenberg, 1970; Warren *et al.*, 1996).

*Boundary relationships*

Along their western margin, the Warrangong Volcanics appear to be faulted against the Silurian Young Granodiorite, albeit the contact not being exposed. The contact has been interpreted from aeromagnetic data. The Warrangong Volcanics have a strong, but variable, regional aeromagnetic signature defining a northeast–southwest-trending block about 6.5 km wide and about 16 km long. The southernmost 5 km portion of the Warrangong Volcanics is unconformably overlain by Late Devonian Hervey Group in the Cootamundra 1:250 000 map sheet area. The Warrangong Volcanics are also overlain by the Hervey Group in the east (in the area of the Goulburn and Bathurst 1:250 000 map sheets) and were intruded by the Broula Granite in the north (Bathurst 1:250 000 map sheet area). The Crowther Monzodiorite also intruded the Warrangong Volcanics and may be comagmatic as well.

*Type area*

The type area for the Warrangong Volcanics is in the Warrangong Hills around GR 639500 mE 6236000 mN (Goulburn 1:250 000 map sheet area) where a wide range of andesitic to rhyolitic extrusive and intrusive rocks are exposed.

*Description*

The Warrangong Volcanics include andesite to dacite and rhyolite lava flow and volcaniclastic units, with minor diorite and granite bodies. The andesites and diorites are dark grey and strongly magnetic ($1500 \times 10^{-5}$ SI to $3000 \times 10^{-5}$ SI). They include volcanic rocks and shallow intrusions. Typically, they are strongly porphyritic, with phenocrysts of plagioclase ($An_{40}$ to $An_{55}$) and augite, and minor apatite phenocrysts. The phenocrysts range up to 7 mm, especially for plagioclase, but are generally less than 1 mm to 2 mm in the lava flow rocks. Augite phenocrysts are equant and subhedral to euhedral. They may contain abundant fine-grained inclusions. The groundmass consists of close-packed plagioclase, disseminated opaque oxides, and chlorite alteration. Interstitial hornblende, or quartz, occurs in some of the intrusions. Plagioclase may be extensively sericitised and augite may be replaced by chlorite and/or actinolite.

The dacites of the Warrangong Volcanics are predominantly dark extrusive rocks, but subvolcanic intrusive equivalents also occur. The extrusive rocks contain phenocrysts, mainly of plagioclase (~$An_{40}$), with lesser phenocrysts of augite, rimmed or replaced by hornblende, and minor quartz and opaque oxide phenocrysts in a siliceous, devitrified and recrystallised, glassy groundmass (Figure 8.2). The phenocrysts are variably euhedral to anhedral, typically less than 1 mm to 2 mm, but up to 3 mm. Plagioclase crystals may show strong oscillatory zoning and extensive sericite alteration. Augite and hornblende phenocrysts are often replaced by actinolite, biotite and/or chlorite. Fine-grained, possibly metamorphic, biotite may occur in the groundmass, as well as accessory opaque oxides and apatite. The subvolcanic intrusions have a similar mineralogy to the extrusive dacites, with rounded phenocrysts of plagioclase, quartz, and augite, rimmed by hornblende, set in a fine- to medium-grained feldspar–quartz groundmass. Crystal-rich, lithic dacitic tuffs also occur. These rocks contain abundant (~50%) angular crystal fragments of plagioclase, quartz, and chloritised hornblende (up to 2 mm), with lesser felsic volcanic and granitic lithic clasts (up to 1 cm) in a very fine-grained ash matrix. The dacites are moderately to strongly magnetic ($600 \times 10^{-5}$ SI to $2400 \times 10^{-5}$ SI).

The more felsic rhyodacites contain abundant plagioclase phenocrysts (up to 5 mm), with lesser coarser-grained, embayed quartz phenocrysts (up to 7 mm) and rounded hornblende euhedra (0.5 mm to 2 mm). The rhyolites range from grey to pink lava flow rocks and ignimbrites, with the lavas typically having a much lower phenocryst content (K-feldspar, plagioclase ± quartz) than the dacites and andesites, and the phenocrysts are generally finer-grained. An ignimbrite just east of the Forbes 1:250 000 map sheet area contains abundant quartz and K-feldspar phenocrysts (1 mm to 2 mm). The groundmass of the rhyolites is typically devitrified (sometimes spherulitic) and strongly recrystallised with secondary quartz, chlorite, epidote, and calcite alteration. Strong sericite–epidote alteration of feldspars is common. The magnetic susceptibility of the rhyolite lavas is usually less than $20 \times 10^{-5}$ SI, but the ignimbrites range from $200 \times 10^{-5}$ SI up to $1100 \times 10^{-5}$ SI in lithic-rich zones.

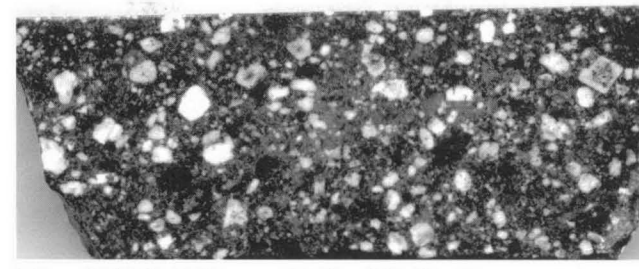


*Figure 8.2. Plagioclase–augite–hornblende–minor quartz-porphyritic dacite of the Warrangong Volcanics. (GR 638250 mE 6239210 mN) (O.L. Raymond photograph)*

Around Bumbaldry, and east and south of Greenthorpe, numerous thin andesitic to rhyodacitic dykes have intruded the Silurian Young Granodiorite and Illunie Volcanics. The dykes near Greenthorpe form the northern extent of a major dyke swarm, which intrudes the northern half of the Young Granodiorite (Cootamundra 1:250 000 map sheet area). In the Greenthorpe area, the dykes trend broadly north–south, but around Bumbaldry the dominant trend is northwest–southeast. Although the dykes crop out very poorly, the more mafic dykes have very high magnetic susceptibility ($2\,000 \times 10^{-5}$ SI to $10\,000 \times 10^{-5}$ SI) and are easily identified in aeromagnetic data. The dykes have similar phenocryst morphology and mineralogy to the volcanic

rocks and intrusions in the Warrangong Volcanics and are possibly related to those rocks.

*Geochemistry*

Geochemical data for the Warrangong Volcanics are limited to that obtained from one rhyodacite dyke (intruded into the Young Granodiorite). This analysis shows S-type characteristics (e.g., ASI >1.1), with a trace element composition similar to the Young Granodiorite. It is possible that this analysis is not representative of the Warrangong Volcanics as a whole, which show demonstrably I-type mineralogy (clinopyroxene + hornblende) — or that the dyke is not derived from the Warrangong Volcanics.

*Age and correlation*

The Warrangong Volcanics have not been isotopically dated and no fossils have been found within them. Contact relationships indicate only that they are older than the overlying Late Devonian Hervey Group. The Warrangong Volcanics are tentatively included in the Early Devonian Black Range Group due to their broadly similar character to volcanic units in that group, such as the Mountain Creek Volcanics. The mineralogy of the Warrangong Volcanics is characteristically I-type with a wide range of compositions, which is unlike the S-type mineralogy and generally more felsic composition of the Douro Group volcanic units, such as the Illunie Volcanics.

## **Yarra Yarra Creek Group** (Dy) Pogson & Felton (1978)

*Previous nomenclature*

Pogson & Felton (1978) applied the name Yarra Yarra Creek Group to an Early Devonian sequence in the Yarra Yarra Creek Syncline, about 70 km northwest of Condobolin. Pogson (1991) and Pogson & McRae (in prep.) divided this Group into six formations, although only three of these are recognisable in the nearest (to the Forbes 1:250 000 map sheet area) outcrops of the Yarra Yarra Creek Group, about 45 km north of Condobolin in the Narromine 1:250 000 map sheet area (Sherwin, 1996; 1997).

Only one unit of the Yarra Yarra Creek Group (the Darbys Ridge Conglomerate) has been mapped in the Forbes 1:250 000 map sheet area (Figure 8.3).

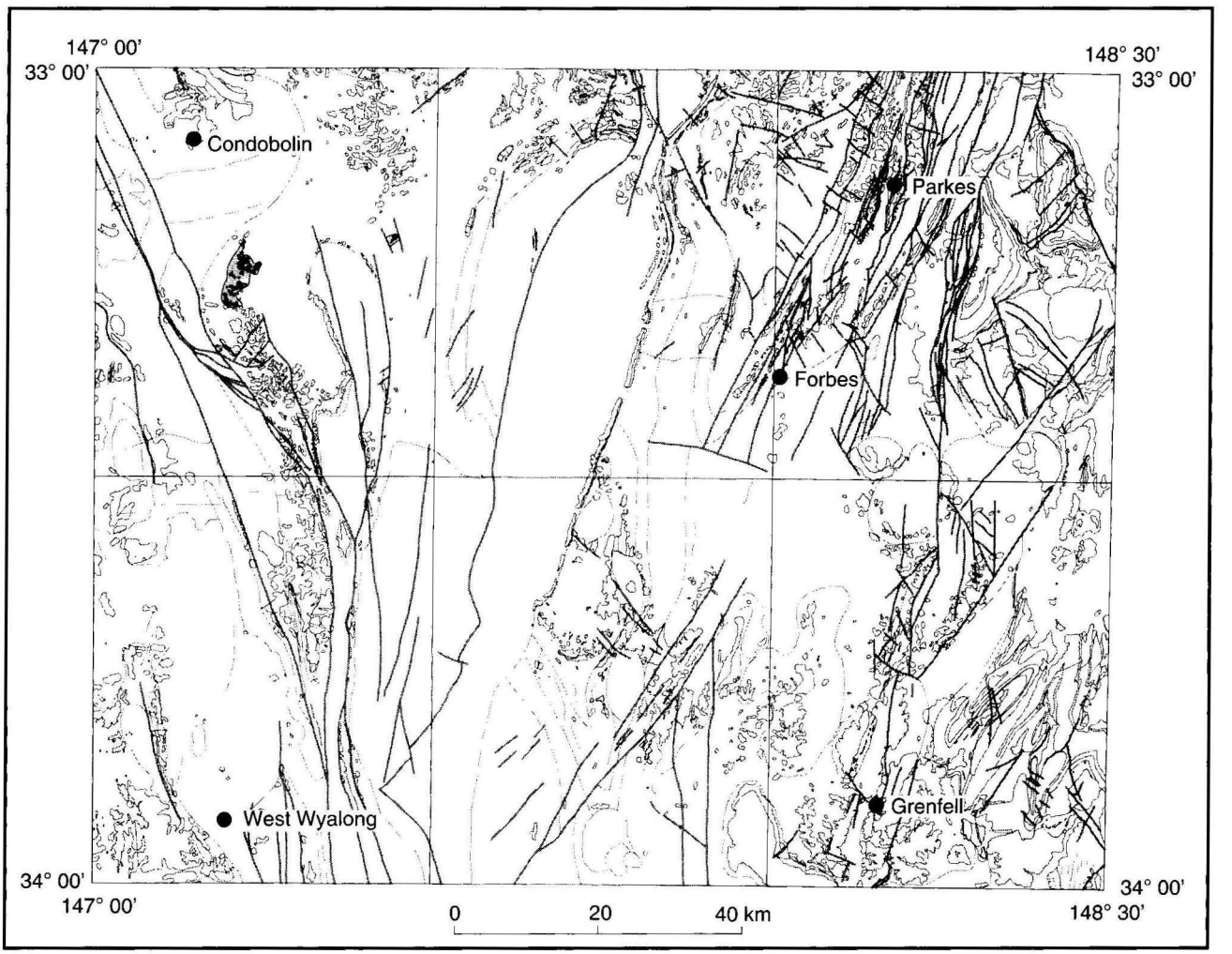



*Figure 8.3. Distribution of the Yarra Yarra Creek Group in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

## **Darbys Ridge Conglomerate** (Dyb) Kemezys (1976)

*Type locality*

Kemezys (1976) did not specify a type area for the Darbys Ridge Conglomerate, but the name, as well as his geological sketch map, implies that it is at Darbys Ridge, a series of low, heavily timbered hills about 18 km south-southeast of Condobolin.

*Previous nomenclature*

Kemezys (1976) regarded the Darbys Ridge Conglomerate as a member ('Darby Conglomerate Member') within his 'Weelah Formation' (now Ootha Group) and, from a distance, it does resemble typical ridges formed by Ootha Group conglomerates. However, the Darbys Ridge Conglomerate overlies the Ootha Group with a marked angular unconformity and generally resembles parts of the Yarra Yarra Creek Group (Pogson & Felton, 1978). The outcrops at Darbys Ridge cannot be confidently correlated with any of those formations and hence the term Darbys Ridge Conglomerate is retained.

*Distribution and outcrop*

The Darbys Ridge Conglomerate is recognised only at Darbys Ridge, where it forms a low, dissected plateau about 10 km in length. This gently warped subhorizontal conglomerate has generally good outcrop. The sedimentary rocks forming the prominent syncline at Mulguthrie Mountain (GR 541200 mE 6325800 mN), 35 km southeast of Condobolin, consist of medium- to coarse-grained sandstone, rather than conglomerate, but occupy a similar stratigraphic position overlying the Ootha Group.

*Description*

The outcrops of Darbys Ridge Conglomerate are mostly brown to reddish brown, pebbly quartz sandstone, although at some localities (e.g., GR 520150 mE 6324600 mN) there is a slight up-sequence fining in grainsize. Coarse conglomerate in the lower part contains subangular to rounded pebbles and cobbles up to 15 cm diameter, although most are less than 10 cm. The clasts are close-packed to matrix-supported, dominated by quartzite, minor quartz, and chert, and may be derived from the Girilambone Group. Higher in the sequence, most of the pebbles are subangular milky quartz but there are some finer chips of sandstone and quartzite derived from the locally underlying sedimentary rocks assigned to the Ootha Group. Clasts include very rare occurrences of rhyolite pebbles similar to the rhyolites of the Yarnel Volcanics. The massive bedding is up to 1 m to 1.5 m thick near the base, but most beds, especially higher in section, are 20 cm to 30 cm thick.

In thin section (T66656, GR 521250 mE 6321280 mN), the sparse oxidised ankeritic matrix in the Darbys Ridge Conglomerate contains rounded grains of metamorphic vein quartz, crenulated phyllite, silty mudstone, and metachert, with minor quantities of magnetite, apatite, tourmaline, and zircon. There is a strong compaction fabric parallel to bedding.

*Thickness*

The base of the blanket of outcrop in the Darbys Ridge area is close to the general level of the plain. Based upon the maximum height of Darbys Ridge, it is unlikely that the Darbys Ridge Conglomerate exceeds 110 m in thickness.

*Environment of deposition*

The Darbys Ridge Conglomerate is believed to represent an outwash deposit from a terrain of Girilambone Group and Ootha Group rocks. The presence of marine fossils in the Yarra Yarra Creek Group, further to the north, suggests that this outwash may have been coastal.

*Boundary relationships and age*

The Darbys Ridge Conglomerate has a markedly angular, discordant contact with underlying sedimentary rocks, assigned to the Ootha Group (exposed at two localities — GR 520150 mE 6323700 mN and GR 521300 mE 6321150 mN). Of the formations in the nearest outcrops of Yarra Yarra Creek Group to the north, the Daalboro Sandstone most closely resembles the Darbys Ridge Conglomerate (Sherwin, 1996, p. 55).

No fossils have been found in the Darbys Ridge Conglomerate and the sediment type gives little hope of any being found. An Early Devonian (?Pragian) age is inferred from that determined for the Yarra Yarra Creek Group (Sherwin, 1996).

## **Trundle Group** (Dt) after Mulholland (1940)

*Previous Nomenclature*

In the Narromine 1:250 000 map sheet area there are two units, the Trundle Group and the Wallingalair Group, separated by at least 12 km of Late Devonian sedimentary rocks in the Tullamore Syncline (Sherwin, 1996). The two groups were regarded as broadly time correlative but differed in the constituent formations — the Trundle Group having a thick volcanic unit, the Kadungle Volcanics, with no equivalent in the Wallingalair Group. In the Forbes 1:250 000 map sheet area, these groups are separated by only 5 km of Late Devonian sedimentary rocks and the units in the two areas can be correlated with confidence. For this reason the two groups have been amalgamated, with the Trundle Group having seniority.

The 'Trundle Beds' were named in an unpublished report (Raggatt, 1936) and referred to units 2 and 3 of a sequence of sandstone, shaly sandstone and limestone between Mineral Hill and Trundle. Raggatt (1937) published a description of these units without assigning a formation name. Mulholland (1940) published the name 'Trundle Beds', drawing upon the definition in Raggatt (1936). Unit 1 of the sequence was called the 'Derriwong Beds' but it is unclear from these earlier reports as to where the boundary between the 'Trundle Beds' and 'Derriwong Beds' was placed. Sherwin (1980a) differentiated the Derriwong Group and Trundle Group in the Trundle district on the

basis of biostratigraphy and used a widespread volcanic unit (following unpublished work by English, 1976) at the base of the Kadungle Volcanics as a convenient marker between the Derriwong Group and the Trundle Group.

*Distribution and outcrop*

The Trundle Group is an extensive unit cropping out parallel to the prominent sandstones of the Hervey Group. It extends from the area around Bogan Gate, in the north, to about 7 km due southwest of Caragabal (Figure 8.4). The area around Bogan Gate is dominated by sediments and interbedded felsic volcanic rocks. The type areas of the northern units are found in the Narromine 1:250 000 map sheet area. In the south, where the basal units crop out, the volcanic rocks have mafic and intermediate components.

*Constituent formations*

The constituent formations of the Trundle Group are:

Beugamel Sandstone (Dtb);

Euchabil Gap Formation (Dte);

Kadungle Volcanics (Dtk, Dtki), including the Bird Flat Volcanic Member (Dtkb);

Carawandool Volcanics (Dtc, Dtca, Dtcr, Dtcm, Dtcs);

Coonardoo Sandstone (Dto); and

Pullabooka Formation (Dtp).

There is no analogue of the Coonardoo Sandstone in the type area of the Trundle Group, where mapping subsequent to Mulholland (1940) revealed that the base of the Trundle Group is faulted against underlying, older units (Sherwin, 1997). Exact stratigraphic equivalence across the Tullamore Syncline is not conclusive because of discontinuous outcrop, the probable vertical and lateral intergradation of the sedimentary units and few fossil occurrences. Useful age-diagnostic fossils are known only from limestone lenses in the Euchabil Gap Formation. All of the above formations, with the exception of the Bird Flat Volcanic Member, have type localities in the Narromine 1:250 000 map sheet area.

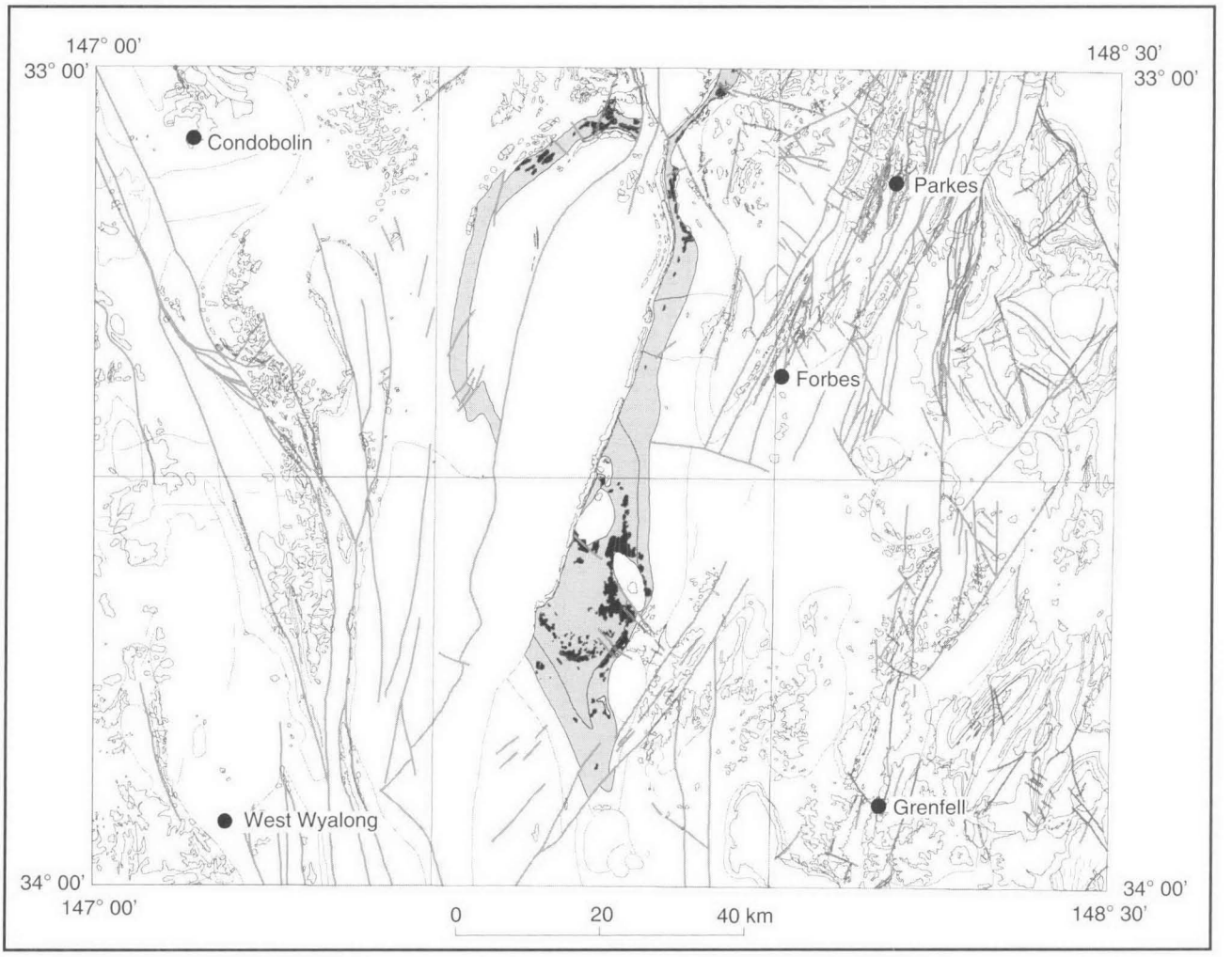



*Figure 8.4. Distribution of the Trundle Group in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

*Thickness*

In the type area for the Trundle Group, Sherwin (1980a, 1996) noted estimates ranging from 1500 m to 2300 m. This variation is indicative of the problems in measuring the thickness of a poorly exposed folded unit. North of Bogan Gate, Sherwin (1980a) estimated the thickness of the Trundle Group at just over 2000 m.

*Boundary relationships and age*

In the Bogan Gate area the Trundle Group paraconformably overlies the Derriwong Group, with a possible short hiatus. The contact with the overlying Late Devonian Hervey Group varies from paraconformable to a slight angular unconformity. East of the Tullamore, this slight angular discordance accounts for the very restricted occurrence of the Beugamel Sandstone and very possibly the complete absence of the Bird Flat Volcanic Member.

Limestone lenses in the Euchabil Gap Formation contain *sulcatus* Zone conodont fauna (Pickett, 1983), indicating an early Pragian (mid-Early Devonian) age.

## **Pullabooka Formation** (Dtp) after Brunker (1972)

*Nomenclature, distribution and boundary relationships*

The name Pullabooka Formation is a formalisation of the 'Pullabooka beds' introduced by Brunker (1972) and Bowman (1976, 1977b). It forms the basal unit of the Trundle Group south of the Lachlan River. The unit is exposed mainly in hills extending north from near Pullabooka to about 9 km north of Wirrinya. Isolated outcrops also occur at Porters Mount (10 km west of Pullabooka), between Pullabooka and Caragabal, and just south of Caragabal. Several of these outcropping hills were previously mapped as Ordovician sedimentary rocks (Brunker, 1972; Bowman, 1976). Much of the Pullabooka Formation is covered by Cainozoic sediments. The unit is interpreted to be folded in the Currowong Syncline and to underlie much of the Cainozoic alluvium between Caragabal and Porters Mount.

The Pullabooka Formation is conformably overlain by the Early Devonian Carawandool Volcanics. Exploration industry workers (e.g., North Mining Ltd, 1996) had interpreted a faulted contact between the two units. However, an undeformed conformable transition from siltstones into basaltic volcanic rocks is exposed in the hills north of Pullabooka. The base of the Pullabooka Formation is not exposed, but it is interpreted to unconformably overlie sedimentary units of the Siluro-Devonian Derriwong Group. The Pullabooka Formation was intruded by the Dalrida Granite, with some contact metamorphism and rotation of bedding near the contact. The Wirrinya Granite, Porters Mount Quartz Diorite, and several unnamed granite, dolerite, and basalt dykes have also intruded the Pullabooka Formation. Several unexposed dyke-like intrusions, similar to the Porters Mount Quartz Diorite, are interpreted from aeromagnetic data to have intruded the Pullabooka Formation between Porters Mount and Caragabal.

*Description*

The Pullabooka Formation is predominantly composed of well-sorted, medium- to fine-grained, massive to thick-bedded, grey to buff, and pink, quartz sandstones and quartzites. In places, the rocks resemble the quartz sandstones of the Late Devonian Hervey Group. Minor thin-bedded siltstone and shales also occur, becoming more prevalent towards the top of the formation (Figure 8.5). Trace detrital tourmaline grains are almost ubiquitous in Pullabooka Formation sandstones (Figure 8.6). Trace detrital lithic grains and muscovite also occur. Rare, very thin layers rich in heavy minerals, such as zircon and opaque oxides, are present at some localities. The sedimentary rocks become less quartz-rich and are often grey to maroon at the top of the unit. The contact with the overlying Carawandool Volcanics is best exposed around GR 570700 mE 6269200 mN where fine-grained dirty sandstones and siltstones of the Pullabooka Formation pass upwards into basaltic sandstones and basalts. The siltstones contain abundant angular quartz grains and disseminated magnetite/hematite in a very fine-grained, clayey matrix, probably containing a lot of fine-grained tuffaceous ash.

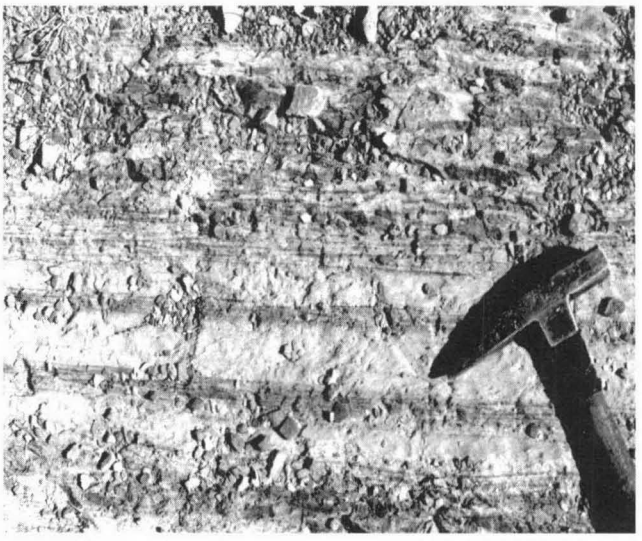


*Figure 8.5. Laminated grey siltstone and shale of the Pullabooka Formation. Many of the thin black laminations are rich in heavy minerals such as zircon and iron oxides. (GR 574920 mE 6280880 mN) (O.L. Raymond photograph)*

Minor cross-bedding and rare graded bedding occur in the Pullabooka Formation, providing facing criteria in the Currowong Syncline. The sandstones are contact metamorphosed around the Dalrida Granite and, in some areas, may also be metamorphosed beneath the basal basalt flows of the Carawandool Volcanics. Silica overgrowths on quartz grains are common in the contact metamorphic zones. Disseminated metamorphic biotite ± andalusite is commonly developed in the quartzites and, in extreme cases, abundant biotite–andalusite spots up to 1 cm in diameter are developed. There is no evidence of any axial plane cleavage developed in the Pullabooka Formation.

The magnetic susceptibility is typically very low ($< 20 \times 10^{-5}$ SI). The gamma ray spectrometric signature of the Pullabooka Formation is variable, but count rates are generally low in all three radioelements (K, Th, U). Increased K count rates occur where the sediments become tuffaceous, and increased count rates in K, Th, and U occur in areas of significant development of contact metamorphic micas, notably near the Dalrida Granite.

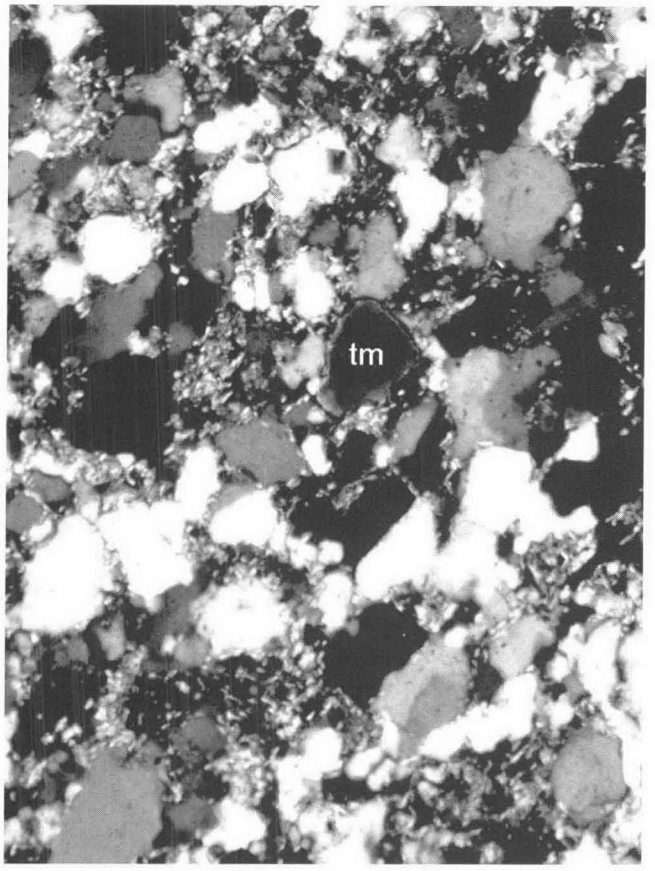



*Figure 8.6. Photomicrograph of a quartz sandstone of the Pullabooka Formation containing a detrital tourmaline grain (tm). Field of view is approximately 4 mm. (GR 574920 mE 6280880 mN) (O.L. Raymond photograph)*

*Alteration and mineralisation*

At Porters Mount, on the western limb of the Currowong Syncline, quartzites of the Pullabooka Formation were intruded by the Early Devonian Porters Mount Quartz Diorite (400 Ma SHRIMP U–Pb zircon age, L.P. Black, pers. comm., 1998). The north–south trending dyke-like intrusion is associated with a prominently outcropping hydrothermal breccia pipe developed within silica–tourmaline altered quartzites of the Pullabooka Formation. The breccia zone extends beneath the Cainozoic sediments around Porters Mount, and contains intense silica–tourmaline (dravite)–sericite (illite) alteration (Figure 8.7) and sericite–ankerite–pyrite–arsenopyrite alteration. Significant jarosite also occurs, probably as a weathering product of finely disseminated sulphides. The breccia and cross-cutting veinlets contain sub-economic As–Ag–Sb–Au mineralisation. The alteration breccia and veinlets are interpreted to represent a phyllic cap to a porphyry mineralising system (Climax Mining Ltd, *in* Lyons & Wallace, 1999). Nd isotopic analysis of the alteration breccia, carried out by Wyborn & Sun (1993), obtained an εNd value of +6.5. This strongly positive value was interpreted to indicate Ordovician magmatic style mineralisation. However, more recent mapping of the Pullabooka Formation and U–Pb zircon dating of the Porters Mount Quartz Diorite indicate an Early Devonian age for the mineralisation.

*Figure 8.7. Hydrothermal breccia with intense silica–tourmaline–illite alteration developed in quartzites of the Pullabooka Formation at Porters Mount. (GR 560800 mE 6267550 mN) (O.L. Raymond photograph)*

*Palaeontology, age, correlation and environment of deposition*

Fossil fish fragments have been collected from the Pullabooka Formation about 2 km southwest of Wirrinya (around GR 573000 mE 6273000 mN). A tentative Late to Middle Devonian age was assigned to some fragments (G. Young, pers. comm., 1998), which resembled others found in the Late Devonian Hervey Group (e.g., Young, 1997a). However, other fragments probably belong to the bulbocanthid group of placoderms (G. Young, pers. comm., 1998), which previously have not been reported in Australia, but occur in Early Devonian rocks in Europe and North America.

The Carawandool Volcanics, which conformably overlie the Pullabooka Formation, have been dated as Early

Devonian (404 Ma, SHRIMP zircon U–Pb date, L.P. Black, pers. comm., 1998). In addition, the Dalrida Granite, which intruded into the Pullabooka Formation, has also been dated as Early Devonian (395 Ma, SHRIMP zircon U–Pb date, L.P. Black, pers. comm., 1998). Bell (1972) reported trilobite tracks in the Pullabooka Formation about 8 km north of Wirrinya. Although he ascribed a possible Late Ordovician age to this trace fossil, it is now clear that the formation is significantly younger than Ordovician.

The Pullabooka Formation is correlated with the Coonardoo Sandstone, which occurs at the base of the Trundle Group in the Bogan Gate area. The well-sorted and quartz-rich sandstones of the Pullabooka Formation were probably deposited in a shallow marine or mature fluvial environment. The presence of minor heavy mineral layers indicates, at least locally, strong influence of currents or wave action. The more silty tuffaceous units at the top of the Pullabooka Formation probably reflect the initial stages of rifting and eruption of the Carawandool Volcanics. The rocks nearest the top of the Pullabooka Formation may be water-lain air-fall ash tuffs.

## Carawandool Volcanics (Dtc) *nov*

*Nomenclature, previous work and distribution*

The Carawandool Volcanics is a new name for a sequence of felsic to mafic volcanic rocks folded into a broad syncline, the Currowong Syncline. This syncline, near Pullabooka and Wirrinya, has a north-northeast to south-southwest trend. Outcrops of the Carawandool Volcanics extend from 5 km west of Pullabooka to just west of the Bundaburrah Cowal swamp. However, the unit is interpreted to occur beneath Cainozoic cover up to 7 km south of Pullabooka.

The name is taken from the Parish of Carawandool and Carawandool State Forest, in which andesites of the Carawandool Volcanics are well exposed. The spelling of Carawandool varies according to which maps or topographic features are referred to (e.g., Carawandool on 1:100 000 scale topographic map; Currawandool on 1:250 000 metallogenic map). The Carawandool Volcanics were previously mapped as unnamed Devonian volcanic rocks by Brunker (1972), and as the southern continuation of the 'Milpose Volcanics' (now Byong Volcanics) by Bowman (1976). The Carawandool Volcanics have been subject to much industry mapping and drilling since 1982 (e.g., Dugmore, 1986), and the research theses of Campbell (1989) and Edgar (1990).

*Boundary relationships*

The Carawandool Volcanics conformably overlie the Early Devonian Pullabooka Formation, and are unconformably overlain by the Late Devonian Cloghnan Shale and Weddin Sandstone of the Hervey Group. Magnetic data suggest that the Carawandool Volcanics extend beneath the Hervey Group in the Tullamore Syncline for at least 20 km north of the northernmost exposed volcanic rocks. The Carawandool Volcanics were intruded by the Bundaburrah Granodiorite in the northern part of the Currowong Syncline, and were intruded by the Early Devonian Dalrida Granite north of Wirrinya.

*Constituent Units*

The Carawandool Volcanics comprise several mapped units. Type areas, rather than sections, are proposed due to the incomplete outcrop of most units.

*Hornblende andesite and dacite; andesitic mass flow conglomerate* (Dtca). This unit occurs in the core of the Currowong Syncline and is probably the youngest of the volcanic units. The type area is in the south-eastern part of the Carawandool State Forest.

*Grey, flow-banded rhyolite and dacite lava flows with minor intercalated basalt flows and epiclastic sediments* (Dtcr). This unit occurs in the eastern and northern parts of the Currowong Syncline. The type area is between Tallabung Mountain and Carawandool Peak, where very large exposures of rhyolite occur (Figure 8.8).

*Maroon rhyolites with basal, and lesser interbedded, basaltic lava flows and volcaniclastics* (Dtcm). It occurs in the southern and western parts of the Currowong Syncline, and appears to be a facies change along strike from Dtcr. This unit is well-exposed in several quarries around GR 562000 mE 6273000 mN.

*Medium-grained, massive, quartzose sandstone* (Dtcs). This unit occurs as a sedimentary lens within Dtcm. It is well-exposed near Stewart Road at GR 562700 mE 6270900 mN.

*Unit Descriptions*

*Hornblende andesite and dacite; andesitic mass flow conglomerate* (Dtca). Variably vesicular hornblende andesites and volcanic mass flow conglomerates are exposed in, and south of, the Carawandool State Forest. Other intermediate volcanic rocks have been reported by exploration companies drilling beneath alluvial cover at several other locations in the Currowong Syncline. The andesites contain abundant plagioclase and hornblende phenocrysts (up to 30% or 40%), which are typically <1 mm, but up to 3 mm (Figure 8.9). Up to 3% of rounded or resorbed augite phenocrysts may occur with or, less commonly, in place of hornblende. The primary igneous mineralogy is at least partly replaced by a regional metamorphic greenschist mineral assemblage.

Primary plagioclase phenocrysts are andesine ($An_{\leq 50}$), which may be albitised. Hornblende (up to 15%) is commonly altered to chlorite, actinolite, and epidote. Augite is typically not altered. The groundmass consists of very fine-grained plagioclase laths, disseminated opaque oxides, and metamorphosed ferromagnesian minerals.

*Figure 8.8. Outcrop of flow-banded rhyolites (Dtcr) on Carawandool Peak, viewed from the south-west. (O.L. Raymond photograph)*

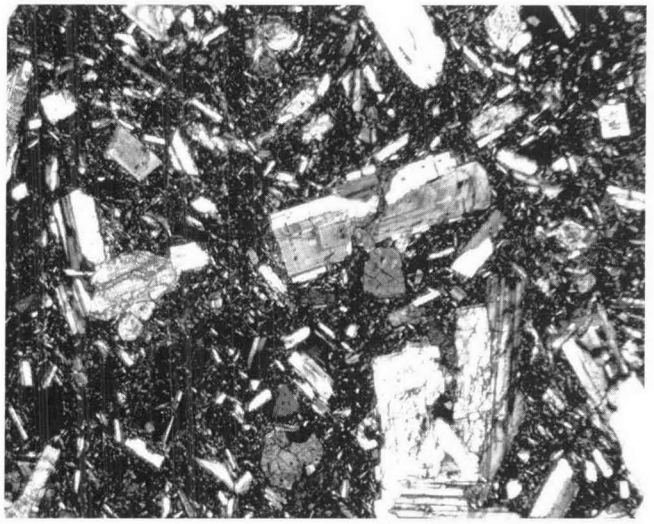


*Figure 8.9. Photomicrograph of porphyritic andesite of the Carawandool Volcanics. Field of view is approximately 4 mm. (GR 566150 mE 6284000 mN) (O.L. Raymond photograph)*

Vesicles may be filled with quartz ± chlorite ± calcite. The andesitic conglomerates are composed predominantly of well rounded to angular, pebble- to boulder-sized clasts of andesite in an angular, coarse-grained, feldspathic sand matrix (Figure 8.10).

Hornblende dacites crop out north of Gooburthery Hill, where they have been intruded by the Bundaburrah Granodiorite. The dacites are porphyritic in plagioclase ($An_{35}$, ≤4 mm, 10% to 20%,), hornblende (≤2 mm, 5% to 10%), and rare quartz, with a devitrified, siliceous groundmass. The plagioclase is typically sericitic and the hornblende is, at least, partly replaced by chlorite ± actinolite. The magnetic susceptibilities of the andesites and dacites are very high ($1200 \times 10^{-5}$ SI to $2300 \times 10^{-5}$ SI), but are significantly reduced in strongly altered rocks. The conglomerates, which are, on the whole, much more altered than the volcanic rocks, have lower susceptibilities ($50 \times 10^{-5}$ SI to $350 \times 10^{-5}$ SI). Despite the high magnetic susceptibility of the unaltered volcanic rocks, the unit does not show a significant magnetic anomaly in airborne magnetic data; suggesting that it is a relatively thin, flat-lying sheet in the core of the Carawandool Anticline.

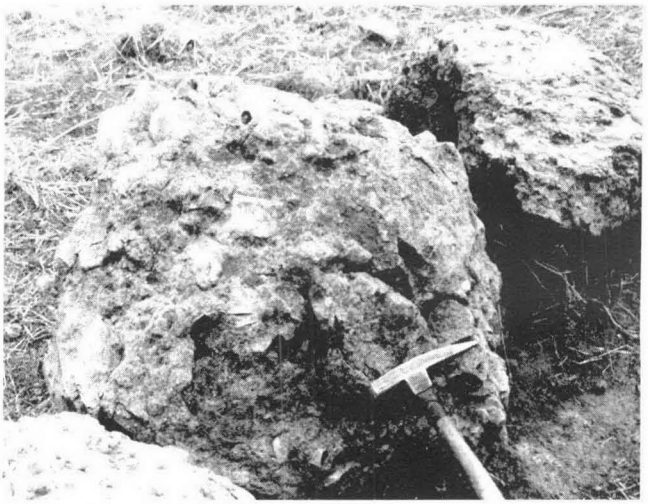


*Figure 8.10. Subangular to rounded cobbles in an andesitic mass flow conglomerate (unit Dtca) of the Carawandool Volcanics. (GR 565470 mE 6281530 mN) (O.L. Raymond photograph)*

*Flow-banded grey rhyolites and dacites; minor felsic tuffs, basalt, andesite and epiclastic sediments* (Dtcr). This unit is predominantly grey, thinly flow-banded, rhyolite to dacite lava flow rocks (Figure 8.11). Minor to trace maroon rhyolites are also present within this unit. The volcanic rocks vary from glassy, aphyric rhyolites to porphyritic dacites containing from 1% to 15% plagioclase ($An_{30}$ to $An_{35}$) phenocrysts. The plagioclase phenocrysts are rounded, typically less than 1 mm (but up to 3 mm) in size, and may show glomeroporphyritic textures. Very minor K-feldspar phenocrysts are present. Quartz does not occur as a phenocryst phase. The groundmass of the flow rocks may appear glassy in hand specimen, but typically shows to be strongly devitrified in thin section. Spherulites and lithophysae are variably, but generally not strongly, developed. The spherulites are typically very fine-grained and visible only under a microscope, but may be up to 2 cm or more in diameter (Figure 8.12). Rarely, a very fine-grained, trachytic groundmass texture may be developed by feldspar microlites in non-glassy volcanic rocks. Accessory opaque iron oxides and zircon are very finely disseminated through the groundmass. Flow-banding in the volcanic rocks is commonly contorted, but autobrecciation is not common. Some mixing of the volcanic rocks occurs, with irregular scalloped boundaries between the aphyric and porphyritic rocks (Figure 8.13). Campbell (1989) reported resorbed basaltic clasts within some flow-banded rhyolites in the Currowong Hills.

*Figure 8.11. Steeply-dipping flow-banding in a glassy aphyric rhyolite of the Carawandool Volcanics (unit Dtcr). (GR 569250 mE 6269290 mN) (O.L. Raymond photograph)*

Lesser basalt and andesite lava flows and dykes, between 5 m and 150 m thick, are intercalated with and intruded into the felsic volcanic rocks. The basalts commonly occupy topographic lows between ridges of more resistant felsic rocks. The basalts are variably massive to vesicular and are generally aphyric. Less commonly, the andesites and some of the basalts are plagioclase- ± clinopyroxene-phyric, containing microphenocrysts typically less than 0.5 mm, but up to 2 mm. The groundmass of these rocks is very fine-grained, albitised plagioclase laths, disseminated opaque iron oxides, and ferromagnesian minerals typically altered to chlorite, actinolite and epidote. Sericite and quartz alteration may also be present.

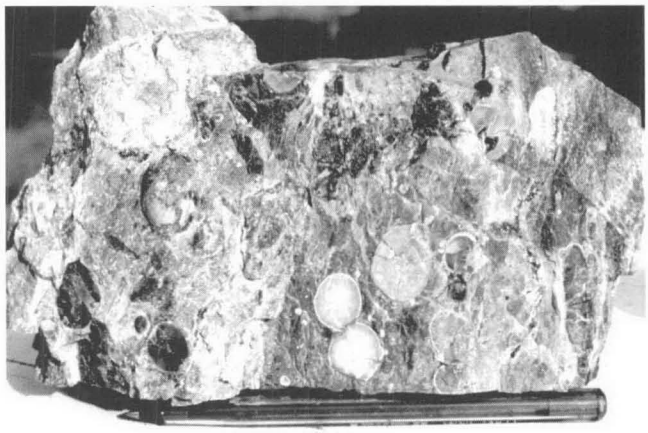


*Figure 8.12. Silicified spherulites in flow-banded rhyolite of the Carawandool Volcanics. (GR 572580 mE 6290200 mN) (O.L. Raymond photograph)*

*Figure 8.13. Irregular and scalloped contacts between feldspar-phyric and aphyric rhyolites, caused by mixing of different lava types in the Carawandool Volcanics (unit Dtcr). (GR 571660 mE 6284920 mN) (O.L. Raymond photograph)*

The magnetic susceptibility of the felsic volcanic rocks varies widely, ranging from around $50 \times 10^{-5}$ SI to over $3000 \times 10^{-5}$ SI, but is generally less than $1000 \times 10^{-5}$ SI. The altered rocks are typically less than $50 \times 10^{-5}$ SI. The basalts are highly magnetic (typically $2000 \times 10^{-5}$ SI to $4000 \times 10^{-5}$ SI, but up to $9000 \times 10^{-5}$ SI). Although the basalts are thin and make up only a small fraction of the generally felsic volcanic pile, they are represented by strong linear anomalies in airborne magnetic data. The strength of these anomalies gives a misleading impression that the Carawandool Volcanics, as a whole, are strongly magnetic.

Minor vitric–crystal–lithic, ash and lapilli tuffs are also present. The lapilli clasts consist of angular, fragmented plagioclase and trace quartz crystals (≤1 mm), rhyolite and lesser basalt lithic fragments, and fine-grained shale or ash lithic fragments up to 2 cm in size. These clasts are in a fine-grained ash matrix of unwelded glass shards (Figure 8.14). Campbell (1989) reported eutaxitic textures in some of the tuffs.

Minor epiclastic sedimentary horizons also occur within unit Dtcr. Grey to purple tuffaceous shales and siltstones contain angular quartz grains and accessory muscovite, zircon, and tourmaline in a very fine shaly matrix containing abundant disseminated opaque iron oxides. Coarser, epiclastic sandstones and breccias consist of very poorly sorted, angular lithic clasts up to 10 cm (rhyolite and sandstone), and quartz and plagioclase crystals in a tuffaceous shaly matrix. Epiclastic sandstones and shales have also been intersected during exploration company drilling beneath Cainozoic cover in the Currowong Syncline.

*Maroon rhyolites; minor basalt and felsic to mafic volcaniclastic rocks* (Dtcm). In the southern part of the Currowong Syncline, primarily south of the Back Marsden Road, rhyolites of the Carawandool Volcanics are distinctly maroon. The maroon rhyolites occur along strike from the grey rhyolites (Dtcr), and it is not clear why this apparent facies change occurs. The change is quite distinct and there is very little intercalation of the grey and maroon types. The maroon rhyolites are markedly less magnetic than the grey rhyolites. Magnetic susceptibility ranges up to $500 \times 10^{-5}$ SI, but the median value is much lower at around $35 \times 10^{-5}$ SI. The intense maroon colour of the rhyolites suggests that any primary magnetite may have been oxidised to hematite, resulting in the lower magnetic susceptibility.

The maroon rhyolites are generally flow-banded extrusive rocks (Figure 8.15). They are typically strongly devitrified, with pumpellyite sometimes developed in a recrystallised groundmass. Fine-grained spherulites are often only visible in thin section. The rhyolites range from aphyric to strongly porphyritic and glomeroporphyritic in plagioclase (up to 15% to 20% rounded oligoclase euhedra, up to 2 mm). Minor K-feldspar phenocrysts are also present. Quartz phenocrysts have only been observed in clasts in a single volcanic breccia. Small vugs and lithophysae may be developed along flow layering. Accidental rhyolite xenoliths occur in some extrusive rocks.

Minor, non-welded to partially welded, crystal–lithic ignimbrites and polymict epiclastic breccias are minor components of unit Dtcm (Figure 8.16). Clasts types in these volcaniclastic rocks include plagioclase, minor K-feldspar, locally abundant quartz crystals, plagioclase-phyric pumice and rhyolite clasts, and minor basalt lithic fragments. The clasts are angular to rounded and typically range in size up to 20 mm.

Basalts and mafic volcaniclastic rocks also occur in unit Dtcr, being more common towards the base of the unit. The basalts are generally aphyric and range from massive to strongly vesicular. Mafic volcaniclastic horizons range from basaltic epiclastic sandstone to diffusely layered airfall ash and lapilli tuffs (Figure 8.17), and scoriaceous block and ash flow breccias (Figure 8.18). Mass flow breccias are polymict, with clasts including attenuated scoria or pumice up to several centimetres long, rhyolite volcanic and ash lithic clasts, basaltic lithic clasts, and quartz and feldspar crystals. The lithic clasts range up to 20 cm (Figure 8.19). Accretionary lapilli have been observed, probably formed in a dyke resulting from degassing of underlying volcanic rocks (Figure 8.20).

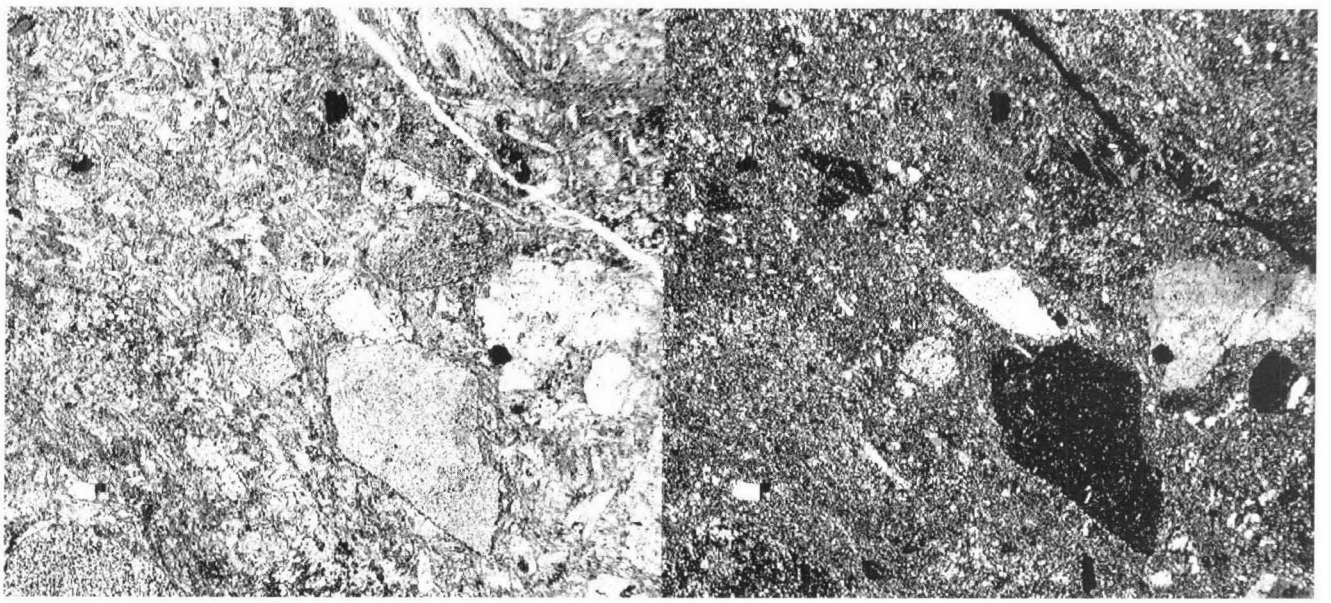


*Figure 8.14. Photomicrographs (plane polarised light and cross polars) of devitrified glass shards and lithic and crystal fragments in a vitric ash of the Carawandool Volcanics (unit Dtcr). Field of view is approximately 4 mm. (GR 573280 mE 6283200 mN) (O.L. Raymond photograph)*

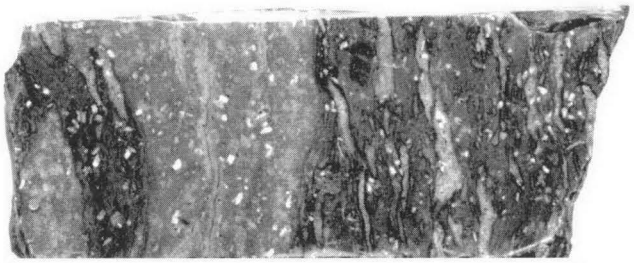


*Figure 8.15. Fine-grained, maroon, plagioclase- and minor K-feldspar-phyric, flow banded rhyolite of the Carawandool Volcanics (unit Dtcm). Width of sample is approximately 60 mm. (GR 563930 mE 6270500 mN) (O.L. Raymond photograph)*

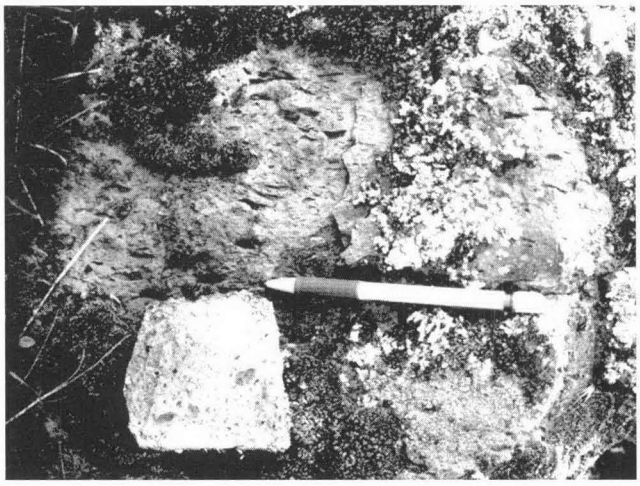


*Figure 8.16. Eutaxitic texture in a maroon ignimbrite (unit Dtcr, Carawandool Volcanics), defined by weathering of attenuated pumice clasts. Smaller block shows small basaltic lithic clasts. (GR 568080 mE 6268690 mN) (O.L. Raymond photograph)*

*Quartz-lithic sandstone and quartzite* (Dtcs). A lens of quartz–lithic sandstone and quartzite occurs within the maroon rhyolite unit of the Carawandool Volcanics (Dtcm). This unit crops out in the hinge area of the Currowong Syncline, about 6 km northwest of Pullabooka. Minor smaller lenses, too small to be represented on the map, also occur near the main mapped lens. The rock consists, predominantly, of pink to grey, very thick- to thin-bedded, fine- to medium-grained sandstone. Sub-angular, moderately well sorted quartz grains make up 80% to 90% of the rock with 5% to 10% felsic lithic fragments, and around 5% to 10% sericitic matrix. Contact metamorphism from the surrounding volcanic units has resulted in recrystallisation of some quartz grain boundaries and formation of quartzite in places. Internal bedding structure is generally massive to parallel laminated, but minor cross-bedding also occurs. The sandstone has been subject to variable amounts of ferruginous alteration, ranging from minor limonitic spotting to pervasive ferruginisation in places, notably where the sandstone overlies a basalt horizon (GR 563900 mE 6269100 mN). Magnetic susceptibility of the unit is very low, around $10 \times 10^{-5}$ SI.

The sandstone is very similar to the predominant rock type of the Pullabooka Formation, which directly underlies the Carawandool Volcanics. This implies a short period of sediment influx from the same detrital source that had contributed to the Pullabooka Formation into the Carawandool Volcanics environment, and provides supporting evidence of the conformable relationship between the Pullabooka Formation and the Carawandool Volcanics.

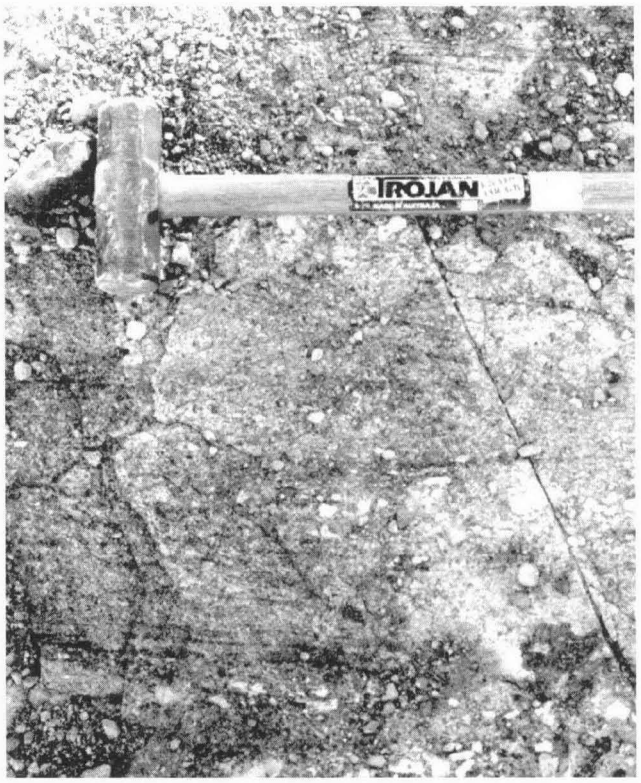



*Figure 8.17. Diffuse layering in a basaltic ash air-fall tuff (Carawandool Volcanics, unit Dtcr). (GR 569480 mE 6269300 mN) (O.L. Raymond photograph)*

*Figure 8.18. Basaltic block and ash-flow breccia, showing attenuated scoria clasts in a matrix of scoriaceous ash and lithic lapilli (Carawandool Volcanics, unit Dtcr). (GR 569480 mE 6269300 mN) (O.L. Raymond photograph)*

### *Minor Devonian intrusions*

The Carawandool Volcanics were intruded by quartz diorite bodies, which are too small to be shown on the map. The quartz diorites (63.5 wt% $SiO_2$ to 66.5 wt% $SiO_2$) are grey

and weakly porphyritic (to glomeroporphyritic) in plagioclase ($An_{30}$ to $An_{45}$), hornblende (~2 mm), and rare augite, with a fine- to medium-grained groundmass of plagioclase, hornblende, minor quartz, titanite, and accessory opaque iron oxides. Secondary chlorite ± biotite ± actinolite alteration of hornblende is common, and feldspars may show alteration to titanite. Three of the four diorites analysed have anomalously low Fe (< 2.5 wt% total Fe as FeO). The sample with the lowest Fe content is characterised by very pale green to almost colourless hornblende. This unusual low-Fe composition is similar to the Porters Mount Quartz Diorite and the diorite phase of the Bundaburrah Granodiorite, suggesting a similar source for all these Early Devonian intrusions. Magnetic susceptibility of the diorites varies widely from $20 \times 10^{-5}$ SI to $1500 \times 10^{-5}$ SI, with the low Fe diorites having lower magnetic susceptibility.

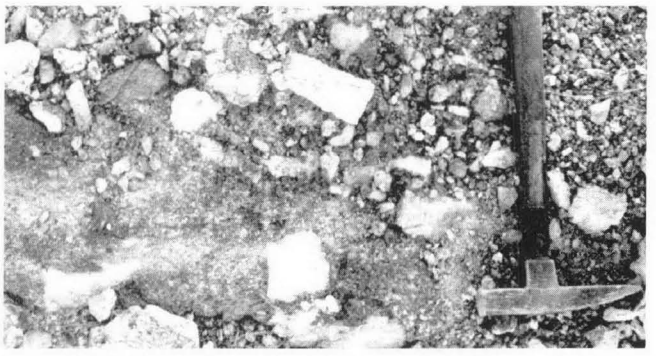


*Figure 8.19. Block and ash flow breccia in the Carawandool Volcanics (unit Dtcr) containing angular clasts of altered volcanic rocks up to 20 cm. (GR 569480 mE 6269300 mN) (O.L. Raymond photograph)*

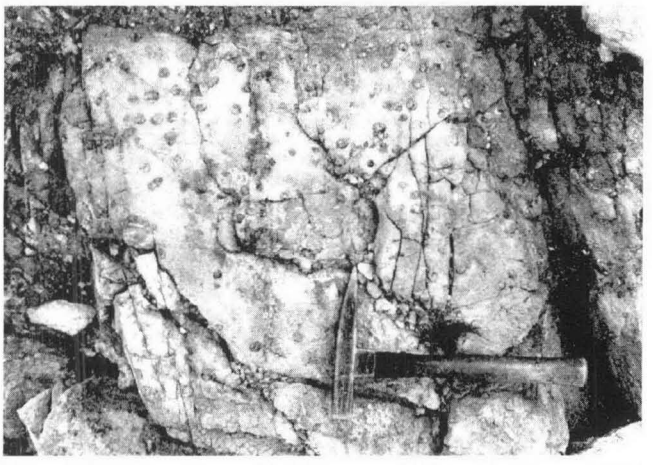


*Figure 8.20. Accretionary lapilli scattered through a fine-grained ash, probably a tuff dyke formed by degassing of underlying volcanic rocks Carawandool Volcanics, unit Dtcr. (GR 569480 mE 6269300 mN) (O.L. Raymond photograph)*

*Hydrothermal alteration*

An advanced argillic epithermal alteration zone in the Carawandool Volcanics is centred about 6 km west of Wirrinya around a prominent outcrop of intensely silica–alunite altered rhyolite (GR 568700 mE 6274800 mN). In the Currowong Hills (often misspelt "Currawong" in previous literature), immediately east of this location, variably altered rhyolites were first noted by exploration geologists in 1982. Edgar (1990) suggested that the alteration forms a thin, largely flat-lying sheet about 2 $km^2$. However, more recent exploration drilling suggests the alteration extends, in places, several hundred metres below the surface. Edgar (1990) described five alteration assemblages including quartz ± alunite ± hematite ± sericite ± kaolinite ± illite ± limonite (after sulphides). He also noted that quartz + kaolinite occurred largely peripheral to quartz + alunite, and noted a vertical zonation from quartz + alunite to quartz + hematite ± alunite at shallower depths. Exploration geologists from Samedan Oil Corporation (1982) also reported minor pyrophyllite, diaspore, zunyite, and jarosite. Minor tourmaline was found in more recent drilling (Figure 8.21). Edgar (1990), however, stated that pyrophyllite and diaspore were absent from the alteration assemblages.

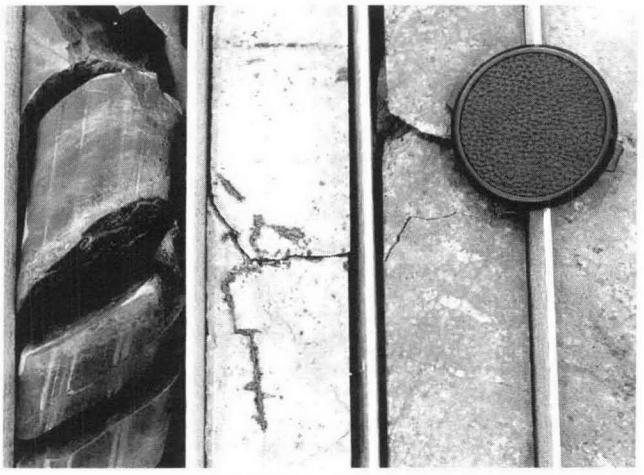


*Figure 8.21. Intensely silicified and leached rhyolite with tourmaline developed along fractures (centre), and chlorite–sericite–silica-altered fine-grained ?andesite (left), from exploration drilling in the Currowong Hills alteration zone. (GR 569400 mE 6275000 mN) (O.L. Raymond photograph)*

The alteration style in the Carawandool Volcanics ranges from intensely and pervasively silicified breccias containing up to 40% alunite, to weak silicification and sericitisation of rhyolites. Minor vugs and some late-stage quartz veining are also developed, but the alteration is generally pervasive and is not vein-dominated. There is only minor development of disseminated pyrite ± arsenopyrite mineralisation and that is now largely replaced by limonite. Rare gossanous outcrops occur in the alteration zone. Campbell (1989) also reported hydrothermal brecciation of rhyolite and chalcedonic quartz veining in basalt about 3 km east of the Currowong Hills alteration zone.

The alteration exposed at Currowong Hills has many features characteristic of high sulphidation epithermal systems (Heald *et al.*, 1987; White & Hedenquist, 1990). However, Edgar (1990) concluded that the alteration occurred by oxidation by near-surface meteoric waters or gases boiled off a near-neutral pH, low sulphidation, chloride fluid. Although gold mineralisation could possibly

be expected below the currently exposed alteration, no economic mineral deposits have been found at Currowong Hills. The area to the west of Currowong Hills is largely covered by Cainozoic sediments, and the scattered outcrops there show evidence of pervasive to patchy silicification and disseminated sulphides. It is probable that hydrothermal alteration is widespread in the rocks beneath the alluvial cover.

Elsewhere in the Carawandool Volcanics, patches of weak to strong, pervasive and veined siliceous, sericitic, argillic and/or epidote alteration are not uncommon — notably south of the Back Marsden Road (Figure 8.22) and north of Bundaburrah (referred to as "Jemalong Gossan" in some company reports). Titanite and calcite alteration of feldspars, localised argillic alteration along minor fault zones, and trace disseminated pyrite and chalcopyrite also occur in places. In general, basalts of the Carawandool Volcanics have chlorite + actinolite - epidote ± biotite replacement, probably reflecting regional greenschist metamorphism rather than hydrothermal alteration.

*Figure 8.22. Hydrothermal clay vein stockwork developed in basalt of the Carawandool Volcanics. Possible basalt pillows are defined by zones of interstitial chloritic alteration. (GR 569480 mE 6269300 mN) (O.L. Raymond photograph)*

*Geochemistry*

The Carawandool Volcanics are composed predominantly of I-type, high-K to normal-K rhyolites. Silica content is generally above 70 wt% $SiO_2$, but ranges as low as 64 wt% for the hornblende dacites and diorites, and 51 wt% to 58 wt% for the basalts and andesites. This range of compositions means that the Carawandool Volcanics cannot be described as truly bimodal. The volcanic rocks have a predominantly calc-alkaline affinity, but there is significant overlap of the basaltic compositions with tholeiitic compositions as shown on ($Na_2O+K_2O$)–FeO*–MgO and Mg–Al–(Fe+Ti) diagrams (Figure 8.23).

The Carawandool Volcanics are oxidised to strongly oxidised, with compositions similar to other Devonian to Silurian felsic volcanic rocks in the region, such as the Byong Volcanics and Kadungle Volcanics. The similarity of composition of these volcanic assemblages suggests derivation from a single source region during the Late Silurian and Early Devonian. The Carawandool Volcanics are unfractionated, having only a moderate increase in Rb and marginal decrease in Ba at high $SiO_2$ levels. Compared to igneous rocks of the Early Devonian Boggy Plain Supersuite (Wyborn *et al.*, 1987), the rhyolites have relatively high Ti, Zr, and Sr; and low Ca, Th, and Rb. The volcanic rocks have relatively low levels of precious metals — up to 5 ppb Pt and Pd, and up to 10 ppb Au.

A single basalt sample (GR 573500 mE 6283000 mN) was analysed for Nd isotopes and yielded a εNd value of +8.1. This strongly positive value is in the range of MORB and island arc basalts (DePaolo, 1988) and suggests a mantle-derived source with no influence from crustal sources. The εNd value is higher than any other Early Devonian and Ordovician mafic volcanic rocks from the northern Lachlan Fold Belt that have been reported (Raymond & Sun, 1998).

*Age, correlation and environment of deposition*

A flow-banded rhyolite from the Carawandool Volcanics (GR 572600 mE 6290200 mN) was dated by the SHRIMP zircon U–Pb method (L.P. Black, pers. comm., 1998). Most of the zircon grains crystallised at 403.8 ± 2.1 Ma, with a 430.7 ± 3.0 Ma age for the dominant inherited zircon population. The Early Devonian age of the Carawandool Volcanics is only marginally older than the post-tectonic Dalrida Granite (395 Ma) and Porters Mount Quartz Diorite (400 Ma), which intruded the folded Carawandool Volcanics. These three dates tightly constrain the age of folding of the Carawandool Volcanics in the Currowong Syncline to around 400 Ma.

The Carawandool Volcanics are correlated with the Kadungle Volcanics of the Trundle Group, which crop out some 40 km to the north. However, magnetic data suggest an interpretation that the two volcanic units are possibly in contact, beneath Hervey Group sedimentary rocks in the Tullamore Syncline. The Kadungle Volcanics are similar to the Carawandool Volcanics, being predominantly felsic volcanic rocks with minor basalts, with a similar I-type geochemistry.

The Carawandool Volcanics were probably deposited in a subaerial or shallow marine rift setting. The strongly positive εNd value obtained from one basalt indicates that the rift tapped a primitive mantle-derived magma source. Fossils found in other Trundle Group rocks suggest, at least, a partly marine environment of deposition. However, there is no evidence of quench fracturing or hyaloclastites in the rhyolites, which might be expected if they were extruded into water. A brief and localised period of

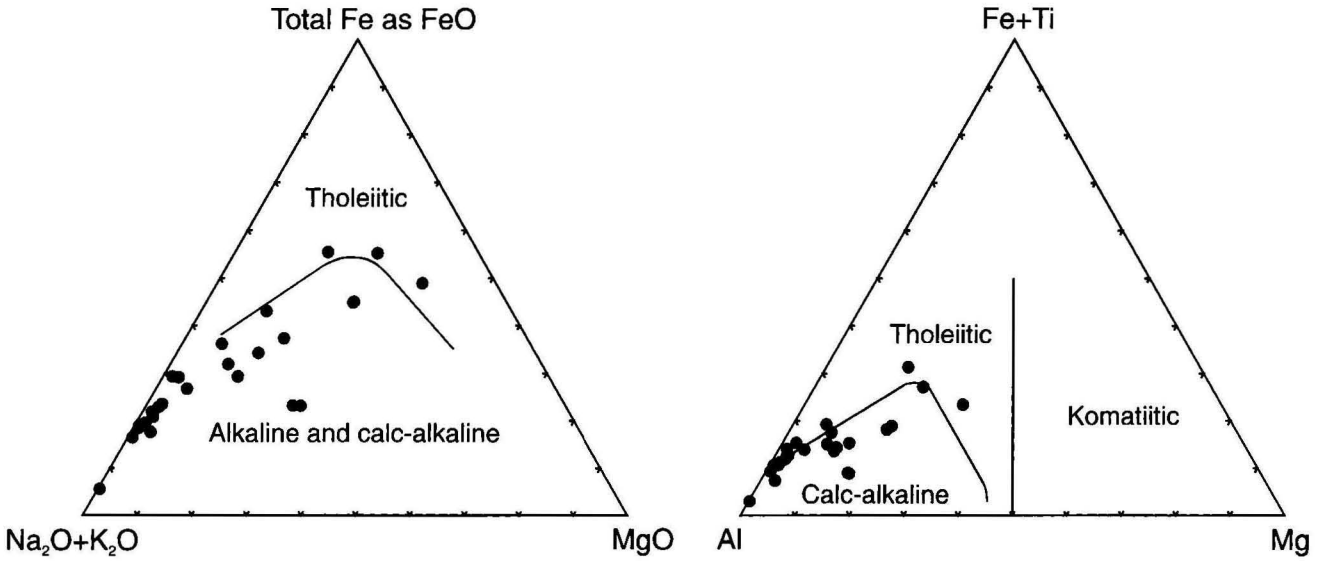



*Figure 8.23. AFM (wt%) and Al–(Fe+Ti)–Mg (mol%) diagrams (after Irvine & Baragar, 1971; Jensen, 1976) showing the predominantly calc-alkaline composition of the Carawandool Volcanics. Basalts show overlap with tholeiitic compositions.*

aqueous sedimentation is indicated by the quartzose sandstone member, which is very similar to sandstones of the underlying Pullabooka Formation. Volcanic activity was mainly in the form of passive extrusion of lavas. Eruption from multiple vents may account for the geographic separation of the grey and maroon rhyolites. Minor explosive activity deposited ignimbrites and air fall tuffs alongside epiclastic breccias and finer-grained sediments.

## **Coonardoo Sandstone** (Dto) Sherwin (1994)

*Previous nomenclature*

Outcrops of the Coonardoo Sandstone east of the Tullamore Syncline had been doubtfully assigned to the Troffs Formation, at that time regarded as part of the Late Devonian Hervey Group (Conolly, 1965b). Sherwin (1973b) placed the outcrops in a composite sandstone member (sandstone Dw3-4) in a new unit, the 'Wallingalair Beds', of Early Devonian age. The Coonardoo Sandstone was later differentiated as a discrete formation at the base of the Wallingalair Group (Sherwin, 1994, 1996). Hence, the Coonardoo Sandstone is now included as a formation of the Trundle Group and is a marker bed for the Trundle Group.

*Distribution and outcrop*

The Coonardoo Sandstone crops out sporadically at the base of the Trundle Group to the northwest and southeast of Bogan Gate. The outcrops are generally very resistant and, where thickest, several kilometres southeast of Bogan Gate, form low rocky ridges. Lack of (or limited) outcrop is partly due to the sandstone being very thin, or not having been deposited in places. Even where the Coonardoo Sandstone is only a few metres thick the outcrops appear like a low wall.

*Description*

Sandstone outcrops (GR 573650 mE 6341400 mN) about 5 km north of Bogan Gate are medium- to very coarse-grained in massive beds, 15 cm to 1.5 m thick, although there are some indistinct cross-bedded units up to 20 cm thick. In some outcrops (GR 554830 mE 6333380 mN) south of the railway line near Yarrabandai, there are laminate beds; the laminae being about 5 mm thick. The reddish pink to grey sandstone is partly silicified and generally well-sorted, with rare quartz pebbles, concentrations of the latter being variable along strike. Some of the thicker outcrops east of Monumea Gap are very conglomeratic. Pebbles throughout this formation are dominated by rounded to subangular quartz.

*Thickness*

The thinnest outcrops of the Coonardoo Sandstone are only a metre or so thick and it is likely that the thickness varies from zero to 100 m.

*Environment of deposition*

The massive to cross-bedded sands of the Coonardoo Sandstone were possibly deposited as fluvial outwash from Girilambone Group terrain to the west. There is little evidence of derivation from the Ordovician volcanic rocks to the east.

*Boundary relationships and age*

At several localities the Coonardoo Sandstone overlies flaggy sandstone of Yarrabandai Formation. On 'North Gunning' (GR 583600 mE 6341800 mN) it obliquely truncates the beds of Cookeys Plains Formation interbedded with the Byong Volcanics. The western end of the line of outcrop (GR 573650 mE 6341400 mN) north of Bogan Gate is truncated (?faulted) against intrusive rhyolites of the Kadungle Volcanics. The flow-banding in the rhyolites is parallel to the truncation and almost perpendicular to the strike of the sandstone. Where the

Coonardoo Sandstone is not overlain by volcanic rocks it grades up into the Euchabil Gap Formation. No fossils of age-determinative value are known from the Coonardoo Sandstone. The age is constrained by the underlying Lochkovian (Early Devonian) Yarrabandai Formation and the overlying Pragian (late Early Devonian) Euchabil Gap Formation.

## **Kadungle Volcanics** (Dtk, Dtki) Sherwin (1980a)

*Previous nomenclature*

The dominantly rhyolitic Kadungle Volcanics were not differentiated from the older Byong Volcanics until their different nature was recognised by McClatchie (*in* English, 1976). The outcrops in the Bogan Gate area are well separated from the type locality at Mount Leadley some 50 km to the north and it is likely that they erupted from a separate volcanic centre or centres.

*Distribution and outcrop*

The Kadungle Volcanics in the area of the Forbes 1:250 000 map sheet area are distributed in a band to the northwest of Bogan Gate. The small area of volcanic rocks at Monumea Gap (GR 578400 mE 6331000 mN) is also believed to belong to this formation. The outcrops are generally more prominent than the surrounding sedimentary rocks, regardless of whether the igneous rocks have been intruded or are interbedded. The areas mapped as intrusive rhyolite (unit Dtki) are more prominent.

*Description*

The predominant rock types in the Kadungle Volcanics are flow-banded rhyolite, which commonly weathers and parts along the banding, and less abundant feldspar porphyry (unit Dtki). The outcrops have a distinctive gamma ray spectrometric signature. On RGB images they appear as a slightly paler pink than the underlying siliceous Byong Volcanics, a feature that is common to both the intrusive and eruptive members. Flow-banding is not obvious in the intrusion that forms Carlachy Hill (GR 558600 mE 6335750 mN). The strong aeromagnetic anomaly associated with the Kadungle Volcanics contrasts with the almost negligible magnetic susceptibility of outcrops. Only after a detailed search was the source of the anomaly traced to a thin vesicular basalt, represented at the surface by sparsely scattered float.

The feldspar porphyry is mottled, off white to reddish pink and reddish purple, flow-banded in part; with some float full of spherulites. Thin sections (e.g., sample T64717, GR 566950 mE 6342110 mN) reveal a flow-banded, submicrolitic quenched trachyte porphyritic in ?plagioclase, ?altered augite and K-feldspar, with accessory magnetite, apatite and zircon. Alteration minerals include zeolite, sericite, and ?pumpellyite. In sample T64720 (GR 569000 mE 6341100 mN), another porphyritic submicrolitic quartz trachyte, the plagioclase has been identified as $An_{45}$. The porphyries are slightly more magnetic than the banded rhyolites with magnetic susceptibilities of $100 \times 10^{-5}$ SI to $250 \times 10^{-5}$ SI.

*Geochemistry*

The Kadungle Volcanics comprise primarily I-type, low- to high-K, calc-alkaline rhyolites. Minor mafic volcanic rocks are interpreted from airborne magnetic data, but do not crop out and have not been analysed. The rhyolites show characteristics typical of other volcanic rocks of the Jemalong Trough (e.g., the Byong and Carawandool Volcanics), such as very low concentrations of Th (<10 ppm) and Rb (<80 ppm). They are strongly oxidised, unfractionated, and have relatively high levels of HFSE (e.g., Zr up to 647 ppm, Y up to 96 ppm). The Kadungle rhyolites generally have low CaO and high $Na_2O$ (up to 6.4 wt%), similar to other Jemalong Trough volcanic rocks.

The Kadungle Volcanics were probably derived from partial melting of the Ordovician volcanic basement during a phase of intraplate rifting.

*Thickness*

The outcrop distribution indicates considerable variation in thickness. Sherwin (1980a) estimated a thickness between 400 m and 800 m.

*Boundary relationships and age*

The intrusive contacts of the rhyolite are clearly exposed in some outcrops (GR 573650 mE 6341400 mN) where it truncates both the Yarrabandai Formation and Coonardoo Sandstone. The intrusion at Carlachy Hill (GR 558840 mE 6336010 mN), believed to be part of the Kadungle Volcanics, has clearly disrupted the local trend of the Coonardoo Sandstone. Unequivocal intrusive contacts with the Coonardoo Sandstone are exposed in a quarry (GR 579000 mE 6332900 mN) southeast of Bogan Gate.

The overall trend of the Kadungle Volcanics suggests they are more or less conformable with the rest of the Trundle Group and very likely interbedded with the Euchabil Gap Formation. About 7 km northwest of Bogan Gate the Kadungle Volcanics are associated with fine-grained sediments and fossiliferous limestone with a fauna (*Spinella pittmani*) characteristic of the Euchabil Gap Formation.

## **Bird Flat Volcanic Member** (Dtkb) *nov*

*Type locality*

The type locality (GR 568000 mE 6339700 mN) for the Bird Flat Volcanic Member is along an unnamed road, which crosses the western end of the ridge formed by the volcanic rocks. The unit is named after Bird Flat, a nearby valley, about 6 km northwest of Bogan Gate.

*Previous nomenclature*

These Bird Flat Volcanic Member was previously an undifferentiated unit of the Trundle Group (Brunker, 1972), although this discrete ridge of volcanic rocks had been mapped as "acid volcanics" by Conolly (1965b) and Foldvary (1969).

*Distribution and outcrop*

Volcanic rocks of the Bird Flat Volcanic Member form a discrete crescent-shaped ridge about 7 km long. The outcrops are generally good, and are prominent in the higher parts of the ridge.

*Description*

The generally reddish to reddish purple colour of the Bird Flat Volcanic Member is apparent even in outcrops. Hand specimens show that both flow-banded and agglomeratic volcanic rocks are present, the latter being well-bedded. In the type section, the latter are also more typical of the lower part of the unit but this distribution is not as obvious in the middle part of the ridge. Thin sections from this part of the ridge (e.g., T64499, GR 571900 mE 6340300 mN) are of red vitric rhyolitic tuff, containing a mixture of distal and medial pumice lithic crystal fragments, strongly compacted but not welded; with clay, sericite and ankerite alteration. In the middle part of the type section (T64732, GR 567850 mE 6339766 mN) a geochronology sample consists of a red to beige, mildly welded leucocratic crystal lithic vitric trachytic/phonolitic tuff or ignimbrite with very obvious shards and angular fragments of perlitic phonolite and alkali rhyolite. Accessory minerals include magnetite, apatite, and zircon. The rock has undergone axiolitic recrystallisation.

Barron (pers. comm., 1999) considered the Bird Flat Volcanic Member unusual in that broken phenocrysts of quartz are a significant component, indicating a rhyolitic bulk composition, but the lithic clasts appear to be welded felsic tuff lacking quartz. The clasts show differing degrees of recrystallisation indicating that they were derived from disruption of a strongly lithified and already recrystallised source rock.

*Thickness*

The thickness of the Bird Flat Volcanic Member, based upon the maximum width of the outcrop, is approximately 300 m, assuming that the volcanic rocks are broadly conformable with the dips of enclosing sedimentary formations.

*Boundary relationships and age*

The outcrop trend of the Bird Flat Volcanic Member suggests that it is conformable above the Beugamel Sandstone, at least in part. The unit is overlain by the Late Devonian Hervey Group with only a slight divergence in trends. The deep reddish purple colour of the volcanic rocks is very suggestive as a source of the sedimentary rocks of similar colour in the Hervey Group, especially the basal Cloghnan Shale. East of Bogan Gate, the Hervey Group rests on lower formations of the Trundle Group but the implied transgressive boundary may only reflect a restricted distribution of the Bird Flat Volcanic Member.

The gamma ray spectrometric (RGB) signature of the Bird Flat Volcanic Member is close to that of the Kadungle Volcanics, being just slightly pinker and brighter. In this respect it resembles closely both the intrusive body at Carlachy Hill assigned to the Kadungle Volcanics and the Ganantagi Granite. It possibly had the same magma source as the Kadungle Volcanics.

The Bird Flat Volcanic Member overlies sedimentary units of the Euchabil Gap Formation, which have a maximum age of Pragian (Sherwin, 1992). This is at odds with a Siluro-Devonian SHRIMP U–Pb zircon age of 419 Ma (L.P. Black, pers. comm., 1999) for the Bird Flat Volcanic Member. This apparent discordance can be explained if the zircons are reworked from the prior crystallisation of the source rock as noted above.

## Euchabil Gap Formation (Dte) Sherwin (1994b)

*Previous nomenclature*

Many of the outcrops of the Euchabil Gap Formation in the Bogan Gate area were included in the Late Devonian Hervey Group by Conolly (1965b). The outcrops east of Bogan Gate were placed in the 'Wallingalair Beds' by Sherwin (1973b), later the Wallingalair Group — and hence the Euchabil Gap Formation is now regarded as part of the Trundle Group.

*Distribution and outcrop*

The Euchabil Gap Formation has much the same distribution as the rest of the Trundle Group in the Bogan Gate area. As is the case in the type area 45 km to the northeast, the outcrops are the poorest of any formation within the Trundle Group because of the presence of friable fine-grained rocks. The sandy beds are thick flags and, where best developed (GR 579400 mE 6329500 mN, just east of Monumea Gap), form prominent, steep ridges. The finer-grained rocks form limited outcrop, if any, and limestone bodies normally occur as scattered float in topographically low areas. Some low ridges of blocky sandstone float north of the railway line between Yarrabandai and Bogan Gate have been included with the Euchabil Gap Formation because of their alignment with the Kadungle Volcanics.

*Description*

The blocky sandstone float of the Euchabil Gap Formation between Yarrabandai and Bogan Gate is reddish brown, fine- to medium-grained and laminated to massive, with rare brachiopod fragments. The outcrops northeast of Bogan Gate form a low ridge (GR 582250 mE 6342180 mN), where there is mostly fine-grained, flaggy, reddish to reddish brown sandstone, with comparatively isolated beds of medium-grained to pebbly sandstone. In areas of poor outcrop (GR 569920 mE 6341800 mN), there is scattered float of flaggy fine- to medium-grained reddish sandstone and less abundant limestone. The latter is grey, fine-grained micrite with abundant brachiopods and crinoid debris. One isolated patch of limestone float and calcrete (GR 559120 mE 6336460 mN) contains pale grey limestone, very fossiliferous in part, with ?algae and a fauna of brachiopods and tabulate corals (?*Favosites*). The surrounding float indicates fine-grained sandstone is the local dominant rock type.

*Thickness*

It is very difficult to estimate the thickness of the Euchabil Gap Formation because of the poor outcrop and the possibility of undetected structural complications. The apparent thickness could also be inflated by the locally interbedded Kadungle Volcanics.

*Environment of deposition*

The varied rock types grouped in the Euchabil Gap Formation suggest a variety of environments. All are consistent with shallow-water sedimentation, the corals and brachiopods indicating that marine conditions prevailed at least intermittently.

*Boundary relationships and age*

The Euchabil Gap Formation is believed to be conformable with the underlying Coonardoo Sandstone, the contact being gradational. The base of the overlying Beugamel Sandstone is sharper (although the actual contact is not exposed) but the strike trends are concordant. The outcrop and float distribution indicate a part intrusive, part interbedded contact with the Kadungle Volcanics.

Limestone lenses within the Euchabil Gap Formation contain the large spiriferid brachiopod *Spinella pittmani*, a genus elsewhere restricted to the Emsian (late Early Devonian) in southern New South Wales and Victoria (Young, 1989). Some of the limestone lenses also contain a *sulcatus* Zone conodont fauna (Pickett, 1983), indicating an early Pragian (mid-Early Devonian) age.

### **Beugamel Sandstone** (Dtb) Sherwin (1994b)

*Previous nomenclature*

Brunker (1972) did not separate outcrops of the Beugamel Sandstone in the Bogan Gate district from the other units of the Hervey Group and Trundle Group, following Conolly (1965b). Bowman (1976) separated the outcrops from the Hervey Group but did not differentiate them from the remainder of the 'Trundle Beds'.

The outcrops between Bogan Gate and Forbes were placed in the upper part of the 'Wallingalair Beds' by Krynen *et al.* (1990), but not given a specific formation name. The type locality specified by Sherwin (1996) is approximately 5 km northeast of Bogan Gate.

*Distribution and outcrop*

There is very little outcrop of the Beugamel Sandstone east of the Tullamore Syncline because of transgression by the overlying Late Devonian Hervey Group. Northwest of Bogan Gate, the Beugamel Sandstone forms prominent outcrops between the Kadungle Volcanics and Euchabil Gap Formation and the Bird Flat Volcanic Member and very bouldery float. The hardness of some outcrop suggests secondary silicification.

*Description*

The Beugamel Sandstone consists of thick-bedded pinkish grey sandstone, with cross-bedded units up to a metre thick. Some thinner beds are indistinctly laminate. The more thickly bedded and cross-bedded units comprise coarse-grained sandstone with pebble bands, the laminated units being medium-grained. Some thicker outcrops (e.g., GR 570050 mE 6341700 mN) show the grainsize coarsening upwards. Otherwise the sandstone varies little along strike.

*Thickness*

The thickness of the Beugamel Sandstone is variable, based on the width of outcrop, but has a maximum of about 150 m.

*Environment of deposition*

The marked change in lithology from the underlying Euchabil Gap Formation to the Beugamel Sandstone indicates an equally marked change in the environment of deposition. The shallow marine conditions during deposition of the older formation were replaced by (probable) very marginal or deltaic conditions.

*Boundary relationships and age*

The boundary of the Beugamel Sandstone with the underlying Euchabil Gap Formation is not exposed because of the poor outcrop of the latter. Contacts with the Kadungle Volcanics show no obvious erosion of the older unit and trends of the two units are parallel for several kilometres on 'The Grange', 4 km northwest of Bogan Gate. The trends are also parallel to those of the overlying and/or interbedded Bird Flat Volcanic Member. No fossils are known from the Beugamel Sandstone. A late Early Devonian age is based on the fossil fauna in the underlying Euchabil Gap Formation.

## Ungrouped Devonian Unit

### **Coonambro Volcanics** (Dcv) *nov*

*Nomenclature, derivation of name and distribution.*

The Coonambro Volcanics are named after the Parish of Coonambro, located about 22 km southeast of Parkes.

The name is used for a sequence of intermediate to felsic volcanic rocks that crop out to the north of the Eugowra Suite granitoids. Previously this poorly mapped area was thought to consist of granite. The Coonambro Volcanics form a wedge-shaped belt, elongate east-northeast to west-southwest, about 6 km long and up to 2.5 km wide at its eastern end. The Coonambro Volcanics occupy an area between the Eugowra Granite to the south, and the Hervey Group to the north, in an area northwest of 'Rawene' homestead (GR 629700 mE 6317900 mN). Exposures are plentiful and the rock is commonly quite fresh.

*Type locality*

The type locality for the Coonambro Volcanics are designated as outcrops in the unnamed creek at GR 629200 mE 6319500 mN, where a dacitic ignimbrite is

well exposed. Outcrop is excellent in the creek. About 50 m downstream, to the east, the dacite is in contact with a coarse-grained diorite.

*Description*

Two distinctive rock types are prominent in the Coonambro Volcanics, a ?basal dacitic ignimbrite to the northeast, overlain by a more felsic rhyolitic ignimbrite to the southwest. The dacitic ignimbrite is dark purplish blue to black, and the rhyolite is dark pink to purple. Plagioclase phenocrysts, exhibiting well-developed igneous zoning, are abundant (20%) and up to 2 mm long. Quartz phenocrysts are rare, even in the rhyolitic ignimbrite, where they are sparsely distributed as embayed grains, mainly less than 0.3 mm across. Most mafic phenocrysts are clinopyroxene, with some grains of dark green bastite (after ?orthopyroxene) and magnetite. Igneous fragments, composed of accumulations of the phenocryst population, are also present. Magnetic susceptibilities are high, $3000 \times 10^{-5}$ SI to $5000 \times 10^{-5}$ SI.

Rare macroscopic evidence of eutaxitic texture indicates steep westerly dips upstream from the type locality. Welded eutaxitic texture is well displayed in thin section, so oriented samples would give an indication of the attitude of the ignimbrites from place to place. To the south, in contact with the Eugowra Granite, the volcanic rocks are recrystallised, and in the vicinity of GR 628500 mE 6318600 mN, rhyolitic ignimbrite has similar field appearance to fine-grained granite, making it difficult to map the granite contact.

*Geochemistry*

The Coonambro Volcanics are silica-rich, in the range 68 wt% $SiO_2$ to 72 wt% $SiO_2$, and $Na_2O$ is high, (over 4 wt%), perhaps suggesting the accumulation of plagioclase phenocrysts during ignimbritic eruption. They are chemically similar to the adjacent I-type Eugowra Granite. The silica ranges of the Coonambro Volcanics and the Eugowra suite are similar, and most elements plot on the same trend in Harker diagrams, although, in the Coonambro Volcanics, $P_2O_5$ is a little low; and $Na_2O$, REEs, Ga, Y, Zn, and Zr are a little high, compared to Eugowra Suite trends at the same silica level.

The Lords Granite, in the northeastern part of the batholith, also has high REEs, Ga, Y, Zn, and Zr, compared with other granites of the batholith, so the Coonambro Volcanics may be related to this particular phase. However the Lords Granite is more felsic (74 wt% $SiO_2$ to 77 wt% $SiO_2$).

*Boundary relationships and age.*

The Coonambro Volcanics overlie the Late Silurian Moura Formation, possibly with a slight unconformity. However, the relationship is unclear because the contact has been extensively intruded by a dioritic body. The contact with the diorite is exposed at GR 629230 mE 6319500 mN in the bed of the creek, 50 m downstream from the type locality. A thin section of phenocryst-poor rock from within 20 cms of the diorite appears to be a hornfelsed andesite indicating the diorite is probably younger than the Coonambro Volcanics. The field relations are somewhat ambiguous, despite good exposure. The Coonambro Volcanics are more strongly hornfelsed by the slightly younger Eugowra Granite, which is a much larger body. The Coonambro Volcanics are unconformably overlain by the Late Devonian Hervey Group to the north. This appears to be a relatively high angle unconformity, since the volcanic rocks dip quite steeply west, with a dip similar to the Moura Formation, while here the overlying Hervey Group dips gently to the northwest.

There is no direct evidence for the age of the Coonambro Volcanics. The stratigraphic position and similar chemistry to the Lords Granite suggest a late Early Devonian age.

# 9. EARLY–MIDDLE DEVONIAN INTRUSIONS

## Eugowra Suite Chappell *et al.*, (1991)

*Nomenclature, distribution and boundary relationships*

Intrusive rocks of the Eugowra Suite (Chappell *et al.*, 1991) were included by Wyborn *et al.* (1987) in the Boggy Plain Supersuite, a broad grouping of potassic, high-temperature, mainly felsic, I-type intrusions of Early Devonian age. The Eugowra Suite consists mainly of an elongate batholith of granitic intrusions, almost 60 km long and up to 20 km wide, which extends from 20 km northeast of Eugowra, southwest to about 20 km north of Grenfell (Figure 9.1). This composite batholith has been referred to as the 'Eugowra Granite' by many previous authors (e.g., Conolly, 1965b; Packham, 1969; Brunker, 1972; Bowman, 1976; Wyborn *et al.*, 1987). The component intrusions of the batholith are:

Clear Hills Monzodiorite (Dcm);

Eugowra Granite (Deg);

Milandra Granite (Dmg) (including the Lock Lomond Granite (Dmgl)); and

Lords Granite (Dog).

The Gumble Granite, which probably represents the felsic end-member of the Eugowra Suite, consists of several bodies near Manildra in the Bathurst 1:250 000 map sheet area, about 25 km northeast of the main batholith. The Eugowra Suite was named after the town of Eugowra, which lies near the middle of the main batholith.

The Eugowra Suite intruded the Ordovician Kirribilli Formation, as well as folded Silurian to Early Devonian sedimentary rocks of the Cowra Trough. The suite is unconformably overlain by the Late Devonian Hervey Group, minor Tertiary basalt, and Cainozoic–Quaternary colluvial and alluvial sediments. The main Eugowra batholith is transected by the north–south trending Coolac–Narromine Fault Zone and by the presently active, northeast-trending Eugowra Fault.

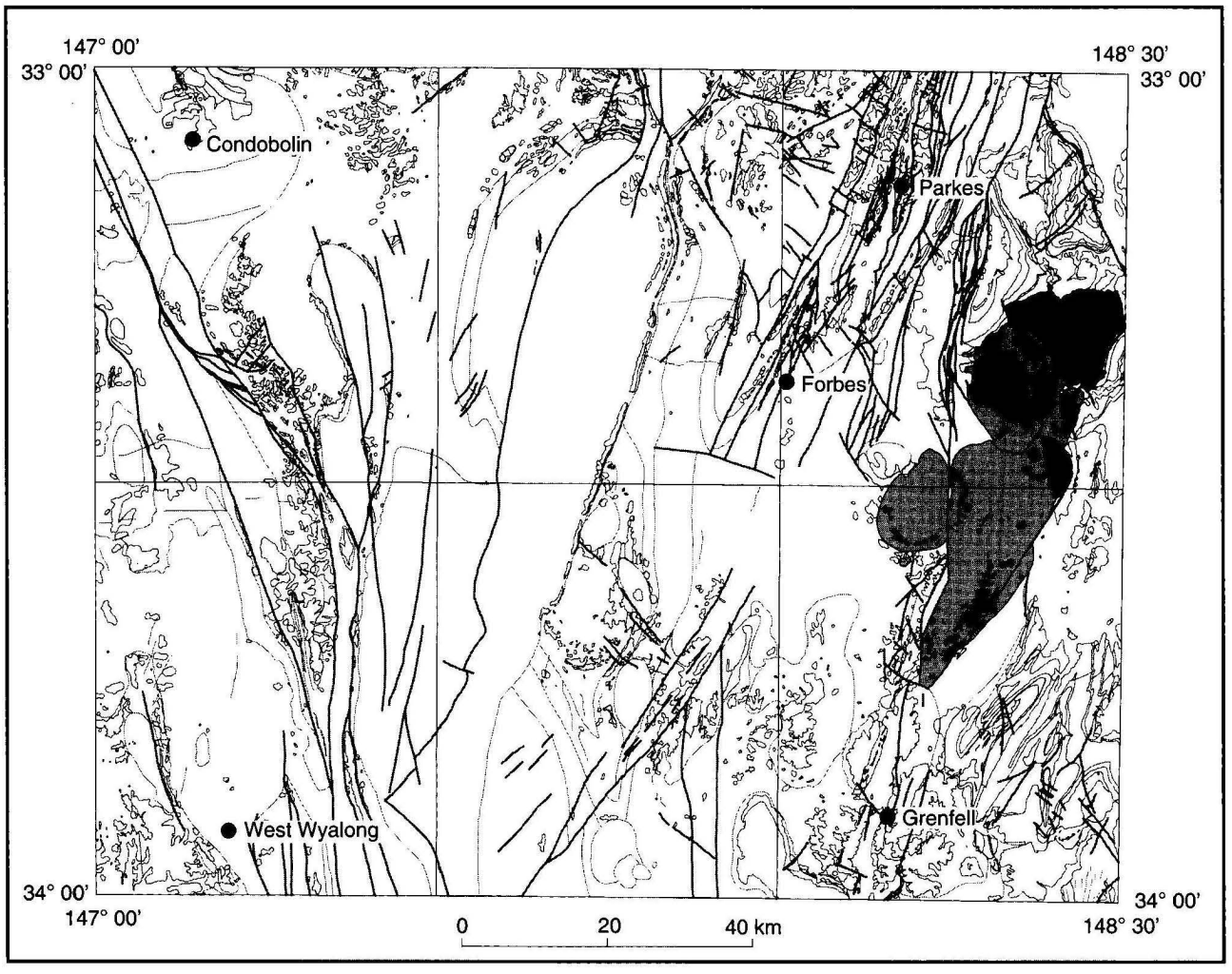



*Figure 9.1. Distribution of the Eugowra Suite in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

*Description*

The Eugowra Suite is a predominantly oxidised, I-type granite suite. In general, the suite has a prominent magnetic signature, contrasting strongly with the mainly weakly magnetic country rocks.

The Eugowra Suite is potassic (Figure 9.2a) and generally ranges from 67 wt% to 78 wt% $SiO_2$, with only the Clear Hills Monzodiorite being more mafic (~57 wt% $SiO_2$). The suite typically shows tightly constrained linear trends in many major element Harker diagrams (e.g., Figure 9.2b), although the Clear Hills Monzodiorite has a relatively high MgO and low $Al_2O_3$ composition relative to the rest of the Suite. The intrusive rocks are predominantly pink biotite granites, with or without hornblende, with abundant pyroxene present in the more mafic Clear Hills Monzodiorite. The Eugowra Suite also has weakly- to strongly-fractionated felsic end members — the Gumble Granite, Lock Lomond Granite, and minor parts of the Eugowra Granite (Figure 9.2c). Some vein- and skarn-style copper, gold and iron mineralisation is known to be associated with the Eugowra Suite — notably the Vychan deposit and Delayneys Dyke/Pine Hill deposit adjacent to the Eugowra and Gumble Granites, respectively. Alluvial gold deposits occur on the Milandra Granite, 20 km south of Eugowra.

*Age*

Two granites of the Eugowra Suite have been SHRIMP U–Pb zircon dated as Emsian (late Early Devonian). The Milandra Granite yielded an age of 393.0 ± 2.5 Ma, and the Eugowra Granite 394.2 ± 2.1 Ma (L.P. Black, pers. comm., 1999).

## Lords Granite (Dog) *nov*

*Nomenclature, distribution and boundary relationships*

The Lords Granite is a new name for a felsic intrusion with a broadly circular outline. The Lords Granite occurs at the northeastern limit of the Eugowra Granite, centred about 17 km north-northeast of Eugowra. The granite is named after House of Lords Mountain, near the middle of the granite body, and it covers almost 60 $km^2$. The Lords Granite was previously included as part of the Eugowra Granite (e.g., Brunker, 1972; Bowman, 1976; Wyborn *et al.*, 1987; Raymond *et al.*, 1998), although Turner (1983) had largely mapped the current extent of the Lords Granite as a distinct phase of the Eugowra Granite. The contact between the Lords Granite and Eugowra Granite is evident in aeromagnetic data, with the Lords Granite being marginally less magnetic than the Eugowra Granite. The shape of the contact suggests that the Lords Granite intruded the Eugowra Granite. The magnetic data also suggest that the southern contact of the Lords Granite is offset by a northeast-trending fault. The Lords Granite has intruded folded sedimentary rocks of the Late Silurian Moura Formation along its northern margin, and is unconformably overlain by the Late Devonian Hervey Group along its southeastern margin.

*Description*

The Lords Granite is typically a medium-grained (1 mm to 4 mm; average 2 mm), pink, equigranular, ferrohastingsite–biotite leucogranite. The leucogranite is composed primarily of equant anhedral to subhedral quartz and weakly perthitic K-feldspar, with lesser subhedral to euhedral plagioclase (~$An_{25}$ to $An_{30}$). Plagioclase cores may be strongly sericitised. Some suturing and recrystallisation of grain boundaries has occurred, and granophyric intergrowth of quartz and K-feldspar may occur as an interstitial phase. Fine-grained ferrohastingsite, biotite, and magnetite typically comprise no more than 5% of the rock in total. The ferrohastingsite is euhedral to anhedral, up to 1 mm, and displays strong dark brown to green, and sometimes blue–green, pleochroism. Ferrohastingsite and biotite may be partially replaced by chlorite. Trace amounts of fine-grained titanite, zircon, apatite and secondary epidote also occur.

The Lords Granite is variably magnetic, with susceptibilities ranging from $100 \times 10^{-5}$ SI to $1800 \times 10^{-5}$ SI. Regional aeromagnetic data reflect this, showing a magnetic anomaly, with an irregular distribution of magnetic intensity, but the Lords Granite is generally less magnetic than the surrounding Eugowra Granite. Turner (1983) noted a fine-grained, white to pink, aplitic phase of the Lords Granite that broadly corresponds to a weakly magnetic zone, about 1.5 km × 4 km, in the eastern part of the intrusion. Some strongly granophyric granite occurs in that area.

The Lords Granite typically has a high gamma ray spectrometric count rates in all three radioelements (K, Th, U). The thorium count rate is lower in the northern part of the granite, probably due to development of deep soils in the relatively flat terrain north of House of Lords Mountain.

*Geochemistry*

The Lords Granite is a felsic, unfractionated, I-type granite of the Eugowra Suite. No data are available to indicate the oxidation state of the granite. The granite has between 74 wt% and 77 wt% $SiO_2$, and a high Fe content relative to the rest of the Eugowra Suite, reflecting the presence of iron-rich amphibole in the granite. The Lords Granite is also relatively high in REE, Ga, Sc, Y, Zn, and Zr, compared with other granites of the Eugowra Suite. These features are similar to the Coonambro Volcanics, which occur just to the northwest of the Lords Granite and, although the volcanic rocks are marginally less felsic, suggests a similar source for the two rocks.

*Age and intrusive environment*

The Lords Granite has not been isotopically dated. However, the granite is a late intrusive body of the Early Devonian Eugowra Suite, which has been dated by SHRIMP U–Pb zircon (Eugowra Granite, 394.2 ± 2.1 Ma; Milandra Granite, 393.0 ± 2.5 Ma; L.P. Black, pers. comm., 1999). The presence of granophyric textures in the Lords Granite suggests it is a relatively high level intrusion.

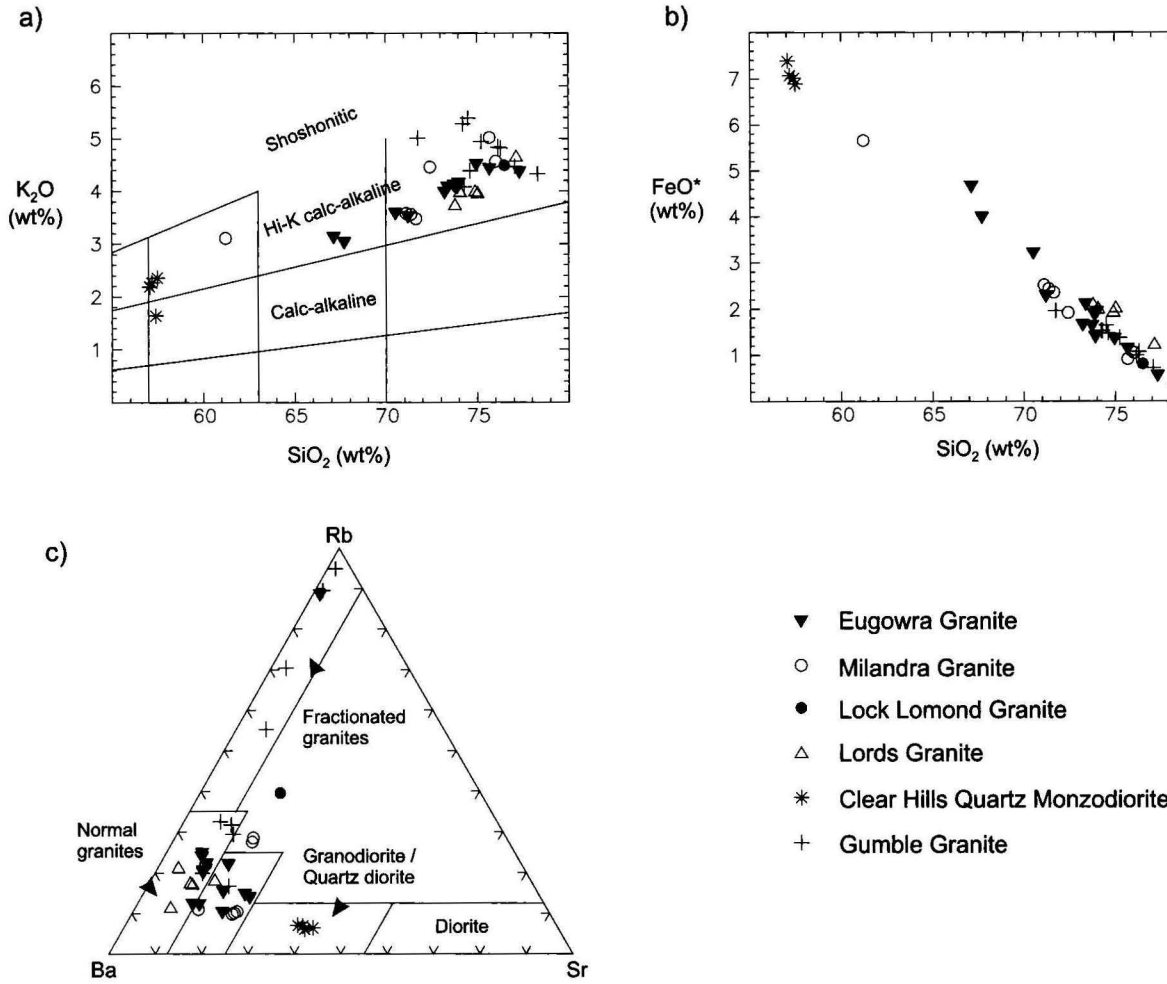



*Figure 9.2. Geochemical characteristics of the Eugowra Suite: a) $K_2O$ versus $SiO_2$ plot showing the potassic calc-alkaline composition of the Suite; b) (Total Fe as FeO) versus $SiO_2$ plot showing a tightly constrained linear trend for the suite; c) Rb–Ba–Sr plot (after El Bouseily & El Sokkary, 1975) showing the predominantly unfractionated character of the Eugowra Suite.*

## Milandra Granite (Dmg) *nov*

*Nomenclature, distribution, type locality and boundary relationships*

The Milandra Granite is a new name for the southernmost member of the Eugowra Suite. The Milandra Granite was included as part of the Eugowra Granite by previous authors (e.g. Bowman, 1976; Chappell *et al.*, 1991). Turner (1983) studied the Milandra Granite in some detail. A quarry at Round Hill, 3 km south of Eugowra, where the granite is well-exposed and has been isotopically dated, is the type locality.

Scattered outcrops of the Milandra Granite occur east of the Coolac–Narromine Fault Zone, for about 35 km southwest from Eugowra. The granite is mostly covered by Cainozoic sediments, but its subsurface extent is delineated by a prominent magnetic anomaly. The Milandra Granite has intrusive contacts with the Eugowra Granite along its northern margin and with the Late Silurian Moura Formation and Ordovician Kirribilli Formation along part of its eastern margin. The western margin of the granite is faulted against the Kirribilli Formation and the Clear Hills Quartz Monzodiorite along the Coolac–Narromine Fault Zone. Sediments of the Late Devonian Hervey Group unconformably overlie the granite in the northeast. Regional magnetic data indicate that the granite is transected by two major faults trending northeast–southwest, including the Eugowra Fault, and by a set of north–south-trending fractures and minor faults.

*Description*

The Milandra Granite is a pink to white, medium- to coarse-grained (typically 1 mm to 5 mm) biotite granite. Minor finer-grained granite also occurs. The granite consists of anhedral, perthitic K-feldspar plates up to 10 mm in finer-grained quartz and plagioclase crystals up to 5 mm. Quartz is typically anhedral, with some sutured and recrystallised grain boundaries. Lesser plagioclase is typically subhedral and may have sutured boundaries with K-feldspar.

Biotite is the most common mafic mineral (~5%), occurring as ragged grains up to 3 mm. Euhedral titanite, up to 2 mm, is a common accessory mineral. Biotite grains typically enclose accessory apatite and zircon euhedra, and minor magnetite is commonly, but not always, associated with biotite. Trace amounts of muscovite and euhedral to metamict allanite also occur. Muscovite occurs only in

samples that lack titanite. Minor secondary alteration includes chloritisation of biotite, sericitisation of feldspars, and development of trace amounts of epidote.

The Milandra Granite is the most magnetic granite of the Eugowra Suite, and forms a strong and well-defined magnetic anomaly elongated northeast–southwest. The magnetic susceptibility of the granite in outcrop is similar to that of the Eugowra Granite, typically in the range from $600 \times 10^{-5}$ SI to $2000 \times 10^{-5}$ SI. However, regional magnetic data indicate that the Milandra Granite as a whole is significantly more magnetic than the Eugowra Granite. Outcropping Milandra Granite has generally comparable gamma ray count rates for K, but slightly lower for Th and U, compared with other granites of the Eugowra Suite. This results in a primarily red colouration in RGB gamma ray spectrometric images.

*Geochemistry*

The Milandra Granite is a high-K calc-alkaline, I-type intrusion of the Eugowra Suite, with silica compositions ranging mainly from 71 wt% to 76 wt% $SiO_2$. A single sample of a more mafic composition (~62 wt% $SiO_2$) probably represents a small intermediate intrusive within the granite. The other 6 analyses of the granite have compositions similar to the more felsic members of the Eugowra Granite. The granite is oxidised and unfractionated.

*Age*

A sample of the granite from the type locality at Round Hill, 3 km south of Eugowra, has yielded a SHRIMP U–Pb zircon age of 393.0 ± 2.5 Ma (L.P. Black, pers. comm., 1999). This Emsian age is similar to a SHRIMP zircon age obtained for the Eugowra Granite (394.2 ± 2.1 Ma) (L.P. Black, pers. comm., 1999).

## **Lock Lomond Granite** (Dmgl) *nov*

*Nomenclature, distribution and boundary relationships*

The Lock Lomond Granite is a new name for the southeastern portion of the Milandra Granite that coincides with a marked gamma ray spectrometric anomaly extending from about 11 km west of Gooloogong to 20 km southwest of Gooloogong. The name is derived from the property 'Lock Lomond', 11 km west-southwest of Gooloogong. The Lock Lomond Granite was included in the Eugowra Granite by Brunker (1972) and Bowman (1976). Outcrops of the granite are largely surrounded by Cainozoic colluvial sediments. The Lock Lomond Granite is interpreted to have intruded the Ordovician Kirribilli Formation, which crops out nearby.

The Lock Lomond Granite is probably a late, felsic phase of the Milandra Granite. It coincides, in part, with the distinctive magnetic anomaly of the Milandra Granite. However, the southern part of the Lock Lomond Granite extends beyond this anomaly into an area of very low magnetic intensity. This suggests that the granite is a thin, weakly magnetic body, lying above the Milandra Granite proper.

*Description*

The Lock Lomond Granite is typically a fine- to medium-grained (0.5 mm to 1 mm), reasonably equigranular, leucocratic granite, containing 35% to 45% K-feldspar. Some coarser-grained granite (grainsize up to 4 mm) also occurs, with perthitic K-feldspar. Biotite comprises about 2% of the rock, with accessory magnetite, ilmenite, apatite, titanite, zircon, and rare metamict allanite. Minor secondary sericite, epidote, clinozoisite and chlorite also occur.

*Geochemistry*

A single analysis of the Lock Lomond Granite exists in the AGSO/GSNSW database. The sample is a felsic (76.8 wt% $SiO_2$), oxidised, I-type granite, which shows signs of weak fractionation. That granite sample has high levels of Th (27 ppm) and U (6.6 ppm), moderately high Rb (207 ppm), and moderately low Ba (226 ppm). However, its Rb/Sr ratio is not particularly high, suggesting the Lock Lomond Granite is not strongly fractionated. The granite also has low levels of HFSE (e.g., Y, Zr) relative to nearby granites (e.g., Eugowra Granite and Milandra Granite), but is still considered to be a felsic member of the Eugowra Suite of granites.

*Age*

The Lock Lomond Granite is considered to be a felsic phase of the Milandra Granite, which has been isotopically dated (SHRIMP U–Pb zircon) as Early Devonian (393 ± 2.5 Ma, L.P. Black, pers. comm., 1999).

## **Eugowra Granite** (Deg) Conolly (1965b)

*Nomenclature, distribution and boundary relationships*

The Eugowra Granite was originally named, and its distribution described, by Conolly (1965b) and Brunker (1972), although the name referred to the batholith herein divided into the Lords, Eugowra, and Milandra Granites. The redefined Eugowra Granite is a roughly equant intrusive body, about 19 km across, occurring immediately north of the township of Eugowra. The granite intruded the folded sedimentary rocks of the Late Silurian Moura Formation, as well as the Early Silurian Glenisla Volcanics. The Eugowra Granite is unconformably overlain by the Late Devonian Hervey Group along its northwestern and southeastern margins. The Eugowra Granite was intruded by the Lords Granite in the northeast, and it may be associated with extrusion of the Coonambro Volcanics, which occur at its northern margin. Turner (1983) studied the granite in some detail.

*Description*

The Eugowra Granite is a complex body of variable composition, ranging from pink, biotite and biotite–hornblende granite to less common aplite and grey, biotite–hornblende–orthopyroxene granodiorite. The granodiorite phase is restricted to the northern margin of the intrusion, but there is an irregular distribution of the more felsic hornblende-bearing and hornblende-free phases. The

Eugowra Granite ranges from medium- to coarse-grained, and is typically rather equigranular. Quartz, K-feldspar and plagioclase ($An_{25}$ to $An_{35}$) are generally anhedral, with perthitic K-feldspar forming large interstitial plates up to 6 mm across. Some graphic intergrowth occurs between quartz and K-feldspar in more felsic granite samples.

Biotite is the most common mafic mineral in the Eugowra Granite, occurring as ragged grains up to 3 mm. Up to 10% biotite occurs in the most mafic granodiorite phase, ranging down to around 1% in the most felsic granite phases. Biotite grains typically include accessory apatite and zircon euhedra, and the zircon crystals may be unusually large — up to 0.25 mm. Magnetite is also commonly, but not always, associated with biotite. Hornblende occurs as euhedral to anhedral grains up to 2 mm, and may comprise up to 5% of the rock in the granodiorite phase. More typically, however, hornblende is absent or comprises less than 3% of the granite. Minor orthopyroxene occurs in restite clots in the granodiorite phase, and it is replaced by biotite, magnetite, and occasionally hornblende. Euhedral, zoned allanite up to 1 mm is a common accessory mineral in the more felsic granite phases. Trace titanite occurs in the more mafic rocks. Secondary alteration minerals include chlorite and epidote after biotite and hornblende, sericite and minor coarser-grained muscovite after plagioclase, and trace actinolite after biotite. This secondary mineral assemblage indicates that the granite has been subject to lower greenschist regional metamorphism.

As well as small mafic clots scattered throughout the Eugowra Granite, Turner (1983) noted an area of about 1 $km^2$, near the contact with the Lords Granite, which contains abundant fine-grained mafic enclaves, possibly restite, and shale xenoliths. The mafic enclaves are fine-grained and commonly subspherical, range in size from a few centimetres to over a metre, and have irregular, sharp to diffuse margins.

The Eugowra Granite forms a well-defined magnetic anomaly, of intensity midway between the less magnetic Lords Granite to the northeast, and the more strongly magnetic Milandra Granite to the south. Magnetic susceptibility of the Eugowra Granite typically ranges from $700 \times 10^{-5}$ SI to $1500 \times 10^{-5}$ SI. The regional magnetic data also indicate that the Eugowra Granite is transected by numerous northwest- and northeast-trending faults and fractures. The most significant of these is the northeast-trending Eugowra Fault, which is active to the present day around the town of Eugowra (Gibson *et al.*, 1994). Outcropping Eugowra Granite has high gamma ray spectrometric count rates in all three radioelements (K, Th, U). However, in areas of deep weathering, or soil or colluvial cover, the Th gamma-ray spectrometric count rate is significantly reduced.

*Geochemistry*

The Eugowra Granite is a complex, moderately to weakly oxidised, I-type, high-K calc-alkaline intrusion with a wide range of silica compositions from 67 wt% to 77 wt% $SiO_2$ (Figure 9.2a) The group of 13 analyses form tightly constrained linear arrays in major element Harker diagrams (e.g., Figure 9.2b), and all analyses have ASI < 1.1; the value taken as the boundary between I- and S-type granites. The Eugowra Granite is generally unfractionated, apart from the single most-felsic sample, which is a strongly fractionated aplitic granite (Figure 9.2c). The Eugowra Granite has a composition very similar to other members of the Eugowra Suite such as the Milandra, Gumble, and Lords Granites, although the Eugowra Granite has some more mafic end-members than these other granites.

*Age*

A sample of the Eugowra Granite from about 5 km northeast of Eugowra gave a SHRIMP U–Pb zircon age of 394.2 ± 2.1 Ma (L.P. Black, pers. comm., 1999).

### **Clear Hills Monzodiorite** (Dcm) Wyborn *et al.* (1987), after Turner (1983)

*Nomenclature, distribution and boundary relationships*

The name Clear Hills Monzodiorite was used by Wyborn et al. (1987) (*after* Turner, 1983) for an intrusive body cropping out in an arcuate line of hills (the Clear Hills) about 23 km southwest of Eugowra. Brunker (1972) had included what is now named the Clear Hills Monzodiorite in the Eugowra Granite. The Clear Hills Monzodiorite has intruded the Ordovician Kirribilli Formation, and some hornfels of the Kirribilli Formation is visible in outcrops near the margin of the intrusion. The Clear Hills Monzodiorite is now mainly covered by Cainozoic colluvial and alluvial sediments. Aeromagnetic data indicate that the intrusion forms a concentrically zoned, roughly elliptical body, about 14 km × 10 km, with its eastern margin faulted against the Milandra Granite and Late Silurian Moura Formation along the Coolac–Narromine Fault Zone.

*Description*

Turner (1983) described the Clear Hills Monzodiorite in some detail and much of the following description is from his work. Samples of the limited outcrop of the intrusion range from quartz monzodiorite to lesser quartz diorite in modal analyses. It is grey and medium- to coarse-grained, ranging from 2 mm to 3 mm, to an average grainsize of around 5 mm. The monzodiorite typically consists of augite, hypersthene, plagioclase, biotite, quartz, K-feldspar, hornblende, ilmenite, magnetite, and accessory apatite and zircon. The pyroxenes occur as euhedral to subhedral grains, with clinopyroxene sometimes rimming hypersthene. Hornblende may also form reaction rims on pyroxenes, and occurs only rarely as discrete grains.

Plagioclase occurs largely as zoned, euhedral grains ranging in composition from $An_{39}$ to $An_{85}$. Interstitial quartz and K-feldspar comprise up to 17% of the rock, with an apparent increase in total quartz and K-feldspar content towards the centre of the intrusion. Biotite is interstitial and is commonly associated with apatite, magnetite, and ilmenite. Ilmenite is the dominant iron oxide mineral, and

this is reflected in the relatively low magnetic intensity of the Clear Hills Monzodiorite in regional magnetic data.

*Geochemistry*

The Clear Hills Monzodiorite represents the mafic end member of the I-type Eugowra Suite of granites, which is part of the Boggy Plain Supersuite (Wyborn *et al.*, 1987). The composition of the monzodiorite ranges from 57.4 wt% to 58.0 wt% $SiO_2$ and lies on most Harker diagram element trends defined by rocks of the Boggy Plain Supersuite (Wyborn *et al.*, 1987). However, the monzodiorite has high MgO (7.6 wt% to 9.1 wt%), Mg/Fe ratios, Ni (116 ppm to 191 ppm) and Cr (355 ppm to 528 ppm), and low $Al_2O_3$ (13.7 wt% to 14.0 wt%), reflecting the abundance of Mg-rich pyroxenes and paucity of plagioclase relative to most other rocks of the Boggy Plain Supersuite (Wyborn *et al.*, 1987). The Clear Hills Monzodiorite also differs from the rest of the Eugowra Suite in its relatively reduced oxidation state. This is reflected in its relatively weak magnetic signature in regional magnetic data, despite its mafic composition.

*Age*

The Clear Hills Monzodiorite is part of the Eugowra Suite of granites, two of which have been isotopically dated (SHRIMP U–Pb zircon method) as late Early Devonian.

## **Bogalong Suite** Chappell *et al.* (1991)

*Previous nomenclature*

Bowman (1976; 1977a,b) described and named the "well zoned" 'Bogalong Granite'. Chappell *et al.* (1991) renamed it the Bogalong Suite. The Bogalong name is here reserved for the Bogalong Suite, which includes the Mortray Hill Granite Complex and the Milroy Granite northwest of Grenfell (Figure 9.3).

### **Milroy Granite** (Dyg) *nov*

*Nomenclature and type locality*

The Milroy Granite is a new name derived from the 'Milroy' property, which lies about 24 km northwest of

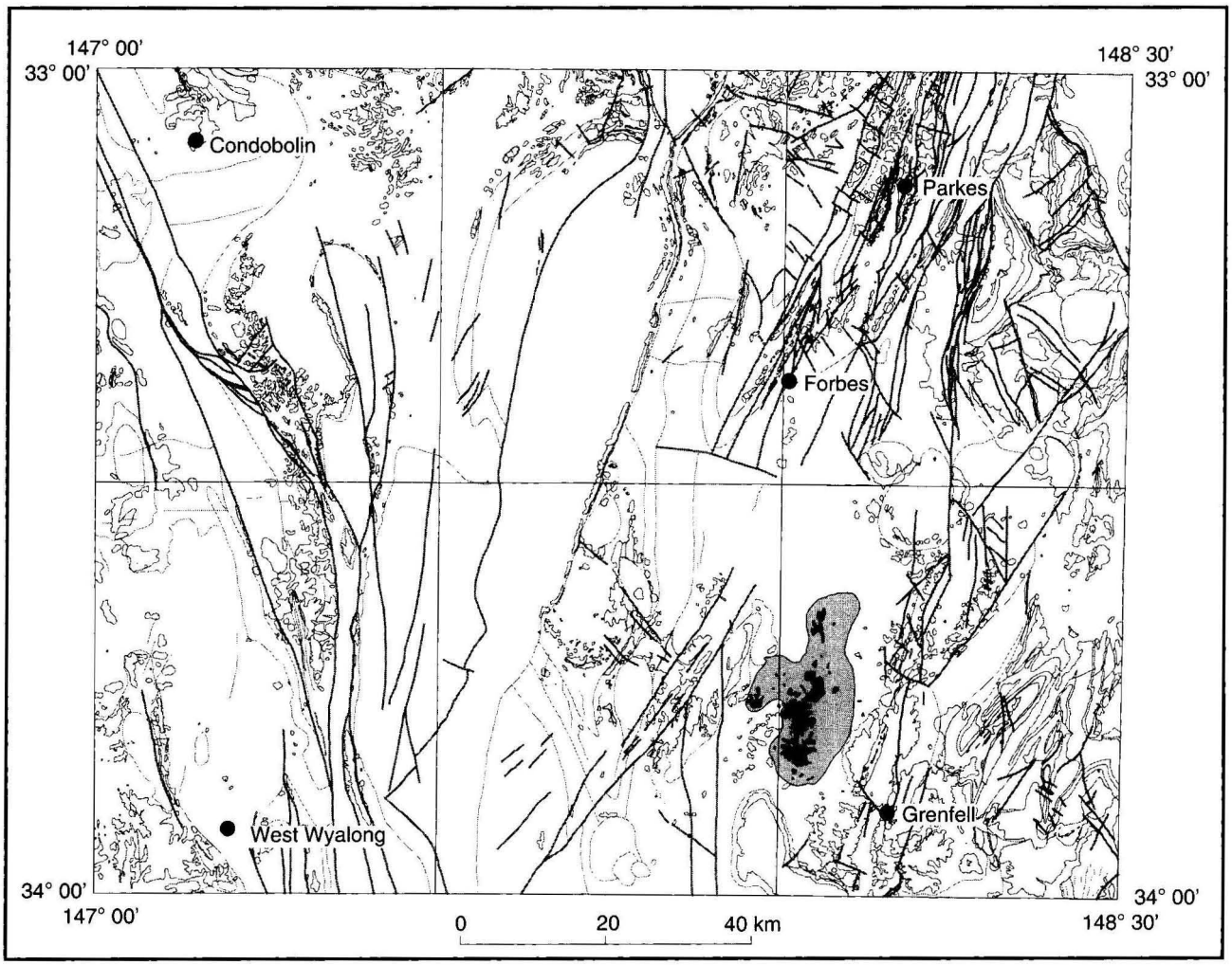



*Figure 9.3. Distribution of the Bogalong Suite in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

Grenfell, at the northern margin of the granite. The unit was referred to as the 'Glenroy Granite' by Duggan *et al.* (1999) and Raymond & Wallace (*in* Lyons & Wallace, 1999), but that name had been previously reserved. The granite was previously included as part of the 'Bogalong Granite' of Bowman (1976; 1977a,b) and Chappell *et al.* (1991). The type locality is on 'Glenroy', around GR 590200 mE 6263520 mN.

*Boundary relationships*

The Milroy Granite occurs as a discrete area of outcrop, of almost 3 $km^2$, surrounded by colluvial sediments. It is interpreted to have intruded the Ordovician Kirribilli Formation, which crops out immediately west of the granite. The low magnetic susceptibility and felsic composition of the Milroy Granite, and its proximity to the Bogalong Suite of granites suggest that the Milroy Granite is a western extension of the Bogalong Suite.

*Description*

The Milroy Granite is a felsic, pink to white, medium- to fine-grained biotite granite with rare miarolitic cavities. In thin section, K-feldspar and quartz tend to be in approximately equal proportions, and there is lesser plagioclase. Quartz and K-feldspar are commonly in micrographic intergrowth and the feldspars are variably sericitised. Fine-grained biotite, as ragged plates, is the main accessory mineral. The biotite is partially chloritised and may occur as acicular crystals. Trace titanite, tourmaline, and zircon also occur. Secondary epidote alteration occurs in places.

The magnetic susceptibility of the Milroy Granite is typically very low ($\sim 10 \times 10^{-5}$ SI), but rarely ranges up to $200 \times 10^{-5}$ SI. The intrusion has a prominent K-dominant gamma ray spectrometric signature, which is similar to the nearby Mortray Hill Granite Complex.

There are no geochemical data available for the Milroy Granite.

*Correlation and age*

The presence of micrographic intergrowths, rare miarolitic cavities and acicular biotite indicates that the Milroy Granite is a high-level intrusion. Although geochemical evidence is lacking, the Milroy Granite is included in the S-type Bogalong Suite due to its similar mineralogy (including tourmaline) and low magnetic susceptibility. The Bogalong Suite has been dated by the SHRIMP U–Pb method as Early Devonian (415.6 ± 5.1 Ma, L.P. Black, pers. comm., 1999).

## **Mortray Hill Granite Complex** (Dag; Daga, Dagb, Dagc) *nov*

*Nomenclature*

The Mortray Hill Granite Complex is a new name derived from a hill about 21 km northwest of Grenfell (GR 597000 mE 6267000 mN) where one phase of the complex crops out. The complex was previously divided into four granites, named by Duggan *et al.* (1999) and Raymond & Wallace (*in* Lyons & Wallace, 1999), the 'Mortray Hill Granite', 'Lucy Hill Granite', 'Rosehill Granite' and 'Hill Sixty Granite'. The formal use of these names for the phases of the Mortray Hill Granite Complex has been discontinued.

The Mortray Hill Granite Complex was previously included in the 'Bogalong Granite' (Bowman, 1976, 1977a,b; Chappell *et al.*, 1991).

*Distribution*

Outcrop of the Mortray Hill Granite Complex occurs in a belt up to 8 km wide, extending 24 km north from 'Roseville' (13 km west-northwest of Grenfell, GR 594700 mE 6254300 mN), to Hill Sixty (28 km north-northwest of Grenfell, GR 598300 mE 6275000 mN).

*Boundary relationships*

The Mortray Hill Granite Complex intruded the Ordovician Kirribilli Formation. Country rocks at, or close to, the contact crop out on the western margin of the complex. The eastern margin of the complex is covered by alluvium of Ootha Creek, and its position is interpreted from aeromagnetic data, which show a broad magnetic aureole developed in the Kirribilli Formation. Small outcrops of Kirribilli Formation on the Bald Hills Road occur within the contact aureole and show extensive cordierite spotting.

Some outcrops of greisenised metasediments occur within, and marginal to, the Mortray Hill Granite Complex (e.g., GR 591400 mE 6255500 mN). These have been the centre of tin exploration in, and around, the complex.

It is possible that the northern margin of the Mortray Hill Granite Complex may extend below shallow alluvial cover and Kirribilli Formation country rock for up to 10 km north of Hill Sixty. There is no apparent magnetisation of the aureole at the northern margin of the complex, and the aeromagnetic data do not define a boundary between the very weakly magnetic granite complex and its country rock. Data from water resources drilling in the area are widely spaced but indicate both granite and shale beneath the alluvial cover north of Hill Sixty. This may indicate that a thin skin of Kirribilli Formation covers the roof of the complex in that area, and that the currently exposed granite is close to the original top of the pluton.

*Constituent units and type localities*

The Mortray Hill Granite Complex consists of three identifiable phases:

*Daga:* This unit is a marginal phase, which occurs at the southern margin of the complex, south of the Mid Western Highway, on 'Roseville' and 'Narweena'. The type locality is at Rose Hill on 'Roseville' (GR 594700 mE 6254300 mN).

*Dagb:* This phase is the most widespread element of the complex. It encloses the Lucy Hill phase (Dagc) and occurs in three main parts: in the areas surrounding Mortray Hill and Hill Sixty, and in the area between the

Mid Western Highway and Lucy Hill. The type locality is exposed on the Henry Lawson Way at GR 600500 mE 6265200 mN.

*Dagc*: This phase is present towards the south of the complex, and occurs in the area surrounding Lucy Hill. The type locality is on Lucy Hill (GR 595400 mE 6260600 mN).

*Description*

*Daga*: The Rosehill phase is a fine- to medium-grained, equant, muscovite granite containing altered sodic plagioclase crystals, intercumulus K-feldspar and minor, but ubiquitous, primary muscovite. Some coarse-grained muscovite and euhedral quartz have crystallised in small, late-stage miarolitic patches up to 5 mm.

*Dagb*: The Mortray Hill/Hill Sixty phase is a grey to pinkish, medium- to coarse-grained granite consisting of quartz, strongly zoned, small sodic plagioclase crystals, intercumulus plates of perthitic K-feldspar, and minor, interstitial biotite as single crystals and small aggregates. The cores of the plagioclase are commonly sericite-altered. Rare flakes of muscovite and a greenish mica (?lepidolite) may occur, as do trace amounts of titanite, zircon, and apatite. Some cordierite occurs in the granite around Hill Sixty. Late-stage tourmaline alteration, with or without fluorite, is commonly developed throughout this phase of the complex (Figure 9.4). The coarse-grained rosettes of tourmaline are collectable for mineral specimens.

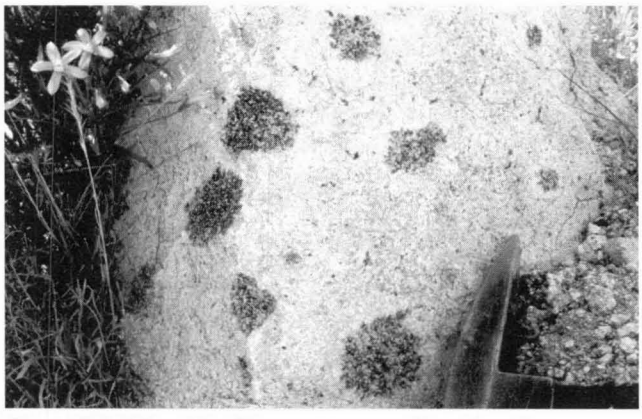


*Figure 9.4. Spheroids of late-stage tourmaline alteration developed in the Mortray Hill Granite Complex at Hill Sixty. (GR 598150 mE 6275070 mN) (O.L. Raymond photograph)*

*Dagc*: The Lucy Hill phase is a coarse-grained granite containing abundant flakes of intercumulus biotite, with large laths of K-feldspar (up to 4 cm in places) and minor plagioclase. The feldspars may be strongly altered. Minor apatite crystals also occur. Some crushing and recrystallisation of the granite has occurred and discrete sericite flakes may occur throughout.

*Geochemistry*

The Mortray Hill Granite Complex is a fractionated, S-type granite complex. Most analyses of the complex have ASI > 1.1. Data for $FeO/Fe_2O_3$ are only available for the Mortray Hill/Hill Sixty and Rosehill phases, but show that the complex is reduced to weakly oxidised.

Well-constrained fractionation trends are defined by decreasing Ba and Zr and increasing Rb/Sr ratio with increasing $SiO_2$. Samples of the Mortray Hill/Hill Sixty phase range from unfractionated to strongly fractionated as $SiO_2$ increases from 70.2 wt% to 76.6 wt%. Single samples of the Lucy Hill phase (75.4 wt% $SiO_2$) and Rosehill phase (76.5 wt% $SiO_2$) are moderately and strongly fractionated respectively. Th, and to some extent U, are not enriched by the fractionation process in these rocks.

*Correlation, age and intrusive environment*

The Mortray Hill Granite Complex is a broadly zoned and fractionated intrusion with a coarse-grained core (Dagc) surrounded by a finer-grained phase (Dagb) and a highly fractionated and felsic fine-grained phase (Daga), which was probably a late stage intrusion along the margin of the complex. The complex is included with the nearby Milroy Granite in the S-type Bogalong Suite (Chappell *et al.*, 1991).

A sample from the type locality of the Mortray Hill/Hill Sixty phase (Dagb) yielded an Early Devonian SHRIMP zircon U–Pb age of $415.6 \pm 5.1$ Ma (L.P. Black, pers. comm., 1999). Typical for S-type intrusions, there is significant scatter in the zircon analyses, probably due to inheritance. The uncertainty of the mean age for the granite has been increased to take account of this scatter (L.P. Black, pers. comm., 1999).

## Ungrouped Early Devonian Intrusions

**Broula Granite** (Dbg) Moffitt (*in* Pogson & Watkins, 1998)

*Nomenclature, distribution and boundary relationships*

The Broula Granite is a roughly elliptical pluton, about 8 km across, which occurs at the boundary of the Forbes and Bathurst 1:250 000 map sheet areas, centred about 18 km southwest of Cowra (Figure 9.5). Only the western margin of the granite crops out in the Forbes 1:250 000 map sheet area. The granite was shown as part of the Young Granodiorite by Brunker (1972) and Bowman (1976), and was included in the 'Bumbaldry Granite' of Chappell *et al.* (1991). The name Broula Granite was proposed by Moffitt (*in* Pogson & Watkins, 1998) and its name is derived from the Broula Range, which occurs within the granite. In the area of the Forbes 1:250 000 map sheet, the Broula Granite intruded the Silurian Young Granodiorite. In the Bathurst 1:250 000 map sheet area, the granite intruded the Early Devonian Warrangong Volcanics, and is overlain by the Late Devonian Hervey Group and alluvial sediments of the Lachlan River floodplain.

*Type area*

Moffitt (*in* Pogson & Watkins, 1998) proposed a type area

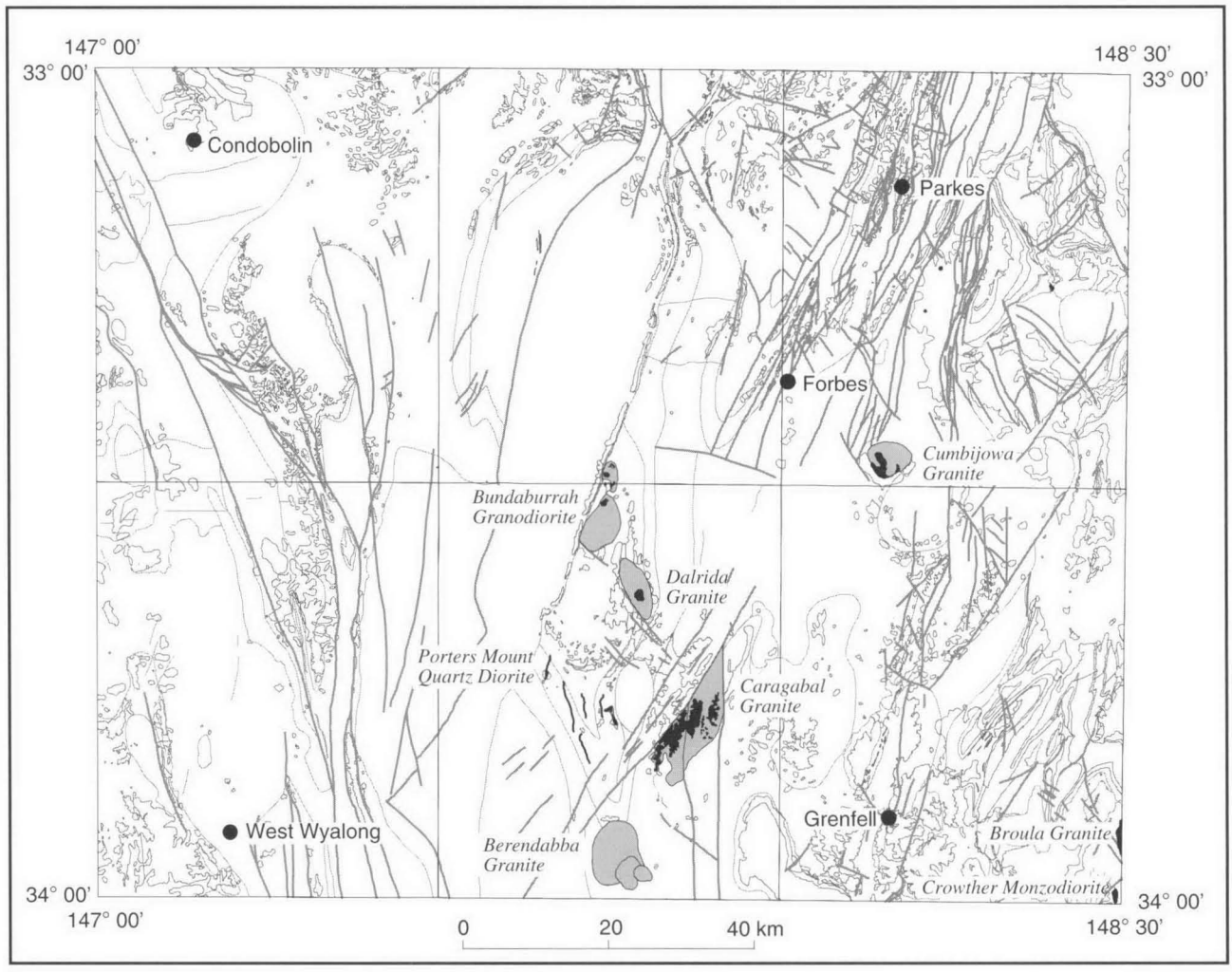



*Figure 9.5. Distribution of ungrouped Early Devonian intrusions in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

around GR 641900 mE 6244300 mN, about 5 km south of Broula in the Bathurst 1:250 000 map sheet area.

*Description*

The Broula Granite is a pink to red, medium- to coarse-grained, equigranular to weakly porphyritic, felsic granite (Figure 9.6). Perthitic K-feldspar, and lesser quartz and plagioclase ($An_{25}$ to $An_{40}$), comprise 95% of the rock. Around 5% consists of accessory minerals, including biotite, hornblende, titanite, magnetite, and trace zircon. There is minor alteration of biotite and hornblende to chlorite, epidote and calcite, and weak sericitisation of feldspars. The granite has a very high gamma ray count rate from all radioelements (K, Th, and U), resulting in a bright white on RGB spectrometric images. The granite is also strongly magnetic, with susceptibility typically greater than $500 \times 10^{-5}$ SI.

*Geochemistry*

The Broula Granite is a strongly oxidised, I-type granite. The granite is metaluminous (ASI = 0.94 to 0.98) and moderately to highly potassic (~5.5 wt% $K_2O$). The Broula Granite also contains extremely high concentrations of U (8 ppm to 20 ppm) and Th (57 ppm to 96 ppm), and very high levels of HFSE (e.g., Ti, Zr, Y and Nb) and REE. Despite these similarities with A-type granite compositions, the Broula Granite does not have the high Ga/Al ratio so characteristic of A-type granites. Also, the Broula Granite does not show typical signs of fractionation, such as a high Rb/Sr ratio. The extreme composition of the Broula Granite appears to have been derived from melting of a highly unusual refractory source rock.

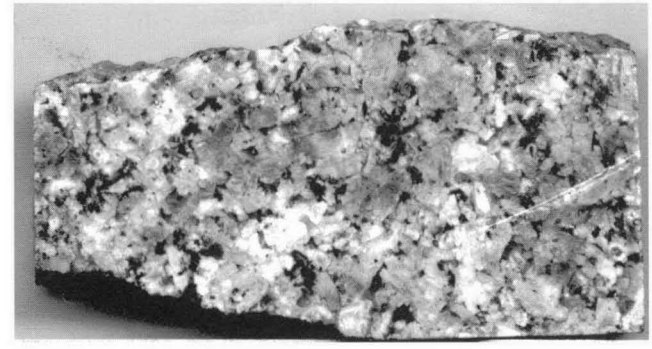


*Figure 9.6. Pink, K-feldspar-rich, biotite granite of the Broula Granite. Length of the sample is approximately 60 mm. (GR 638320 mE 6247180 mN) (O.L. Raymond photograph)*

*Age*

Chappell *et al.* (1991) considered that the Broula Granite was of Early Devonian age, although the only constraints on this age are that it intruded the Silurian Young Granodiorite and the probable Early Devonian Warrangong Volcanics.

## Dalrida Granite. (Ddg) *nov*

*Nomenclature and distribution*

The Dalrida Granite is a new name for a granite that occurs as large tors and whalebacks on 'Dalrida', north of Wirrinya (Figure 9.5). These outcrops are the only exposure of the granite, which is mainly covered by Cainozoic sediments. The outcrops occur near the centre of the intrusion and were denoted as Ordovician sediments on earlier 1:250 000 scale maps (Brunker, 1972; Bowman, 1976).

The Dalrida Granite is an undeformed, discordant granite with a near-elliptical shape. Its subsurface extent is defined by a large elliptical magnetic anomaly, about 9 km long and 3.5 km wide, elongated northwest. The magnetic data suggest the granite is compositionally zoned with several concentric zones of strong and weak magnetic susceptibility. A minor northwest-trending fault, also interpreted from magnetic data, appears to truncate the southern margin of the granite. A small, fine-grained, granophyric aplite body, which intruded the Pullabooka Formation near GR 573600 mE 6269200 mN, is probably a late stage, high level dyke sourced from the Dalrida Granite. Intrusion of the main granite body appears to have displaced and slightly rotated bedding in the Pullabooka Formation along the eastern margin of the Dalrida Granite. Howeyer, magnetic data suggest that basalt horizons in the Carawandool Volcanics were truncated at the northern and southern contacts of the Dalrida Granite with no associated deformation.

*Description*

The Dalrida Granite is a grey to pink, medium-grained, rather equigranular, felsic granite with minor (~5%) muscovite and biotite. Quartz (~45%), perthitic K-feldspar (~30%) and sodic plagioclase (~$An_{15}$, ~20%) are the dominant minerals. The plagioclase commonly contains marginally more calcic, oscillatory zoned and sericite-altered cores. Biotite, and to a lesser extent muscovite, is commonly replaced by chlorite ± epidote. Trace amounts of opaque iron oxide minerals, titanite, zircon, and apatite are also present. The outcropping granite, which occurs near the centre of the pluton, is moderately magnetic, with susceptibilities ranging from $150 \times 10^{-5}$ SI to $1150 \times 10^{-5}$ SI. The gamma ray spectrometric count rate is high for K, but relatively low for Th and U, compared with most granites.

*Geochemistry*

The Dalrida Granite is an unfractionated, felsic (72 wt% to 74 wt% $SiO_2$) S-type granite. It displays a typical S-type ASI *versus* $SiO_2$ trend (>1.1 and declining with increasing $SiO_2$; Chappell & White, 1974), and plots between the S-type compositions of the Young Granodiorite and the Bogalong Suite. However, the Dalrida Granite has anomalously high Sr (300 ppm to 400 ppm) for an S-type granite. The granite plots on the boundary between oxidised and reduced granites, as defined by Champion & Heinemann (1994). Although the magnetic signature of the granite suggests some compositional zonation, there is no evidence of fractionation in the samples analysed. The granite does not display common fractionation characteristics such as Ba depletion, or enrichment in Rb (~100 ppm), U (~2 ppm), Th (~10 ppm to 15 ppm) or Sn (1 ppm to 1.5 ppm).

*Age*

An Early Devonian (Emsian) age of 395.4 ± 1.7 Ma (L.P. Black, pers. comm., 1998) was obtained by the U–Pb SHRIMP zircon method. No attempt was made to date the numerous, older, inherited cores of the primary magmatic zircon grains. This crystallisation age is only marginally younger than the folded Carawandool Volcanics (403.8 ± 2.1 Ma), which the Dalrida Granite intruded. These two ages, one pre- and one post-deformation, together with that for the Porters Mount Quartz Diorite (399.7 ± 2.6 Ma) tightly constrain the age of deformation of the Carawandool Volcanics in the Currowong Syncline to around 400 Ma.

## Caragabal Granite (Dlg) Bowman (1977a)

*Derivation*

The Caragabal Granite is named after the village of Caragabal, about 7 km southwest of the southernmost out crop of the granite (Bowman, 1977a).

*Distribution*

The Caragabal Granite is a elongate body trending northeast–southwest and cropping out over an area of about 30 $km^2$ between the Mid Western Highway and Mount Wheoga (Figure 9.5). Aeromagnetic data indicate that the granite extends beneath alluvial cover up to 6 km north and 4 km south of the limits of outcrop.

*Boundary relationships*

The Caragabal Granite intruded the Ordovician Kirribilli Formation but no contacts are exposed. Small pods of an unnamed gabbro are located near the southern margin of the intrusion on 'Tatiara' and at the site of Ben Hall's homestead. That gabbro also intruded the Kirribilli Formation but the relationship between the gabbro and Caragabal Granite is unclear. At its northern margin, the Caragabal Granite is faulted against the Kirribilli Formation by a fault trending northeast–southwest, which is interpreted from aeromagnetic data to be a southern part of the Parkes Fault Zone. Although the Ordovician sedimentary rocks within the fault zone are very strongly cleaved, the Caragabal Granite, in outcrop, lacks any deformational fabric. This suggests: (1) that emplacement of the Caragabal Granite was structurally controlled along a pre-existing fault element of the Parkes Fault Zone; (2) that

deformation associated with later faulting has been strongly partitioned into the adjacent shales and sandstones, or (3) that the northwest part of an originally elliptical pluton has been faulted upwards and beyond the present level of erosion.

*Type locality*

The type locality for the Caragabal Granite is a quarry on the Pullabooka Road about 11 km southeast of Pullabooka (GR 580850 mE 6261120 mN) where a sample was obtained for age determination.

*Description*

The Caragabal Granite is typically a pink, medium- to coarse-grained, equant-textured rock, although it may be rhyolitic to microgranitic in places near its margins. The granite contains predominantly quartz and K-feldspar with a relatively low proportion of sodic plagioclase. Micrographically intergrown quartz and alkali felspar is common and biotite is a ubiquitous minor constituent.

The granite has a low to moderate magnetic susceptibility ($70 \times 10^{-5}$ SI to $150 \times 10^{-5}$ SI), and contrasts strongly with the surrounding very weakly magnetic sedimentary rocks. The granite has high gamma ray spectrometric count rates in all three radioelements (K, Th, U), showing as white in RGB images. The colluvial slopes surrounding the granite outcrops also have a high K signature.

*Geochemistry*

The Caragabal Granite is an oxidised I-type granite. Analyses of the granite range from 68.3 wt% to 76.5 wt% $SiO_2$, and only the most felsic sample exhibits any signs of fractionation such as a depleted Ba content and elevated Rb/Sr ratio. The granite has moderately high levels of HFSE (e.g., ≤481 ppm Zr), and does not have the low Th and Rb levels characteristic of the felsic volcanic rocks and granites west of the Parkes Fault Zone (e.g., the Carawandool Volcanics and the Wirrinya and Dalrida Granites).

*Age and correlation*

Zircons from the type locality gave an Early Devonian U–Pb SHRIMP age of 416.7 ± 2.8 Ma (L.P. Black, pers. comm., 1999). There are no other granites of similar composition and age in the region. The Bogalong Suite is the same age, but has a distinctly different fractionated S-type composition.

## **Crowther Monzodiorite** (Drm) Moffitt *in* Pogson & Watkins (1998)

*Nomenclature and distribution*

The Crowther Monzodiorite was named by Moffitt (*in* Pogson & Watkins, 1998) after the Crowther Range, which lies near the eastern margin of the Forbes 1:250 000 map sheet area, just north of the outcrop area of the intrusive. The Crowther Monzodiorite was previously shown as part of the Young Granodiorite by Brunker (1972) and Bowman (1976), and was included in the 'Bumbaldry Granite' of Chappell *et al.* (1991). The Crowther Monzodiorite occurs as a small body (~1km$^2$) at the southeastern corner of the Forbes 1:250 000 map sheet area (Figure 9.5), as well as in the Bathurst and Goulburn 1:250 000 map sheet areas. Outcrop of the monzodiorite is not as widespread as shown by Raymond *et al.* (1998) on the second edition of the Bathurst 1:250 000 geology map. Much of the area shown as Crowther Monzodiorite on that map is underlain by the Warrangong Volcanics.

*Description*

Moffitt (*in* Pogson & Watkins, 1998) described the Crowther Monzodiorite in the Bathurst 1:250 000 map sheet area as a coarse-grained porphyritic monzodiorite, which is intruded by a medium-grained diorite (Figure 9.7). The intrusive body exposed in the Forbes 1:250 000 map sheet area is a fairly equigranular, medium-grained hornblende monzodiorite. The rock consists mainly of plagioclase ($An_{35}$) and minor K-feldspar, with about 20% interstitial hornblende. Disseminated fine-grained titanite and opaque oxides are the main accessory minerals. The feldspars are generally sericitised and hornblende is partially replaced by actinolite. The monzodiorite has very variable magnetic susceptibilities, ranging from less than $100 \times 10^{-5}$ SI up to $3000 \times 10^{-5}$ SI. This is reflected in regional aeromagnetic data, which show a generally low magnetic signature across much of the outcrop of the Crowther Monzodiorite, with smaller magnetic highs, which may represent more mafic phases within a composite intrusion.

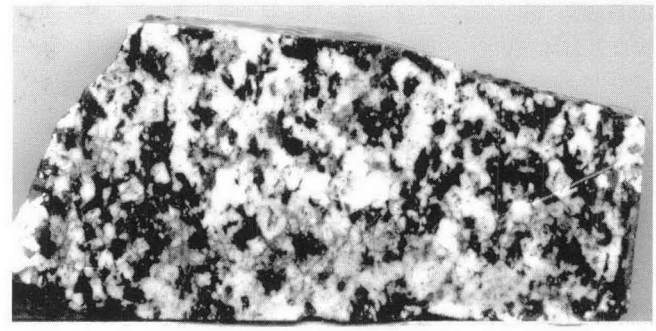


*Figure 9.7. Equigranular hornblende diorite of the Crowther Monzodiorite. Length of sample is approximately 60 mm. (GR 637660 mE 6238570 mN) (O.L. Raymond photograph)*

*Geochemistry*

There are three analyses of the Crowther Monzodiorite from the Bathurst 1:250 000 sheet area (Pogson & Watkins, 1998). The intrusion is a reasonably mafic I-type granitoid, with analysed samples containing 55 wt% to 63 wt% $SiO_2$. Its is metaluminous, unfractionated, and relatively oxidised. The composition of the Crowther Monzodiorite is similar to the Yeoval Granite Complex and Cuga Burga Volcanics of the Early Devonian Boggy Plain Supersuite (Wyborn *et al.*, 1987), with moderate to high $K_2O$ (2 wt% to 4 wt%), low $TiO_2$ (~0.7 wt%), and a relatively high content of incompatible elements, notably Rb. The monzodiorite also contains low Cr (<25 ppm) and Ni (<15 ppm) in more mafic samples.

*Age*

The Crowther Monzodiorite has not been isotopically dated. It is possibly related to the Warrangong Volcanics, which it intruded, and the Boggy Plain Supersuite, and is thought to be of Early Devonian age (Wyborn *et al.*, 1987).

## **Cumbijowa Granite** (Dcg) Chappell *et al.* (1991), modified after Turner (1983)

*Nomenclature, distribution and boundary relationships*

Chappell *et al.* (1991) first used the name Cumbijowa Granite ('Cumbijowa Adamellite' of Turner, 1983) to describe an intrusion cropping out just south-west of the locality of Cumbijowa, about 18 km southeast of Forbes (Figure 9.5). Brunker (1972) and Bowman (1976) included the Cumbijowa Granite as part of the Eugowra Granite. The Cumbijowa Granite intruded the Ordovician Kirribilli Formation, but it only appears in outcrop near its southern margin. The majority of the granite is overlain by Quaternary colluvium and alluvium up to 60 m deep. The granite is very weakly magnetic, but the boundary of a roughly elliptical body 5 to 6 km across can be delineated in aeromagnetic data by a moderately magnetic contact aureole in the surrounding Kirribilli Formation.

*Description*

Turner (1983) described the Cumbijowa Granite in some detail, and much of the following description is taken from his work. The granite is a coarse grained leucogranite, with euhedral to subhedral, perthitic K-feldspar grains up to 20 mm. The K-feldspar crystals are white, unlike the pink K-feldspar of the more oxidised Eugowra Suite granites. The granite also contains plagioclase, quartz, biotite, muscovite, accessory garnet, apatite, zircon, and minor secondary chlorite and clinozoisite. The granite contains virtually no visible iron oxide phase. Plagioclase ($An_{15}$ to $An_{42}$) occurs as euhedral to subhedral crystals up to 7 mm, with oscillatory zoning. Quartz (up to 10 mm) is commonly euhedral, but may have sutured and recrystallised grain boundaries. Biotite and minor muscovite occur as elongate subhedral to ragged grains up to 2 mm. Biotite contains abundant apatite and zircon inclusions with pleochroic haloes.

*Geochemistry*

The Cumbijowa Granite is a reduced, fractionated S-type granite and is readily distinguished from the generally oxidised, I-type granites of the adjacent Eugowra Suite. The two analyses of the Cumbijowa Granite have $SiO_2$ around 73.9 wt%, with an ASI above 1.06 — higher than all the I-type granites of the adjacent Eugowra Suite. Biotites in the Cumbijowa Granite are also an order of magnitude more aluminous than those from the Eugowra Suite (Turner, 1983). The granite has high Rb (257 ppm to 274 ppm) and low Ba (309 ppm to 343 ppm) indicating a moderately fractionated magma.

*Age*

The Cumbijowa Granite has not been isotopically dated. Contact relations indicate only that it is younger than the Ordovician Kirribilli Formation, which it intruded. It is inferred to have been emplaced some time during the Early Devonian. The adjacent I-type Eugowra Suite has been dated at about 394 Ma (Emsian). The S-type Bogalong Suite, which is geochemically similar to the Cumbijowa Granite but crops out about 20 km to the south, has been dated at 416 Ma (Lochkovian).

## **Porters Mount Quartz Diorite** (Dpd) *nov,* modified after Duggan *et al.* (1999)

*Nomenclature, distribution and boundary relationships*

The Porters Mount Quartz Diorite is a new name for a small dyke-like intrusion at Porters Mount, 15 km west-southwest of Wirrinya (Figure 9.5). The intrusion occurs in a northwest trending valley between two hills of Pullabooka Formation quartzite. The intrusion was referred to as the 'Porters Mount Tonalite' by Duggan *et al.* (1999) and Lyons & Wallace (1999). More recent petrographic and geochemical data indicate that the rock is more properly classified as a quartz diorite. It occurs only in poor subcrop at the surface, but has been observed in exploration pits and shallow drilling. It has a distinct elongate magnetic anomaly extending for 2.5 km north of Porters Mount beneath Cainozoic cover. Hydrothermal activity associated with intrusion of the quartz diorite into the Pullabooka Formation is thought to have produced the extensive Porters Mount breccia zone and quartz–tourmaline–illite ± ankerite alteration.

*Description*

The Porters Mount Quartz Diorite is described from exploration drilling and appears to be a composite body of variably altered quartz diorite, microdiorite and tonalite (Burrell, 1997). The quartz diorite is a pink to grey, medium-grained, sparsely porphyritic intrusive rock containing predominantly euhedral to subhedral oligoclase ($An_{10}$, ~50%) with interstitial quartz (~30%). The plagioclase crystals are typically around 1 mm, but range up to 4 mm, and exhibit a cumulate texture. The plagioclase is strongly sericitised and probably partly albitised. Hornblende and biotite (~15%) are almost entirely altered to some or all of chlorite, epidote, calcite, and actinolite. Up to 5% disseminated opaque oxides and pyrite may occur, with accessory zircon and titanite. A variety of altered rocks, containing extensive sericite–quartz–albite–chlorite–calcite–pyrite alteration with or without clay and leucoxene, have been described in unpublished company drilling reports by Barron (*in* Burrell, 1997).

*Geochemistry*

A single pink quartz diorite sample of percussion chips, provided by Climax Mining Ltd, from a drill hole at GR 561000 mE 6267620 mN was analysed. The quartz diorite is an unfractionated, I-type intrusion with about

61 wt% $SiO_2$. The rock has an unusually high Na/Ca ratio (normative plagioclase composition = $An_{14}$), and could be classified as a trondhjemite. It has very low concentrations of Fe (2.3 wt% total Fe as $Fe_2O_3$) and Ca (3.3 wt% CaO). The rock has moderately high levels of some incompatible elements (K, Ba, Sr, REE), but is low in others (Rb, Th). It has moderately high levels of HFSE, such as Ti and Zr.

Wyborn & Sun (1993) obtained a εNd value of +6.5 from the quartz–tourmaline alteration breccia zone, adjacent to the Porters Mount Quartz Diorite. They concluded that the alteration and, by analogy, the intrusion were related to Ordovician magmatism. However, Raymond & Sun (1998) noted that similar εNd values are associated with some Devonian igneous rocks in the Lachlan Fold Belt and are not exclusive to Ordovician rocks. The strongly positive εNd value does suggest that the quartz diorite was derived from similar source material to that of Ordovician magmatism. Wyborn *et al.* (1987) suggested that the Early Devonian Boggy Plain Supersuite was derived from melting of a mantle-derived, Ordovician gabbroic source in the lower crust. Although the Porters Mount Quartz Diorite has some similarities to the Boggy Plain Supersuite (e.g., high K, Ba, Sr, REE), concentrations of other elements (e.g., low Ca, Rb, Th; high HFSE) are significantly different, and it is problematic whether the quartz diorite should be included in the supersuite.

*Age and intrusive environment*

The Porters Mount Quartz Diorite sample that was chemically analysed was also dated by the SHRIMP zircon U–Pb method (L.P. Black, pers. comm., 1998). A crystallisation age of 399.7 ± 2.6 Ma (Early Devonian) was obtained. The quartz diorite was probably intruded at a reasonably high level, given the amount of hydrothermal brecciation that occurred in the wall rocks. The Porters Mount Quartz Diorite is probably related to other exposed and unexposed dyke-like bodies, interpreted from magnetic data to have intruded the Pullabooka Formation after folding of the Currowong Syncline. This interpretation constrains the folding episode to be between 404 Ma (SHRIMP age of the Carawandool Volcanics) and about 400 Ma (SHRIMP age of the Porters Mount Quartz Diorite).

## **Berendebba Granite** (Drg) *nov*

*Nomenclature*

The Berendebba Granite is a new name, derived from the Parish of Berendebba, in which it occurs.

*Distribution*

The Berendebba Granite forms a recessive erosional low and is entirely covered by alluvial sediments up to 120 m thick. Based on interpretation of aeromagnetic data, the Berendebba Granite is a composite intrusion, with two smaller nested plutons intruded into the south-eastern margin of the main pluton. The main elliptical granite body has a north–south diameter of about 9 km, and is centred about 11 km south of Caragabal (Figure 9.5). The estimated area of the Berendebba Granite is about 70 $km^2$.

*Boundary relationships*

The Berendebba Granite is the southernmost of three, possibly related, post-tectonic, elliptical plutons, which occur in a north–south line in the Wirrinya–Caragabal area. The other plutons are the A-type Wirrinya Granite and the S-type Dalrida Granite. Contact metamorphosed sediments of the Derriwong Group mark part of the northern margin of the Berendebba Granite about 6 km south of Caragabal (GR 569780 mE 6248330 mN). The Berendebba Granite is also interpreted to have intruded the Ordovician Kirribilli Formation.

*Description*

A single float boulder, assumed to be derived from the granite, was obtained from alluvial sediments overlying the central part of the granite. The sample had strong sericitic alteration and was extensively recrystallised, and provided no useful primary mineralogical information.

*Geochemistry*

The altered float boulder was chemically analysed. Despite the alteration, the analysis shows few signs of metasomatism. $Na_2O$ is not abnormally low (3.6 wt%) and $SiO_2$ is not obviously elevated (71.9 wt%). CaO is fairly low (0.6 wt%), but this could be a primary feature. Assuming the composition of the sample was not greatly affected by the alteration, the granite is both oxidised and unfractionated. It has a high Aluminium Saturation Index (ASI ≈ 1.5), suggesting an S-type origin, but has relatively high Zr for an S-type granite (277 ppm).

*Age, correlation and intrusive environment*

The elliptical shape of the Berendebba Granite indicates a post-tectonic intrusive environment, similar to the Dalrida Granite and the Wirrinya Granite. All these granites intruded the Currowong Syncline, which formed around 400 Ma. The age of the Berendebba Granite is probably comparable to the Dalrida Granite, which has been isotopically dated as Early Devonian (395.4 ± 1.7 Ma, L.P. Black, pers. comm., 1999).

## **Bundaburrah Granodiorite** (Dug) modified after Bowman (1976)

*Nomenclature, distribution and boundary relationships*

The Bundaburrah Granodiorite was named after the locality of Bundaburrah by Bowman (1977a). It was previously named the 'Bundaburrah Granite' (Bowman, 1976) and was earlier included as part of the Grenfell Granite by Brunker (1972). The granodiorite crops out on Gooburthery Hill, 3 km northeast of Bundaburrah (Figure 9.5), and in several smaller outcrops 2 km to 4 km north of there. The subsurface extent of the granodiorite may be indicated by a poorly defined magnetic anomaly extending south from Gooburthery Hill to the Carawandool State Forest. However, it is likely that the granite underlies a larger area

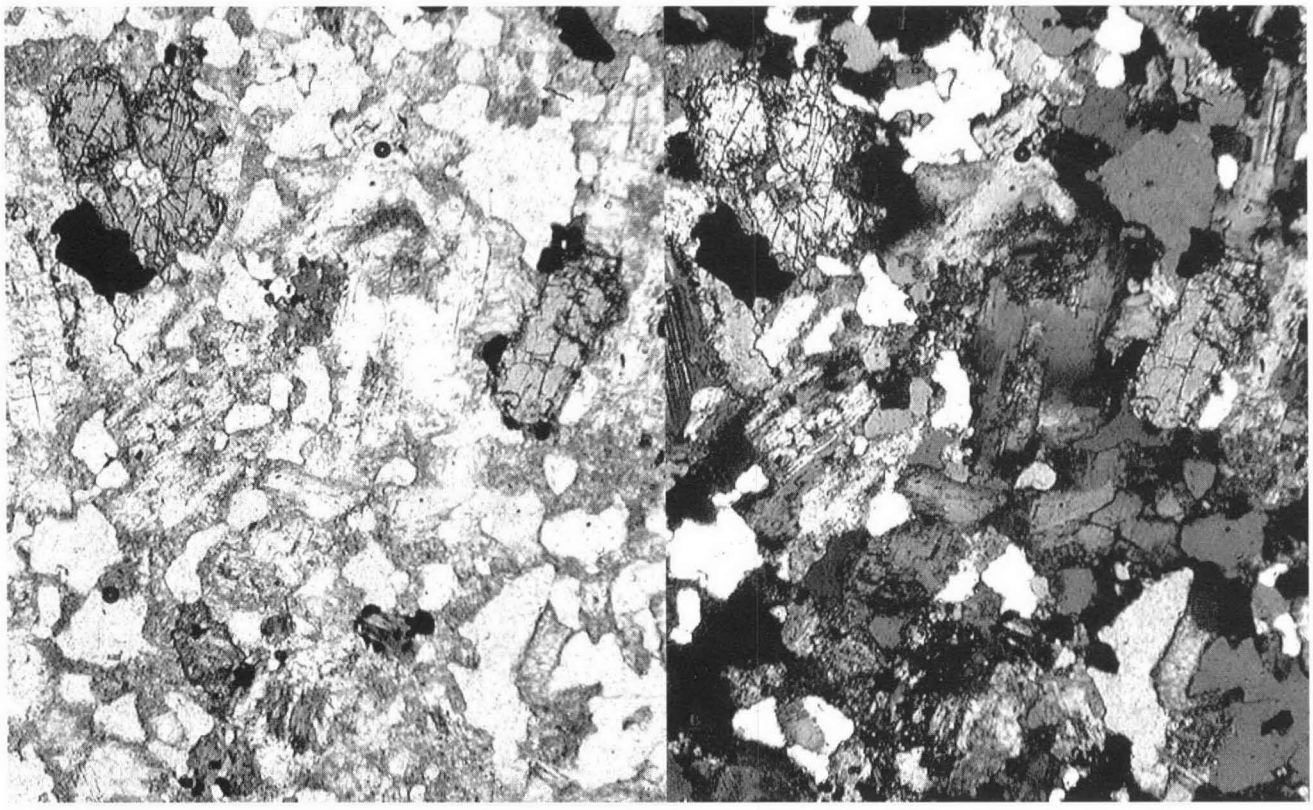


*Figure 9.8. Photomicrographs (plane polarised light and crossed polars) of the Bundaburrah Granodiorite showing orthopyroxene with minor hornblende, magnetite and biotite in a quartz–feldspar matrix. Fields of view are approximately 2 mm across. (GR 570250 mE 6293070 mN) (O.L. Raymond photograph)*

defined by a shallow topographic basin, about 5 km across, filled with Cainozoic sediments up to 60 m thick. The recessive expression of the Bundaburrah Granodiorite is similar to that of the nearby Dalrida Granite and Wirrinya Granite. The Bundaburrah Granodiorite intruded the Early Devonian Carawandool Volcanics, and is unconformably overlain by the Late Devonian Hervey Group

*Description*

The Bundaburrah Granodiorite is a composite intrusion comprised mainly of fine- to medium-grained (typically ≤ 1 mm) orthopyroxene–augite–hornblende granodiorite. A more mafic monzodiorite phase occurs north of Gooburthery Hill, and one sample taken at Gooburthery Hill has a tonalitic composition. The granodiorite is unusual in that it commonly contains both orthopyroxene and clinopyroxene (Figure 9.8). The rock consists predominantly of a fairly equigranular, anhedral to subhedral intergrowth of plagioclase, quartz, and lesser K-feldspar. Minor hornblende, orthopyroxene, clinopyroxene, titanite, magnetite, biotite, and trace apatite comprise 5% to 15% of the rock in total. Plagioclase may occur as subhedral to euhedral phenocrysts, up to 2 mm, and is commonly composed of zoned calcic cores ($An_{35}$ to $An_{60}$) rimmed by alkali feldspar. Hornblende may have cores of clinopyroxene, and may be partially altered to chlorite, actinolite, and biotite. The orthopyroxene, probably hypersthene, is weakly pleochroic (pink to colourless).

The magnetic susceptibility of the granodiorite typically ranges between $1000 \times 10^{-5}$ SI and $1800 \times 10^{-5}$ SI. Minor weakly magnetic outcrops occur. The granodiorite appears dull red on gamma ray spectrometric RGB images, reflecting a moderate count rate in K with low Th and U.

*Geochemistry*

The Bundaburrah Granodiorite is an oxidised, calc-alkaline, I-type intrusive, typically containing 68 wt% to 69 wt% $SiO_2$. The more mafic monzodiorite phase contains around 58 wt% $SiO_2$. The granodiorite phase has moderately high $TiO_2$ concentrations (up to 0.7 wt% $TiO_2$) – significantly higher than the monzodiorite and tonalite phases (~0.5 wt% $TiO_2$). Concentrations of other HFSE (e.g., Zr, Nb, Y) are not anomalously high, and REE are relatively low (e.g., 30 ppm to 55 ppm Ce). The Bundaburrah Granodiorite is not fractionated, having low to very low Rb (≤ 75 ppm) and Th (≤ 10 ppm), and high Sr (> 270 ppm).

Many geochemical features of the granodiorite are similar to the Carawandool Volcanics, which the granodiorite intruded, suggesting a similar source rock. The presence of pyroxenes in the granodiorite suggests that the magma was relatively dry. The mafic mineralogy of the granodiorite is similar to some of the more mafic members of the Boggy Plain Supersuite (Wyborn *et al.*, 1987). However, the Bundaburrah Granodiorite is not high in incompatible elements (e.g., K, Ba, Rb, U, Th, REE) and is, therefore, geochemically unlike the Boggy Plain Supersuite.

*Age and intrusive environment*

The Bundaburrah Granodiorite has not been isotopically dated. It is older than the overlying Late Devonian Hervey Group and may be related to the Early Devonian Carawandool Volcanics, which it intruded. However, it is apparently undeformed and may have been emplaced after folding of the Carawandool Volcanics in the Currowong Syncline, at around 400 Ma. The granodiorite is possibly of similar age to the Early Devonian Dalrida Granite (~395 Ma).

### **Unnamed Devonian intrusions** (Di) *nov*

Various small Devonian intrusions are scattered throughout the eastern half of the Forbes 1:250 000 map sheet area. They comprise plugs and dykes of dolerite, gabbro, diorite, quartz diorite, and tonalite. Some of these have very poor outcrop and their extent and contact relationships have been interpreted from aerial photography and geophysics.

*Distribution and boundary relationships*

The unnamed Devonian intrusions occur between Pullabooka and Caragabal; at the southern end of the Caragabal Granite; 5 km east of Wheoga Hill; immediately north of the Eugowra Granite, on 'Rawene'; and in two occurrences some 21 km and 26 km due northeast of Forbes.

Except for a quartz diorite exposed on 'Rawene', most occurrences of Di are either surrounded by Cainozoic sediments, as is the case for the tonalite outcrops east of Wheoga Mountain, or their country rocks have been inferred. The quartz diorite on 'Rawene' occurs in a creek bed (GR 629800 mE 6318700 mN) and shows intrusive contacts with the Late Silurian Moura Formation, and granitic dykes derived from the Early Devonian Eugowra Granite.

*Description*

The quartz diorite occurring on 'Rawene' is a medium- to coarse-grained, two-pyroxene–quartz diorite and is coincident with a strong magnetic anomaly. The various dolerite intrusions have similarly strong magnetic anomalies. They are typically medium-grained, equigranular, clinopyroxene dolerites with trace amounts of quartz and secondary metamorphic chlorite, epidote and actinolite.

The tonalite east of Wheoga Mountain is a leucocratic, medium- to fine-grained, high level intrusion. It consists primarily of euhedral to anhedral, zoned, plagioclase crystals (~35%), in a fine-grained matrix of anhedral quartz (~30%) and albite (~25%). The matrix may be weakly granophyric. Anhedral to bladed green clinopyroxene (10% to 15%) is partly replaced by epidote. Accessory minerals include euhedral titanite (up to 3%), lesser apatite, and zircon. The tonalite has no magnetic expression.

*Geochemistry of the tonalite*

The tonalite is a weakly reduced, unfractionated, metaluminous I-type intrusion with 71 wt% $SiO_2$. The lack of K-feldspar is reflected in its high CaO (5.5 wt%), and very low $K_2O$ (0.2 wt%) and Rb (3 ppm) concentrations. The tonalite has very high levels of HFSE (e.g., 0.65 wt% $TiO_2$), and high Sr (400 ppm), similar to the Carawandool Volcanics.

*Age*

Field relationships show that the quartz diorite has an Early Devonian age, as it intruded the Late Silurian Moura Formation and was intruded by the Late Devonian Eugowra Granite.

The tonalite has not been isotopically dated and no contact relationships are exposed. Although the tonalite is adjacent to granites of the Early Devonian (Lochkovian) Bogalong Suite, its I-type composition contrasts strongly with the fractionated S-type Bogalong Suite, and it was most probably not emplaced at the same time. A slightly younger Early Devonian age (Pragian to Lochkovian) is suggested, similar to the majority of I-type magmatism in this part of the Lachlan Fold Belt, but the origin of the tonalite is unclear.

The poorly exposed dolerite and gabbro intrusions intrude Ordovician and early Devonian country rocks, and in the absence of other evidence, their age is inferred to be similar to the tonalite and quartz diorite intrusions.

## Ungrouped Middle Devonian Intrusions

### **Bindogandri Granite** (Dig) Bowman (1976, 1977a)

*Nomenclature, distribution and boundary relationships*

The Bindogandri Granite was named by Bowman (1976) after the locality and the creek of that name, which flows between outcrops of the granite, about 18 km east of Parkes. In 1979 the spelling of the geographical names was changed to Bindogundra, but the name and spelling of the granite remains Bindogandri. The granite was referred to as the 'Bumberry Granite' by Powell *et al.* (1980).

The Bindogandri Granite crops out as several discrete bodies on the eastern and western sides of the Bumberry Syncline (Figure 9.9). It is overlain by the Late Devonian Hervey Group and is interpreted to be folded in the Bumberry Syncline. On the western side of the syncline, the granite is substantially covered by Cainozoic colluvial sediments. The granite intruded the Ordovician Kirribilli Formation and Late Silurian Moura Formation with minor contact metamorphism. The contact with the Kirribilli Formation may be partially faulted along a splay of the Coolac–Narromine Fault Zone. On the eastern side of the Bumberry Syncline, the granite is faulted against the Hervey Group along the Bumberry Fault. The contact with the Middle Devonian Dulladerry Volcanics is probably intrusive, but the Dulladerry Volcanics may also overlie the

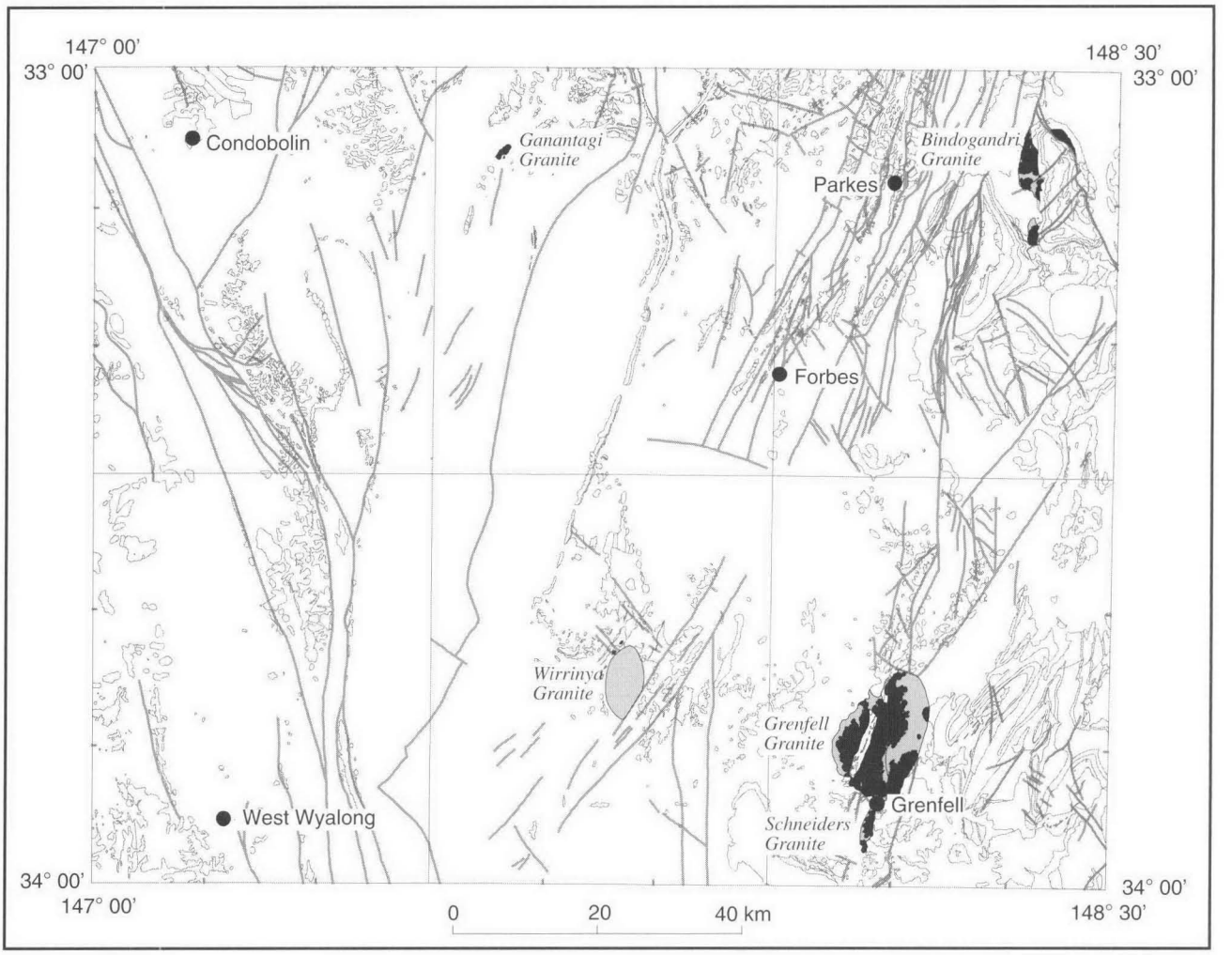



*Figure 9.9. Distribution of ungrouped Middle Devonian intrusions in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

granite. In either case, the Bindogandri Granite is probably of similar age and genetically related to the Dulladerry Volcanics.

Exposures of the Bindogandri Granite south of the Parkes–Orange road have been previously mapped as Dulladerry Volcanics (e.g., Brunker, 1972; Williams, 1975; Chappell *et al.*, 1991). There is a small area of rhyolitic tuff in this region, but the majority of the bedrock in the area is a fine-grained pink microgranite.

*Description*

The Bindogandri Granite consists of pink, fine- to medium-grained, generally equigranular, granophyric granite and microgranite (Figure 9.10). Some areas of the granite south and southwest of Bumberry Dam have miarolitic cavities filled with varying proportions of quartz, alkali feldspar, chlorite, calcite, muscovite and, rarely, a weakly-coloured allanite. Quartz, K-feldspar and minor plagioclase ($An_{35}$) occur mainly as rounded to euhedral, volcanic-like crystals in a groundmass of granophyric-textured quartz and alkali feldspar. The feldspars may be strongly sericitised. Northern exposures of the granite are generally medium-grained (1 mm to 2 mm) and have a small proportion of granophyric groundmass (~20%) relative to quartz and feldspar crystals. The southern parts of the granite are generally finer-grained (<1 mm) and have more granophyric groundmass (up to 80%; Figure 9.11). These features, combined with the distribution of miarolitic cavities, suggest that higher levels of the granite are exposed in the southern areas of outcrop. This is especially true of the microgranite body south of the Parkes–Orange road, parts of which can be almost entirely composed of very fine grained granophyric quartz and feldspar, and may resemble a rhyolitic volcanic rock in hand specimen.

*Figure 9.10. Pink, medium-grained, equigranular granite of the Bindogandri Granite. (GR 626890 mE 6335150 mN) Length of sample approximately 60 mm. (O.L. Raymond photograph)*

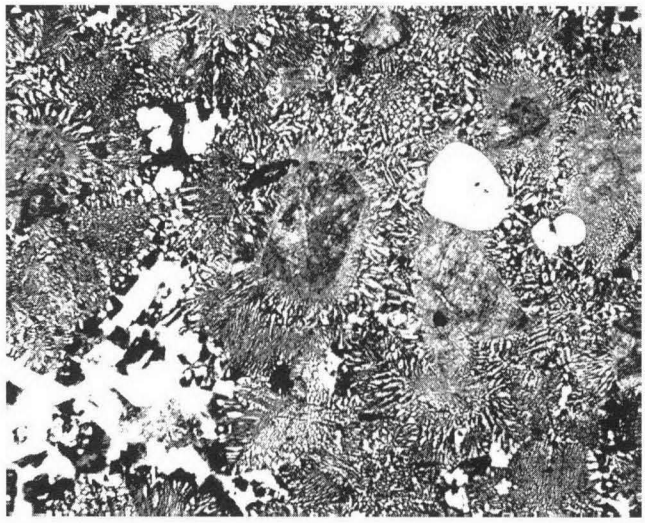


*Figure 9.11. Photomicrograph (plane polarised light) of quartz and K-feldspar crystals in a granophyric groundmass from a strongly granophyric part of the Bindogandri Granite. Width of field of view is approximately 4 mm. (GR 631010 mE 6339610 mN) (O.L. Raymond photograph)*

The granite has only very minor amounts of mafic minerals. Typically, biotite is strongly altered to chlorite ± muscovite ± epidote ± opaque oxides and comprises up to 2% of the rock. Accessory primary iron oxide minerals, and trace amounts of zircon and titanite also occur. Trace amounts of prismatic, sodic hornblende were observed in one sample, and fluorite in another. The granite has a low but variable magnetic susceptibility, with a median of around $50 \times 10^{-5}$ SI, within a range of $5 \times 10^{-5}$ SI to $400 \times 10^{-5}$ SI. The strongly felsic composition of the granite results in high gamma ray spectrometric count rates for K, Th, and U.

*Geochemistry*

The Bindogandri Granite is an oxidised to strongly-oxidised, felsic granite (75 wt% to 77 wt% $SiO_2$). Despite its highly felsic composition, the granite is not fractionated. It has high Ba (650 ppm to 900 ppm) and only moderately high Th (21 ppm to 24 ppm), U (3 ppm to 5.5 ppm) and Rb/Sr ratio. The granite has some A-type characteristics, such as high Ga/Al and Fe/Mg ratios (Figure 9.12) and high Zn (30 ppm to 85 ppm) and F (≤ 1000 ppm). However, levels of other elements (e.g., HFSE, REE) are in the upper range of normal fractional crystallisation trends of the I-type Boggy Plain Supersuite (Wyborn *et al.*, 1987) (Figure 9.13).

The composition of the Bindogandri Granite lies in the uncertain area between the A-type and the felsic, particularly fractionated, I-type granites. Many felsic I-type granites of the Lachlan Fold Belt, both fractionated and unfractionated, could be classified as A-type on some discriminant diagrams (e.g., Ga/Al ratio *versus* Zr+Nb+Ce+Y; Whalen *et al.*, 1987; Eby, 1992). The Bindogandri Granite displays some A-type affinities without evidence of strong fractionation. That, and the proximity of the granite to the A-type Dulladerry Volcanics, suggest that the granite is probably A-type and related to the Dulladerry Volcanics.

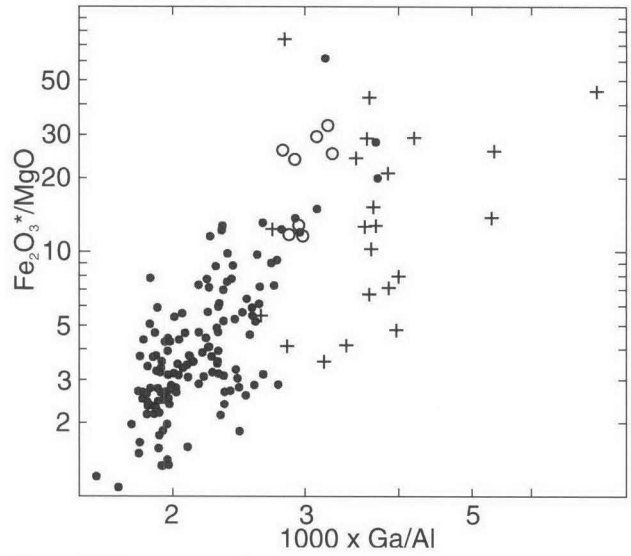



*Figure 9.12. $Fe_2O_3^*/MgO$* versus *1000 × Ga/Al plot (after Whalen* et al., *1987) of the A-type Bindogandri Granite (open circles) and Dulladerry Volcanics (crosses), and for comparison, rocks of the I-type Boggy Plain Supersuite (dots) including the Eugowra Suite, Yeoval Granite Complex, and Mountain Creek Volcanics.*

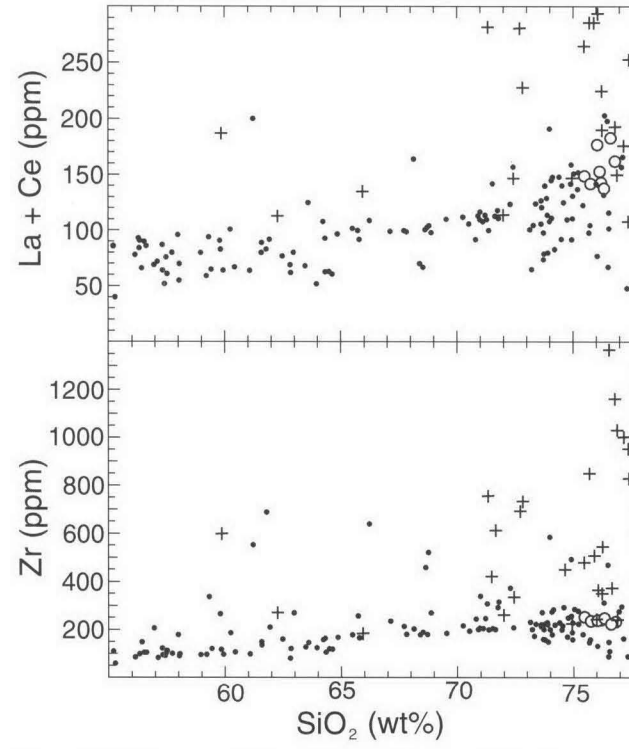



*Figure 9.13. Zr* versus *$SiO_2$ and (La+Ce)* versus *$SiO_2$ plots showing the relatively low levels of HFSE and REE in the Bindogandri Granite. Symbols as for Figure 9.12.*

*Age and intrusive environment*

Previous authors (Williams, 1975; Wyborn *et al.*, 1987; Chappell *et al.*, 1991) assigned an Early to Middle Devonian age to the Bindogandri Granite. A Middle

Devonian age is favoured here because of its relationship to the Dulladerry Volcanics. The Bindogandri Granite is a high level, subvolcanic intrusion, characterised by fine-grained, granophyric and miarolitic textures. The granite was probably intruded into a continental rift environment during eruption of the Dulladerry Volcanics.

## **Ganantagi Granite** (Dng) Raggatt (1937)

*Previous nomenclature*

Raggatt (1937) named the "granitic rock" at Ganantagi Mountain the 'Ganantagai Granite' but provided no details of the petrography or composition of the rock.

*Distribution and outcrop*

The Ganantagi Granite forms the prominent Ganantagi Mountain, which rises steeply above the surrounding plains, 3 km northeast of Yarrabandai. The steeper slopes have very little soil cover so that there is extensive outcrop. The elongate outcrop is crossed by many lineaments that are very obvious on aerial photographs.

*Description*

The peralkaline granite is medium- to coarse-grained and pink to flesh-coloured. Many thin sections (e.g., T64711, GR 556000 mE 6336450 mN), sampled near, or in line with lineaments, show evidence of strong crushing with breccia and gouge lenses. A thin section of a mildly crushed sample (T64712, GR 556250 mE 6336700 mN) contains miarolitic K-feldspar, aegirine, 15% quartz, Ti-magnetite, apatite, and arfvedsonite, with some of the quartz being a cavity filling. A less-disturbed sample from near the edge of the main outcrop (T64215, GR 557000 mE 6337800 mN), has around 25% interstitial K-feldspar, rimming and as exsolution in plagioclase ($An_{35}$); 20% quartz in granophyric intergrowth with K-feldspar, accessory ?biotite, Ti-magnetite, and titanite; and possible trace zircon and allanite. There is minor alteration to sericite and clay.

*Geochemistry*

The Ganantagi Granite is a peralkaline A-type granite. The granite has a peralkalinity index of around 1.1, high $SiO_2$ (73 wt% to 74 wt%) and $Na_2O$ (4.8 wt% to 5.3 wt%); and very low CaO (0.05 wt% to 0.13 wt%). The granite is also strongly oxidised; has very high levels of HFSE, (e.g., Zr, Nb, Y); and has a high Ga/Al ratio, typical of A-type granites.

*Age and relationships*

Raggatt (1937) stated that the Ganantagi Granite "...is clearly a sill intruding the Ootha Series, but there is no other field evidence bearing on its age relationships." (p. 94). The peralkaline composition of the granite is not conducive to zircon crystallisation and no datable zircon grains were found (L.P. Black, pers. comm., 1999). Because the hill formed by this unit is surrounded by Quaternary colluvial sediments, it is difficult to determine the nature of its relationship with other Palaeozoic units in the area. The main axis of the outcrop is aligned, more or less, with the local strike of the Cookeys Plains Formation. On the northern side of Ganantagi Mountain there is a small area (GR 556100 mE 6337830 mN) of ?hornfelsed fine-grained sandstone, of Cookeys Plains type, at the foot of the slope and part way up the northern slope. A weathered, grey, feldspar porphyry in the same vicinity could be either intruded Byong Volcanics or a chilled margin of the Ganantagi Granite. Boundary relationships indicate that the maximum age is Early Devonian. However, the extreme peralkaline composition of the Ganantagi Granite is unlike any other Early Devonian intrusion in the region. It is more likely that the Ganantagi Granite is younger, perhaps Middle Devonian, similar to the A-type Bindogandri Granite or Wirrinya Granite, or Late Devonian, similar to the peralkaline Narraburra Suite north of Temora (Cootamundra 1:250 000 map sheet area).

## **Wirrinya Granite** (Dwg) Bowman (1976)

*Nomenclature and distribution*

The Wirrinya Granite (Bowman, 1976; 1977a) is named after the locality of Wirrinya, approximately 5 km north of the northern margin of the granite. The main body of the Wirrinya Granite does not crop out. The granite is recessive relative to the surrounding quartzose sedimentary rocks and forms a topographic low covered by Cainozoic sediments up to 100 m thick. However, the subsurface extent of the granite can be defined by an approximately elliptical anomaly in regional aeromagnetic data. The southeastern margin of the Wirrinya Granite appears to be truncated by a northeast trending fault (also interpreted from magnetic data), which is probably related to the Parkes Fault Zone. Several small felsic granite plugs and dykes have intruded the Pullabooka Formation, just west and northwest of the main granite pluton. These bodies are thought to be small apophyses of the main Wirrinya Granite. Bowman's (1977a) type locality outcrops (around GR 569500 mE 6266300 mN) are of granite dykes within the Pullabooka Formation and are not as extensive as he reported.

*Description*

The exposed dykes and small intrusive bodies of the Wirrinya Granite are typically composed of fine-grained, pink, graphic microgranite, containing scattered pink oligoclase phenocrysts ($An_{10}$ to $An_{15}$) up to 2.5 mm. Very minor, late stage aggregates of sodic hornblende ± fluorite ± opaque grains, up to 3 mm across, are commonly centred on small miarolitic cavities or altered feldspar phenocrysts. Magnetic susceptibility is variably low to moderate; typically around $200 \times 10^{-5}$ SI to $400 \times 10^{-5}$ SI, within a range of $\sim 20 \times 10^{-5}$ SI to $1000 \times 10^{-5}$ SI. Some of this variation is due to weathering and minor alteration.

Sedimentary rocks within the contact metamorphic aureole of the Wirrinya Granite contain andalusite spotting and some secondary biotite up to 750 m from the contact of the

granite as interpreted from aeromagnetic data. A quartz–andalusite hornfels is developed in sandstones about 250 m from the granite contact at GR 575020 mE 6268740 mN.

*Geochemistry*

The discussion of the geochemistry of the Wirrinya Granite is based on a single sample taken from a small intrusive body just northwest of the main pluton. Its composition is very similar to the Bindogandri Granite, an A-type granite that lies about 18 km east of Parkes. The Wirrinya Granite sample is a felsic metaluminous granite (76.7 wt% $SiO_2$) with a composition approaching peralkaline (Al/K+Na = 0.9). Its redox state is near the boundary of oxidised and reduced granites as defined by Champion & Heinemann (1994). The granite has A-type features, such as high concentrations of HFSE (e.g., Zr, Y, Nb, Ce), high F (1749 ppm) and Zn (77 ppm), and high Ga/Al ratio. The granite is not fractionated, having relatively low levels of Rb (98 ppm), Th (12 ppm) and U (4 ppm). The granite also has a very low V content (<1 ppm).

*Age and intrusive environment*

The Wirrinya Granite has not been isotopically dated. The granite may be related to the Dalrida Granite, which has been dated as Emsian (395.4 ± 1.7 Ma; L.P. Black, pers. comm., 1998). Both these granites are discordant with folded Early Devonian sedimentary rocks and have similar elliptical outlines indicating a post-tectonic intrusive environment. However, the unusual A-type geochemistry of the Wirrinya Granite possibly indicates a Middle Devonian age. Other A-type magmatism in the region, such as the Grenfell Granite and Bindogandri Granite and the Rocky Ponds Group, appears to be restricted to the Middle Devonian epoch. The granophyric and miarolitic textures of the exposed small intrusive bodies of the Wirrinya Granite indicate intrusion at a high level.

## **Grenfell Granite** (Dgg) Brunker (1972)

*Nomenclature*

The Grenfell Granite was originally named and its distribution depicted by Brunker (1972). Subsequently (Bowman, 1977a) subdivided the body into eastern and western segments, separated by the Brangan Volcanics. These segments were respectively named the 'Bogalong Granodiorite' and 'Warraderry Porphyry'. However, the granite is a homogeneous body so the name Grenfell Granite is restored to the original definition of Brunker (1972).

*Distribution*

The Grenfell Granite is an elliptical body 18 km long and 13 km wide, elongate north–south and extending from the Warraderry State Forest in the north to Grenfell in the south.

*Boundary relationships*

The Grenfell Granite intruded the Ordovician Kirribilli Formation and was intruded by the Schneiders Granite. The Grenfell Granite is bisected by a linear belt of the Brangan Volcanics about 1.5 km wide trending approximately north–south. The Brangan Volcanics, formerly included as part of the now discarded 'Hoskins Formation', have been re-interpreted as a slice of Ordovician basement enclosed in the Grenfell Granite as a large elongate roof pendant.

*Constituent units*

Ryall (1974) subdivided the body into sub-porphyritic, medium-grained and microgranite phases differing in relative proportions of K-feldspar, plagioclase, biotite, muscovite, and quartz. It is clear however that the Grenfell Granite is compositionally homogeneous, and was probably emplaced during a single magmatic episode.

*Type locality*

A type locality for the Grenfell Granite is at GR 607730 mE 6251930 mN, about 3 km north of Grenfell.

*Description*

The granite is pink and texturally variable, including microcrystalline, medium-grained and sub-porphyritic variants. In the coarser-grained phases, plagioclase (~10% of total felspar content) is subordinate to K-feldspar. Euhedral quartz and K-feldspar up to 3 mm occur in a groundmass of similar composition together with minor epidote, biotite, and rare muscovite. Micrographic intergrowths of quartz with microcline and plagioclase are common, especially in finer-grained phases.

The granite has a low to very low magnetic signature and a very high gamma ray spectrometric count rate. The contact is indiscernible magnetically due to the strongly magnetised zone of contact metamorphism adjacent to the older Mortray Hill Granite Complex, which masks the western boundary of the granite on aeromagnetic images. The eastern boundary of the granite is delineated by a moderately magnetised contact with basement sedimentary rocks. A zone of quartz–tourmaline–tin ± bismuth greisen has been shown separately on the map.

*Geochemistry*

The Grenfell Granite is a strongly fractionated, possibly A-type granite. On a $Ga/Al_2O_3$ diagram, the granite plots in the A-type field (see Figure 16.2) but this may result from its high degree of fractionation rather than being a reflection of an intrinsic A-type character since strongly fractionated I- and S-type granites can also plot in this field.

*Thickness*

Interpretation of airborne geophysical data suggests that the granite is an eroded lopolith with a maximum thickness of ~1 km.

*Age*

A sample from the type locality yielded a U–Pb SHRIMP zircon age of 384 ± 3.4 Ma (L.P. Black, pers. comm., 1999).

## **Schneiders Granite** (Dsg) *nov*

*Derivation of name*

Schneiders Granite is named after Schneiders Lane, which crosses the outcrop area of the intrusion.

*Distribution*

The Schneiders Granite is exposed as a narrow linear body, 1 km to 2 km wide and about 10 km long, trending north-northeast through Grenfell township and extending into the Grenfell Granite.

*Relationships*

The Schneiders Granite intruded the Ordovician Kirribilli Formation. It has also intruded the Grenfell Granite and is believed to be a late-stage, highly fractionated phase of that intrusion.

*Type locality*

The type locality for the Schneiders Granite is at GR 606720 mE 6246310 mN, adjacent to a farm house and the Grenfell cemetery.

*Description*

The Schneiders Granite crops out as a prominent ridge at the type locality but, although topographically distinct elsewhere, outcrop becomes less pronounced to the north and south. The granite is pink and uniformly medium- to coarse-grained. Quartz is ubiquitous and sodic plagioclase is present as stumpy crystals in much greater abundance than K-feldspar. Muscovite is present as interstitial flakes and aggregates comprising less than 1% of the rock. The granite has a K-dominant gamma ray spectrometric signature and is slightly more magnetic than the Kirribilli Formation, into which it intruded.

*Geochemistry*

The Schneiders Granite is the most fractionated of the granites in the Forbes 1:250 000 map sheet area, having high $SiO_2$ (76.7 wt%), Rb (459 ppm), U (10.8 ppm), and low Th (13 ppm) and Sr (7 ppm). The intrusion cross-cuts the Grenfell Granite and is interpreted to be a late-stage or final expression of the localised Grenfell Granite magmatic event. The northern part is a quartz–tourmaline–tin greisen ± bismuth greisen.

*Age*

The Schneiders Granite is interpreted as a late stage phase of the early Middle Devonian Grenfell Granite (384 ± 3.4 Ma; L.P. Black, pers. comm., 1999).

# 10. MIDDLE DEVONIAN

## Rocky Ponds Group (Dr) *nov*

The Rocky Ponds Group is a new group, which includes the Dulladerry Volcanics and Warrumba Volcanics. The name is taken from Rocky Ponds Creek and the Parish, in the Bathurst and Dubbo 1:250 000 map sheet areas, in which the Dulladerry Volcanics are well exposed. The Dulladerry and Warrumba Volcanics are Middle Devonian, predominantly rhyolitic, A-type volcanic rocks, which are overlain by the Late Devonian Hervey Group. The Rocky Ponds Group has been correlated with the Boyd Volcanic Complex on the south coast of New South Wales (Fergusson *et al.*, 1979; Dadd, 1992), which contains similar rock types with similar geochemistry. These volcanic groups were probably developed in widely separated, subaerial, intracontinental rift settings, with some associated intrusive rocks — including the Grenfell Granite and Bindogandri Granite in the Forbes 1:250 000 map sheet area.

### Dulladerry Volcanics (Drd) after Packham (1968)

*Nomenclature, distribution and previous work*

The name Dulladerry Volcanics was used by Raymond (1995; 1996; *in* Pogson & Watkins, 1998; 1999) and Sherwin (1996) to replace the term 'Dulladerry Rhyolite' introduced by Packham (1968). The name more accurately reflects the nature of the unit, which is a complex of rhyolitic flows, intrusions, ignimbrites, breccias, and minor intercalated epiclastic sedimentary rocks, basalt, and andesite. The name is taken from the Parish of Dulladerry, in which the unit occurs, immediately west of Manildra in the Bathurst 1:250 000 map sheet area. The Dulladerry Volcanics form a belt, 10 km to 20 km wide and 90 km long, extending from just east of Tomingley, in the north, to Murga, in the south — occurring across the intersection of the boundaries of the Forbes, Bathurst, Dubbo, and Narromine 1:250 000 map sheet areas. An area of approximately 170 km$^2$ of the Dulladerry Volcanics is exposed in the northeastern corner of the Forbes map sheet

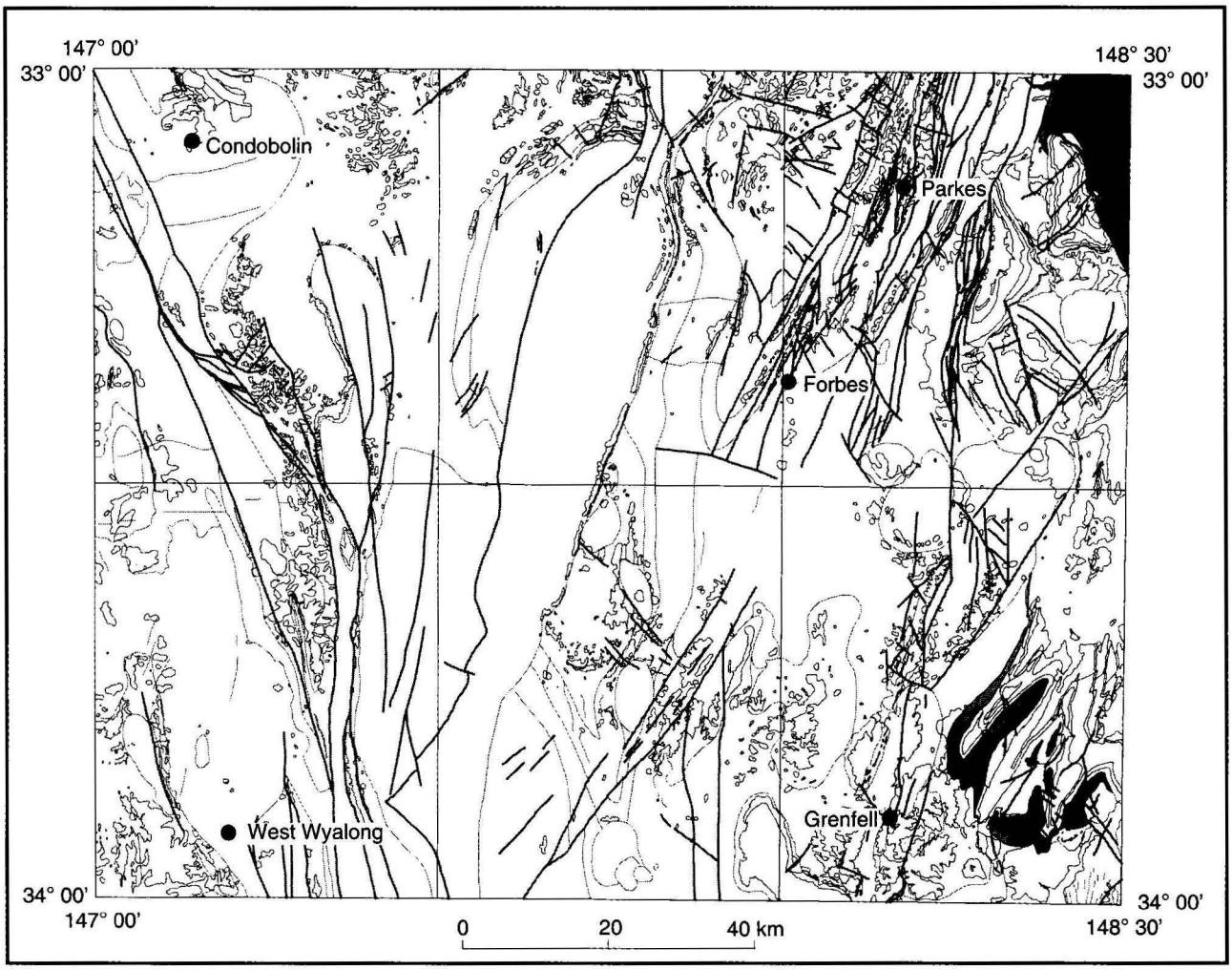



*Figure 10.1. Distribution of the Rocky Ponds Group in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

Area (Figure 10.1), where they primarily occur in the Curumbenya Nature Reserve.

The Dulladerry Volcanics have been mapped by many earlier workers, including Joplin & Culey (1938), Joplin *et al.* (1952), Packham (1968), Offenberg *et al.* (1971), and Brunker (1972), among others. Many university theses and exploration company reports have described small areas of the Dulladerry Volcanics, mainly outside the Forbes 1:250 000 map sheet area (e.g., Coleman, 1975, Mullholland, 1979, McCaughey, 1989; O'Sullivan, 1992). More recently, the Dulladerry Volcanics were mapped in the second edition geological mapping programs of Narromine (Sherwin, 1997), Bathurst (Raymond, *in* Pogson *et al.*, 1998), and Dubbo (Morgan *et al.*, 1999) 1:250 000 map sheet areas, and described in some detail by Raymond (*in* Pogson & Watkins, 1998; 1999) and Sherwin (1996).

*Boundary relationships*

In the Forbes 1:250 000 map sheet area, the Dulladerry Volcanics are faulted against the Late Silurian Moura Formation and the Late Devonian Hervey Group by the northwest trending Bumberry Fault. Originally, an unconformable contact with the Moura Formation probably existed close to the present faulted contact, and little movement is inferred along the fault at that location. Small isolated outcrops of the Dulladerry Volcanics within the Moura Formation, west of the fault, preserve parts of the original unconformity. Drag folding in the Hervey Group indicates westward thrusting of the Dulladerry Volcanics over the Hervey Group on the Bumberry Fault. It is unclear whether the Dulladerry Volcanics overlie or were intruded by the Bindogandri Granite, which is of probable similar age and is apparently genetically related to the Dulladerry Volcanics. Near the northern edge of the Forbes 1:250 000 map sheet area, the Dulladerry Volcanics unconformably overlie the Early Silurian Glenisla Volcanics and may be faulted against (or unconformably overlie) Ordovician Kirribilli Formation.

The Dulladerry Volcanics in the Forbes 1:250 000 map sheet area appear to consist of a mainly horizontal to shallow-dipping sheet, except where folded around the northern hinge of the Bumberry Syncline. In areas of relatively flat-lying volcanic rocks, a maximum preserved thickness of 400 m is inferred. However, up to 800 m of true thickness may occur in the shallow- to moderate-dipping volcanic units exposed in the Nangar Anticline and Mandagery Syncline (Bathurst 1:250 000 map sheet area).

The Dulladerry Volcanics are unconformably overlain by the Hervey Group west of the Bumberry Fault. The angle of unconformity and time gap between the two units is thought to be negligible. Turner (1983) reported that the Early Devonian Eugowra Granite intruded the Dulladerry Volcanics southwest of Mount Boulton. However, more recent mapping has shown that the Eugowra Granite intruded the Coonambro Volcanics, which are unrelated to, and most probably older than, the Dulladerry Volcanics.

*Constituent units*

The Dulladerry Volcanics in the Forbes 1:250 000 map sheet area are divided into several members:

Warraberry Member (Drdw);

Curumbenya Ignimbrite Member (Drdi); and

unnamed coarse K-feldspar–quartz-phyric rhyolite forming domes and dykes (Drdd).

*Metamorphism and alteration*

The Dulladerry Volcanics have undergone regional prehnite–pumpellyite to lower greenschist facies metamorphism. Pumpellyite and chlorite are commonly developed in the recrystallised groundmass of previously glassy felsic volcanic rocks. Weak hydrothermal alteration is not uncommon, with pervasive sericitic and siliceous alteration of the groundmass of ignimbrites and flow rocks. However, stronger hydrothermal alteration or veining in the volcanic rocks is rare in the Forbes 1:250 000 map sheet area. Minor epithermal quartz veining with banded and cockade textures was observed in the area of 'The Twins' (GR 634000 mE 6337000 mN). Some silicification and massive quartz veining, with some gossanous outcrops has affected the Dulladerry Volcanics along and near fault splays of the Coolac–Narromine Fault Zone.

*Geochemistry*

Raymond (*in* Pogson & Watkins, 1998) described the A-type geochemistry of the Dulladerry Volcanics. The felsic volcanic rocks are oxidised and metaluminous, with some compositions approaching peralkalinity. The volcanic rocks are fractionated, at least in part, showing a decreasing trend in Ba with increasing $SiO_2$ (Figure 10.2) and variable high Rb/Sr and low K/Rb ratios. In this respect, the Dulladerry Volcanics are similar to fractionated I-type granites such as the Gumble Granite, which occurs at the eastern margin of the Dulladerry Volcanics (Bathurst 1:250 000 map sheet area). However, the volcanic rocks show typical A-type characteristics (Collins *et al.*, 1982; Whalen *et al.*, 1987; Eby, 1992), including high Ga/Al and Fe/Mg ratios (Figure 10.3), and high levels of HFSE (e.g., Zr, Nb, Y), REE (e.g., Ce, La), and Zn. Although there is some overlap with fractionated I-type compositions, the ranges for most of the diagnostic elements for A-type rocks are distinct for the Dulladerry Volcanics.

*Age and correlation*

A Givetian (Middle Devonian) age for the Dulladerry Volcanics is indicated by a SHRIMP zircon U–Pb date of ignimbrite from the Bathurst 1:250 000 map sheet area (376 ± 4 Ma; L.P. Black, *in* Pogson & Watkins, 1998). That date is supported by the occurrence of Givetian–Frasnian phyllolepid fish fossils in sedimentary units within the Dulladerry Volcanics near Tomingley (Narromine 1:250 000 map sheet area; O'Sullivan, 1992; Young, 1994) and Merriganowry (Bathurst 1:250 000 map sheet area; Young, 1994), and Middle Devonian lepidodendroid fossils described by Pickett (1993b) — also from Tomingley.

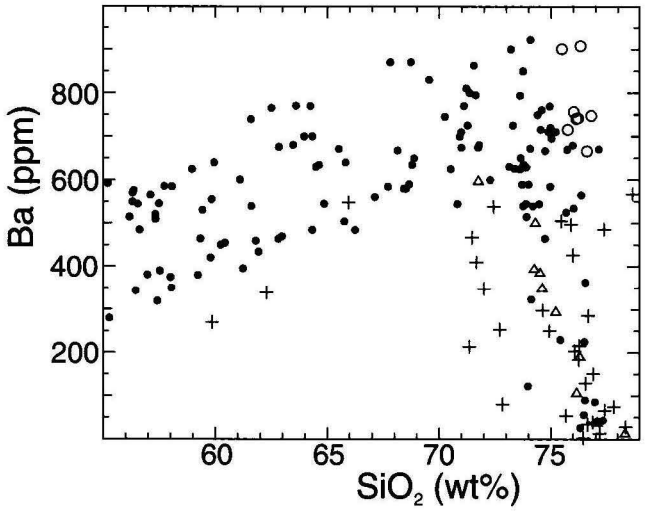



*Figure 10.2. Ba* versus *$SiO_2$ plot showing the fractionation trend of the Dulladerry Volcanics (plus signs), which parallels that of the fractionated I-type Gumble Granite (triangles). For comparison, the unfractionated Bindogandri Granite (open circles) and rocks of the I-type Boggy Plain Supersuite (dots), including the Eugowra Suite, Yeoval Granite Complex, and Mountain Creek Volcanics, are shown.*

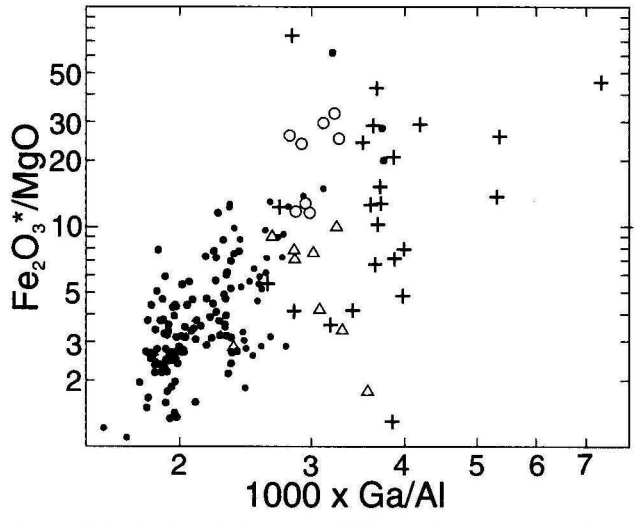



*Figure 10.3. $Fe_2O_3$*/MgO* versus *1000 × Ga/Al plot (after Whalen* et al., *1987) showing the distinct composition of the A-type Dulladerry Volcanics compared to the I-type Boggy Plain Supersuite and Gumble Granite, and the A-type Bindogandri Granite. Symbols are as used in Figure 10.2.*

The Dulladerry Volcanics are of similar age, lithology, and composition to the Warrumba Volcanics, which occur east of Grenfell, some 100 km to the south. These two A-type volcanic units comprise the Rocky Ponds Group. The Dulladerry Volcanics are probably genetically related to the Bindogandri Granite, which also has A-type characteristics although less distinct than those shown by the Dulladerry Volcanics (Figure 10.2). The Bindogandri Granite also shows no signs of fractionation, and was probably intruded as a high level, subvolcanic body during eruption of the Dulladerry Volcanics.

The Dulladerry Volcanics are similar in age and composition to rocks of the Eden–Comerong–Yalwal Volcanic Zone (EVZ) on the south coast of New South Wales (Fergusson *et al.*, 1979; Dadd, 1992), where a similar setting for felsic-dominated bimodal volcanism has been invoked. Dadd (1992) suggested that migration of the Australian plate over a fixed hot spot may have caused EVZ volcanism. However, it is not clear that a similar model can be applied to other widely separated Devonian A-type volcanic units of the Rocky Ponds Group. Restricted areas of Middle Devonian A-type granites and volcanic rocks occur in many parts of the Lachlan Fold Belt of New South Wales and Victoria (Chappell *et al.*, 1991). This suggests a widespread, if volumetrically small, upwelling of A-type magmas, possibly related to extension following the relaxation of stresses after deformation and crustal thickening during the Early Devonian.

*Depositional environment*

The Dulladerry Volcanics were most probably deposited in a sub-aerial, continental rift setting during the Givetian. The Bumberry Fault may have initially formed a growth fault margin of a graben, or half graben, into which the Dulladerry Volcanics were deposited. Only very minor amounts of the Dulladerry Volcanics occur west of the Bumberry Fault, and the fault could have been active during the Middle Devonian. Later reverse movement occurred as reactivation of this fault during the Carboniferous Period (Kanimblan Orogeny).

The Yahoo Peaks Composite Dome, (Dubbo 1:250 000 map sheet area, (Raymond, 1999), was probably an eruptive centre for the volcanic units. The zone of rhyolite intrusions or lava domes along the boundary of the Forbes–Bathurst 1:250 000 map sheet areas may represent a rift zone, along which lavas intruded and extruded. The strong welding of the Curumbenya Ignimbrite Member precludes a submarine environment for the volcanic activity. The poorly sorted and polymict nature of the coarser breccias in the Warraberry Member suggests a mass flow and sheet flood origin. The finer-grained sediments were deposited by alluvial processes.

## **Warraberry Member** (Drdw) (Raymond, *in* Pogson & Watkins, 1998)

*Nomenclature and distribution*

The Warraberry Member primarily occurs at, or near, the base of the Dulladerry Volcanics and consists of complexly intercalated lava flows, epiclastic greywackes and shales, and polymict volcanic breccias. Rare basalts also occur. The name is derived from 'Warraberry' in the Dubbo 1:250 000 map sheet area, on which the unit is well exposed.

*Description*

Aphyric and lesser quartz- or K-feldspar-phyric rhyolite lava flow rocks are common in the unit (Figure 10.4). They are generally flow-banded, flow-folded and may be autobrecciated. The groundmass of the flow rocks is typically devitrified and recrystallised to fine-grained quartz, alkali feldspar, and pumpellyite, but may preserve

spherulites and, more rarely, lithophysae. The volcanic rocks are very variable in their magnetic character, with a median magnetic susceptibility of around $100 \times 10^{-5}$ SI, but with a range of $5 \times 10^{-5}$ SI to $1200 \times 10^{-5}$ SI. Just east of the Bumberry Fault, a particularly thick rhyolite lava flow unit overlies the Bindogandri Granite and forms prominent cliffs at Waterfall Creek (Figure 10.5). The unit has a variable magnetic susceptibility in outcrop ($20 \times 10^{-5}$ SI to $650 \times 10^{-5}$ SI), but coincides with a highly magnetic zone in regional aeromagnetic data. The unit also has higher than average gamma ray spectrometric count rates in K, Th, and U).

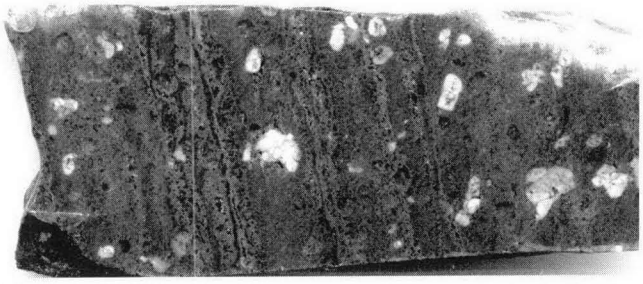


*Figure 10.4. A flow-banded, quartz–K-feldspar-phyric rhyolite in the Warraberry Member of the Dulladerry Volcanics. The sample is approximately 60 mm wide. (GR 632840 mE 6339430 mN) (O.L. Raymond photograph)*

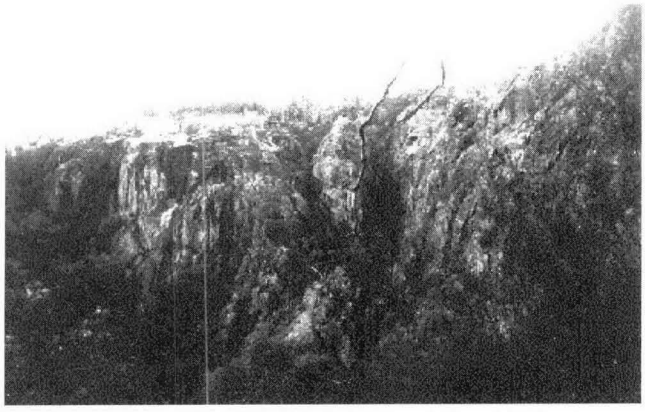


*Figure 10.5. Cliffs at Waterfall Creek formed by a shallow-dipping quartz-phyric rhyolite lava flow, 80 m thick, which exhibits large-scale flow folding. (GR 634400 mE 6338230 mN) (O.L. Raymond photograph)*

The epiclastic sedimentary units of the Warraberry Member range from very coarse-grained greywackes to shale. The coarser units are typically poorly sorted, angular, massive to well-bedded, and contain quartz and K-feldspar crystals and assorted lithic fragments derived from local volcanic rocks. The shales are commonly massive and very siliceous and, in outcrop, may be difficult to distinguish from fine-grained, aphyric rhyolites. The magnetic susceptibility of the sedimentary units averages $20 \times 10^{-5}$ SI.

Coarse, polymict, massive to crudely stratified, mass-flow breccias are intercalated with the volcanic rocks of the Warraberry Member. The breccias are much less prevalent in the Forbes 1:250 000 map sheet area than in other parts of the Warraberry Member. The breccias consist mainly of clasts of flow-banded rhyolite, and lesser quartz–K-feldspar-phyric ignimbrite, and are matrix-supported. Other clast types include quartz, K-feldspar, and trace plagioclase crystals, basalt, trachytic andesite, granite, and sandstone. The generally angular clasts range from less than 1 cm to several metres in size (Figure 10.6). The breccias are generally poorly magnetic, with average susceptibilities about $15 \times 10^{-5}$ SI.

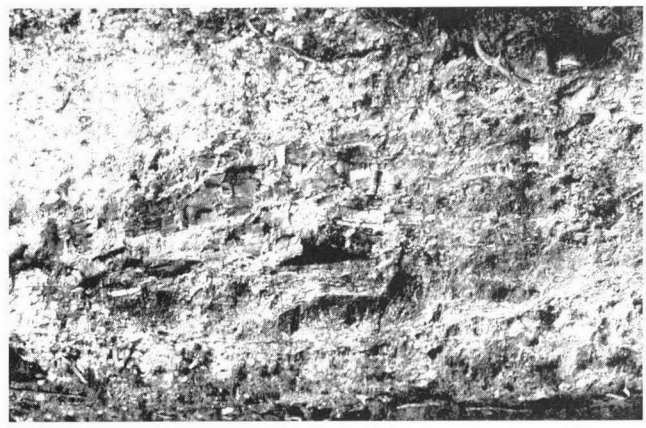


*Figure 10.6. A 5 m-long, flow-banded clast in a rhyolitic debris flow unit in the Warraberry Member of the Dulladerry Volcanics. (GR 639390 mE 6324510 mN) (O.L. Raymond photograph)*

### **Curumbenya Ignimbrite Member** (Drdi) Raymond (*in* Pogson & Watkins, 1998)

The Curumbenya Ignimbrite Member constitutes the majority of the exposure of the Dulladerry Volcanics. The name is taken from the Curumbenya Nature Reserve, which occupies a substantial area straddling the intersection of the Forbes, Bathurst, Dubbo, and Narromine 1:250 000 map sheet areas and is mostly sited on the ignimbrite.

In outcrop, the ignimbrite is a predominantly massive, grey to maroon, quartz–K-feldspar-phyric rhyolite (Figure 10.7), which may contain minor lithic fragments. Phenocrysts of K-feldspar and quartz are typically 0.5 mm to 2 mm across and make up between 5% and 30% of the rock. The phenocrysts vary from euhedral to rounded and embayed. Abundant finer-grained, angular crystal fragments are also present. The K-feldspar is commonly perthitic with microcline twinning. Zircon is a common accessory mineral. Basalt and rare granite and felsic volcanic lithic fragments, usually less than 5 mm, but up to 30 mm, usually comprise less than 1% of the rock. More lithic-rich variants of the ignimbrite rarely occur.

Fresher samples of the ignimbrite contain glass shards and abundant tubular pumice fragments (≤4 mm) showing strong welding, and preserve a fluidal eutaxitic layering in the groundmass. Generally, however, the primary glassy groundmass of the Curumbenya Ignimbrite Member is devitrified and recrystallised into fine-grained quartz and alkali feldspar. Metamorphic chlorite, sericite and pumpellyite may also be present in the groundmass. Eutaxitic layering is rarely seen in outcrop, and generally shows on surfaces where weathering accentuates layer-

parallel devitrification zones (Figure 10.8). Where visible, layering generally displays irregular dips, probably reflecting local flow folding and palaeotopography, and is an unreliable indicator of the regional dip of the unit.

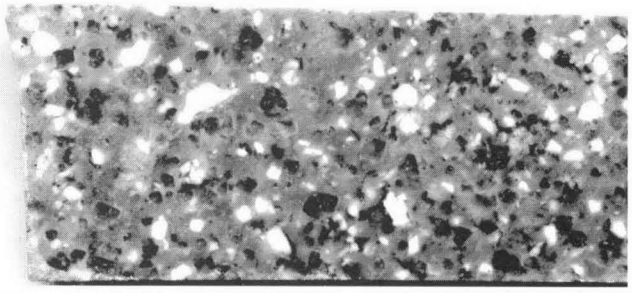


*Figure 10.7. Weakly sericitised, quartz–K-feldspar-phyric, welded ignimbrite of the Curumbenya Ignimbrite Member. Width of the sample is approximately 45 mm. (GR 633560 mE 6340200 mN) (O.L. Raymond photograph)*

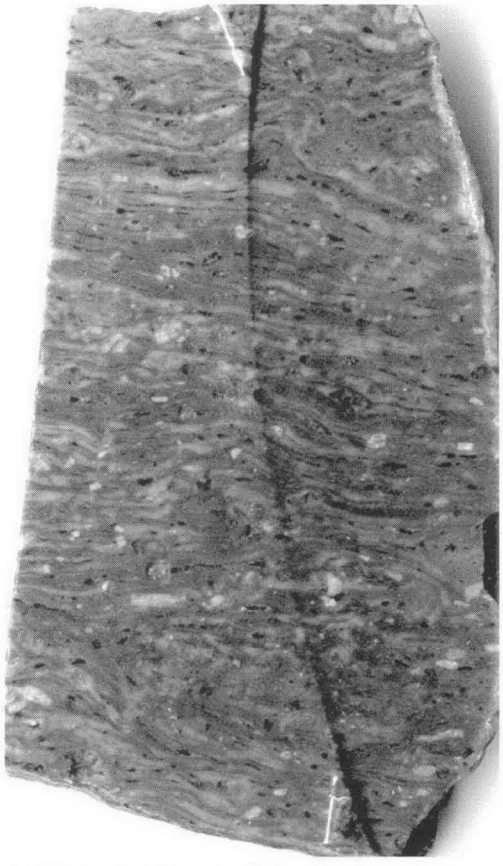


*Figure 10.8. Eutaxitic layering defined by devitrification zones in a strongly welded ignimbrite of the Curumbenya Ignimbrite Member. Sample is approximately 60 mm long. (GR 631800 mE 6344660 mN) (O.L. Raymond photograph)*

Very minor flow-banded rhyolite lava flows, similar to those described in the Warraberry Member, also occur within the Curumbenya Ignimbrite Member. Clasts of ignimbrite occur in the polymict breccia units of the Warraberry Member, which in general underlies the Curumbenya Ignimbrite Member. This suggests virtually contemporaneous deposition of the two units. The Curumbenya Ignimbrite Member is, generally, weakly magnetic (magnetic susceptibility ~$40 \times 10^{-5}$ SI), but more magnetic parts ($200 \times 10^{-5}$ SI to $900 \times 10^{-5}$ SI) are present and may reflect higher concentrations of basalt lithic fragments. The ignimbrite has high gamma ray spectrometric count rates in all three radiometric elements (K, Th, U).

### Coarse K-feldspar–quartz-phyric rhyolite forming domes and dykes (Drdd)

*Distribution*

Strongly porphyritic, high-level intrusive and extrusive rhyolites occur as dykes and domes, which range from 10 m across up to 3 km to 4 km long. A north-trending zone of elongate bodies occurs along the eastern margin of the Forbes 1:250 000 map sheet area and on the western margin of the Bathurst 1:250 000 map sheet area. These bodies probably formed as cryptodomes, or lava flows, along a linear rift, which formed a focus for eruptive activity. However, it is unclear from field relations whether the domes intruded the enclosing ignimbrite unit or formed topographic highs, around which the ignimbrite flowed. Two other intrusive bodies occur at the western margin of the volcanic rocks near the Coolac–Narromine Fault Zone. The westernmost of these bodies has an arcuate dyke-like form, some 4 km long and 200 m to 700 m wide, and intruded the Kirribilli Formation west of the Coolac–Narromine Fault Zone. Other bodies, too small to be represented in regional mapping, occur throughout the Dulladerry Volcanics.

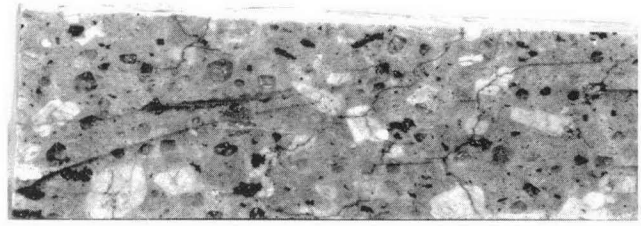


*Figure 10.9. Coarsely K-feldspar–quartz-phyric, high-level intrusive rhyolite of the Dulladerry Volcanics. Field of view is approximately 60 mm wide. (GR 626600 mE 6346730 mN) (O.L. Raymond photograph)*

*Description*

The rhyolite is massive, grey to pink, with prominent euhedral pink K-feldspar and lesser, smaller quartz phenocrysts (Figure 10.9). The K-feldspar crystals may be perthitic, are typically 5 mm to 7 mm long, but range from less than 1 mm to 15 mm, and constitute 5% to 10% of the rock. The quartz phenocrysts are often rounded and embayed, 1 mm to 3 mm, and make up 1% to 5% of the rock. Intrusive rhyolites that have been identified have a fine-grained but holocrystalline groundmass of quartz and alkali feldspar, commonly in microgranophyric intergrowth. Probable extrusive rhyolites have a finer-grained, devitrified groundmass of recrystallised quartz and alkali feldspar, commonly altered, containing variable amounts of chlorite with any or all of sericite, calcite, and pumpellyite. Zircon and finely disseminated iron oxides are

the major primary accessory minerals. Lithic inclusions are rare, rounded, up to 20 mm across, and include mafic and felsic volcanic fragments. Overall, the unit is moderately magnetic, with a magnetic susceptibility ~$100 \times 10^{-5}$ SI, but varying widely from $5\times 10^{-5}$ SI to $1000 \times 10^{-5}$ SI.

The gamma ray spectrometric count rates are high in all three radioelements and the signature is indistinguishable from that of the surrounding Curumbenya Ignimbrite Member.

## Warrumba Volcanics (Drw) *nov*

*Nomenclature, distribution and boundary relationships*

The Warrumba Volcanics is a new name for a sequence of felsic to mafic volcanic units disconformably to unconformably overlain by the Late Devonian Hervey Group. The Warrumba Volcanics occur in several northeast-trending anticlines and synclines from near Bumbaldry, in the east, to about 15 km northeast of Grenfell, at their western extremity. Earlier workers had included these volcanic rocks as part of the Silurian 'Illunie Rhyolite'. However, it is clear from recent mapping and isotope geochronology that the 'Illunie Rhyolite' as mapped by Brunker (1972) and Bowman (1976) comprises two distinct volcanic units of differing ages. The Warrumba Volcanics unconformably overlies an Early Silurian Illunie Volcanics and the Silurian Young Granodiorite, west of Bumbaldry.

The Warrumba Volcanics (as the 'Illunie Rhyolite') have been described in some detail by Colwell (1974) and Jones (1984). Many mineral exploration companies have also mapped parts of the Warrumba Volcanics, notably in the area between the Yambira (or Sugarloaf) Syncline and Bumbaldry.

*Constituent units*

The Warrumba Volcanics are divided into several members:

Walloy Rhyolite Member (Drww);

unnamed sedimentary lenses (Drws);

Coomaloo Ignimbrite Member (Drwc); and the

Adelargo Member (Drwa).

*Drww*. The Walloy Rhyolite Member constitutes most of the western half of the Warrumba Volcanics and unconformably overlies the Ordovician Kirribilli Formation. The member is named after 'Walloy', about 13 km northeast of Grenfell. The Walloy Rhyolite Member is probably laterally equivalent to the Coomaloo Ignimbrite Member on the whole, but appears to overlie the ignimbrite in the few areas where they are in contact.

*Drws*. Minor fine to coarse-grained sediments are included in an unnamed member at the base of and intercalated with the Walloy Rhyolite Member.

*Drwc*. The Coomaloo Ignimbrite Member constitutes most of the eastern part of the Warrumba Volcanics (east of the Yambira or Sugarloaf Syncline). A small area of rhyolitic tuffs in the core of the Gooloogong Anticline is also included in the Coomaloo Ignimbrite Member. The Coomaloo Ignimbrite Member unconformably overlies the Illunie Volcanics and Young Granodiorite. The member is named after 'Coomaloo', north of Bumbaldry.

*Drwa*. The Adelargo Member occurs at the top of the volcanic pile in the western part of the Warrumba Volcanics. The member is named after the Parish of Adelargo. The unit occurs as a thin band folded around the Gooloogong Anticline, and in four smaller fold inliers of Warrumba Volcanics surrounded by Hervey Group sandstones east of the Gooloogong Anticline. There is minor intercalation of the Adelargo Member with the underlying Walloy Rhyolite Member. Colwell (1974) mapped the Adelargo Member as the 'Adelargo Volcanics' and considered that the unit was not related to the underlying felsic rocks of the Warrumba Volcanics. The Adelargo Member has been included here as a member of the Warrumba Volcanics due to its limited thickness (generally less than 10 m), and after a re-evaluation of the its geochemistry.

*Type areas and thickness*

Folding and a paucity of discernible bedding in the Warrumba Volcanics makes estimates of thickness difficult. A maximum thickness of 1200 m is inferred from interpretive cross sections. Type areas are proposed instead of type sections. The Coomaloo Ignimbrite Member is well exposed in the Bungalong Creek area, north of the Mid Western Highway (around GR 626500 mE 6245500 mN). The Walloy Rhyolite Member is well exposed on 'Walloy' in the Gooloogong Anticline (around GR 617000 mE 6256000 mN). The Adelargo Member is best exposed in the nose of the Gooloogong Anticline (around GR 628500 mE 6266500 mN), where this thin unit has a shallow dip and crops out over a substantial area.

*Description*

Description of the constituent members of the Warrumba Volcanics follows the overall discussion of the unit.

*Mineralisation and alteration*

Although the Warrumba Volcanics contain significant hydrothermal alteration, no mineralisation of note has been found. The Walloy Rhyolite Member displays patchy alteration throughout — but notably in two areas: one around 'Billeroy' homestead, in the northern part of the Gooloogong Anticline; and the other east of 'Red Hill' homestead, in the south of the anticline. The rocks in those areas typically show strong sericite and/or silica alteration and often exhibit a well-developed, steeply dipping, penetrative cleavage. The strongest alteration resulted in total destruction of primary volcanic and fragmental textures, and is usually associated with strongest cleavage development. Quartz veining occurs in some of the rocks. Disseminated limonite after pyrite occurs west of 'Billeroy'. The combination of alteration and cleavage in fine-grained rhyolites, in the southern part of the Gooloogong Anticline, makes it difficult, in places, to

distinguish altered volcanic rocks from cleaved rocks of the Ordovician Kirribilli Formation. Alteration in the Walloy Rhyolite Member is magnetite destructive, with the magnetic susceptibility of altered rhyolites reduced to around $10 \times 10^{-5}$ SI.

The Coomaloo Ignimbrite Member also exhibits widespread, patchy sericite, silica and/or argillic alteration, which is most probably of epithermal origin. The Claypit, near Bumbaldry (GR 631100 mE 6247000 mN), is the most extensive example of epithermal alteration. It is developed at the unconformable contact of the Coomaloo Ignimbrite Member and the Illunie Volcanics, which are also strongly altered. Some banded quartz veining occurs, but generally the alteration is massive to brecciated clay, silica, and sericite. Quartz phenocrysts are commonly the only relict igneous textures visible, although some relict volcaniclastic breccia textures may be seen in the ignimbrite. No economic gold grades have been reported from The Claypit. The development of epithermal alteration in the Warrumba Volcanics at The Claypit indicates that the alteration in the underlying Silurian Illunie Volcanics is of Middle Devonian age. It is also possible that the mineralisation at nearby Broula King, which is entirely hosted by the Illunie Volcanics, is located in the deeper parts of a Middle Devonian epithermal system related to the overlying Warrumba Volcanics.

Other strong sericitic and/or siliceous alteration occurs within the Coomaloo Ignimbrite Member around GR 626400 mE 6245100 mN. Weak to strong argillic and/or sericitic alteration occurs in lithic tuffs near the Billeroy alteration zone, and in ignimbrite and volcaniclastic breccias around GR 626130 mE 6248100 mN (Figure 10.10). Strong silicification and argillic alteration, with some limonite after disseminated sulphides, also occurs in the Broula Anticline around GRs 633000 mE 6248600 mN and 634400 mE 6252700 mN, in the Broula Anticline. Some hydrothermal alteration occurs within the Adelargo Member, notably at the southern end of the Gooloogong Anticline (around GR 616520 mE 6254120 mN). There, vesicular basalts are strongly epidote-altered and contain quartz veining with both massive and open-space fill textures.

*Geochemistry*

The Warrumba Volcanics are bimodal, having >70 wt% $SiO_2$ in rhyolites of the Coomaloo Ignimbrite and Walloy Rhyolite Members, and <60 wt% $SiO_2$ in the Adelargo Member intermediate–mafic units. Wyborn *et al.* (1987) included the Warrumba Volcanics (then named the 'Illunie Rhyolite') in their I-type Boggy Plain Supersuite. However, the volcanic rocks exhibit features of A-type geochemistry, similar in many respects to the Dulladerry Volcanics (Figure 10.11). Like the Dulladerry Volcanics, the felsic rocks of the Warrumba Volcanics are fractionated, showing low Ba (typically ≤ 400 ppm) and elevated Rb/Sr ratios at higher silica concentrations. The two rhyolite samples analysed for Eu show strong Eu depletion, indicative of plagioclase feldspar fractionation. The intermediate–mafic volcanic rocks of the Adelargo Member are quartz-normative, suggesting some degree of differentiation in these rocks.

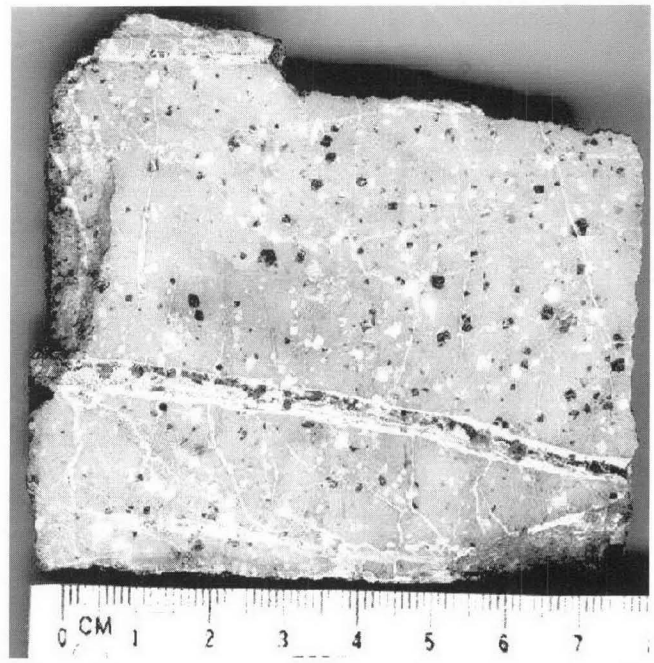



*Figure 10.10. Intensely altered Coomaloo Ignimbrite Member of the Warrumba Volcanics. Quartz phenocrysts and feldspars replaced by clay lie in a strongly sericitic matrix cut by quartz–kaolinite veinlets. (GR 626130 mE 6248100 mN) (O.L. Raymond photograph)*

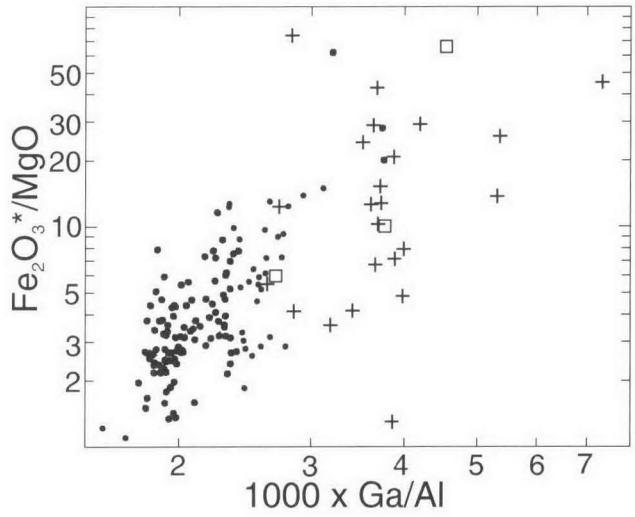



*Figure 10.11. $Fe_2O_3$*/MgO* versus *1000 × Ga/Al plot (after Whalen* et al., *1987) showing the similar composition of the A-type Warrumba Volcanics (open squares) and Dulladerry Volcanics (plus signs), compared to rocks of the I-type Boggy Plain Supersuite (dots) including the Eugowra Suite, Yeoval Granite Complex, and Mountain Creek Volcanics.*

The Warrumba Volcanics are generally metaluminous, and approach, but do not become, peralkaline at high $SiO_2$ concentrations. They have high levels of HFSE and REE, and have high Ga/Al ratios (Ga analyses are available only for the rhyolitic rocks) — features all typical of A-type volcanism. The intermediate–mafic volcanic rocks of the Adelargo Member have extremely high contents of HFSE

(e.g., 1000 ppm to 3000 ppm Zr, 80 ppm to 120 ppm Y) and REE (e.g., 160 ppm to 250 ppm Ce, 70 ppm to 120 ppm La). These extreme concentrations are even significantly higher than the high levels for the Dulladerry Volcanics. Other characteristics similar to the Dulladerry Volcanics are high Th (20 ppm to 30 ppm), Pb and Zn, and low Sr in the more mafic units. Curiously, the intermediate–mafic rocks of the Warrumba Volcanics have the lowest concentrations of V and Cr of any rocks of similar $SiO_2$ content in the northern Lachlan Fold Belt. The Warrumba Volcanics are typically oxidised to strongly oxidised on the $Fe_2O_3$/FeO plot of Champion & Heinemann (1994).

The andesites and basalts of the Adelargo Member have an alkaline major element geochemistry with high concentrations of alkali oxides (2 wt% to 4 wt% $K_2O$, 2.5 wt% to 6 wt% $Na_2O$). They have very low MgO (≤2 wt%) and CaO (2 wt% to 6 wt%) and plot in the tholeiitic field of an igneous AFM diagram. These characteristics are not seen in the few analyses of andesites of the Dulladerry Volcanics. The fractionated, alkaline nature of the Adelargo Member volcanic rocks is similar to Cainozoic intraplate, hot spot-related volcanism of eastern Australia. Some of these Cainozoic basalts also contain the very high levels of HFSE evident in the Adelargo Member (Johnson, 1989). Colwell (1974) considered the Adelargo Member basalts and andesites to be alkaline volcanic rocks of different origin from the felsic members of the Warrumba Volcanics. Fractionation trends cannot be drawn between the felsic and mafic end members of the Warrumba Volcanics, and the mafic units were erupted after the felsic units. However, the unusual trace element characteristics of both the felsic and mafic rocks infer that they originated from a similar mantle source, perhaps with varying degrees of crustal input.

*Age, correlation and environment of deposition*

The age of the Warrumba Volcanics is similar to that of the nearby Grenfell Granite, which has a U–Pb SHRIMP zircon date of 384.4 ± 3.4 Ma (L.P. Black, pers. comm., 1998). The geochemistry of the granite also has A-type affinity. However, the degree of fractionation of the granite means that this interpretation is not definitive. It is probable that the Grenfell Granite is related to the Warrumba Volcanics and may represent the source magma for the unit.

The Coomaloo Ignimbrite at GR 626400 mE 6245250 mN was dated by the U–Pb SHRIMP zircon method and a distinctly bimodal zircon distribution was observed (L.P. Black, pers. comm., 1998). The crystallisation age of the ignimbrite is given by a small but texturally distinct zircon population with a Middle Devonian age of 382.7 ± 2.8 Ma. The majority of zircon grains (>90%) in the ignimbrite were inherited and yielded an Early Silurian age of 432 ± 1.6 Ma. The inherited zircon population suggests melting of an Early Silurian source for the Coomaloo Ignimbrite, probably the underlying Illunie Volcanics or Young Granodiorite.

Jones (1984) ascribed a mid-Silurian (Wenlock to Ludlow) age to the Coomaloo Ignimbrite Member based on a fauna found in limestones in the adjacent Illunie Volcanics. However, it is clear from the abundance of small accidental limestone xenoliths in the Coomaloo Ignimbrite Member that the larger limestone outcrops in the ignimbrite described by Jones (1984) are allochthonous.

The Warrumba Volcanics were most probably erupted in a subaerial, intraplate, probable rift, setting. The geochemical similarity of the more mafic volcanic rocks to eastern Australian Cainozoic basalts may indicate a mantle hot spot influence on the volcanism. The Warrumba Volcanics have similar age, lithology and composition to the Dulladerry Volcanics (about 100 km to the north) and the Boyd Volcanic Complex on the south coast of New South Wales (Fergusson *et al.*, 1979; Dadd, 1992). This suggests a widespread phase of extension, localised in narrow rift basins across the Lachlan Fold Belt during the Middle Devonian, following the relaxation of orogenic stresses after late Early Devonian deformation (Raymond, 1995).

### Walloy Rhyolite Member (Drww) *nov*

The Walloy Rhyolite Member primarily comprises massive, grey to maroon, quartz–K-feldspar-phyric rhyolite lava flow rocks with occasional flow banding (Figure 10.12). Phenocrysts include subhedral to euhedral alkali feldspar (up to 20%; anorthoclase to sanidine), up to 4 mm, and lesser embayed to euhedral quartz (Figure 10.13), up to 1 mm. Some of the flow rocks lack quartz phenocrysts, and aphyric variants also occur. The originally glassy groundmass of the volcanic rocks is devitrified to a microcrystalline mass of quartz and alkali feldspar. The lava flow rocks are rarely vesicular (Figure 10.14). The magnetic susceptibility of Walloy Rhyolite Member rhyolites is low, ranging from $10 \times 10^{-5}$ SI to $2000 \times 10^{-5}$ SI, with a median value around $150 \times 10^{-5}$ SI. Their gamma ray spectrometric count rates are high in K, Th, and U.

### Unnamed conglomerate, sandstone, shale member (Drws)

Discontinuous lenses of tuffaceous shale, sandstone and conglomerate are intercalated with the rhyolite lava flow rocks of the Walloy Rhyolite Member. A conglomerate also occurs at the base of the volcanic units in the Gooloogong Anticline. The finer-grained sedimentary rocks are buff to maroon, and range from quartzose to lithic (Figure 10.15). Rounding and sorting of grains varies from well-rounded and well-sorted to angular and poorly sorted (Figure 10.16). The conglomerates typically contain well-rounded pebbles of vein quartz, fine-grained rhyolitic volcanic clasts, quartzite, and shale, and may show imbrication of clasts (Colwell, 1974). The shales and fine-grained sandstones, and less commonly conglomerates, may have a steep to vertical, well-developed cleavage parallel to regional fold axes.

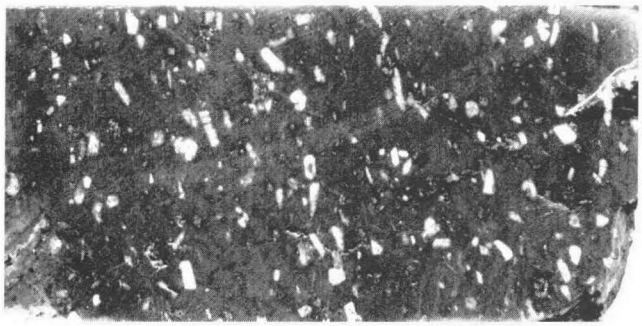


*Figure 10.12. Maroon, fine-grained, K-feldspar–quartz-phyric rhyolite of the Walloy Rhyolite Member of the Warrumba Volcanics. Width of view is approximately 55 mm. (GR 618540 mE 6256780 mN) (O.L. Raymond photograph)*

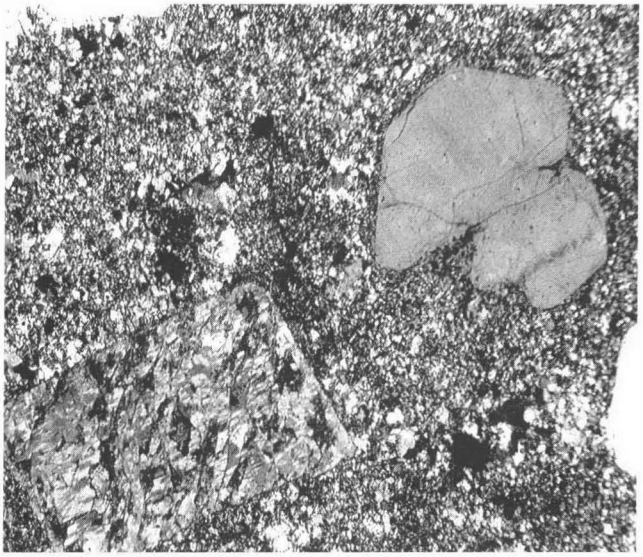


*Figure 10.13. Photomicrograph of quartz and perthitic K-feldspar phenocrysts in a recrystallised siliceous groundmass of a flow-banded rhyolite of the Walloy Rhyolite Member of the Warrumba Volcanics. Field of view is approximately 4 mm. (GR 616300 mE 6255170 mN) (O.L. Raymond photograph)*

*Figure 10.14. Large spherical vesicles in a massive K-feldspar-phyric rhyolite of the Walloy Rhyolite Member of the Warrumba Volcanics. (GR 618760 mE 6256470 mN) (O.L. Raymond photograph)*

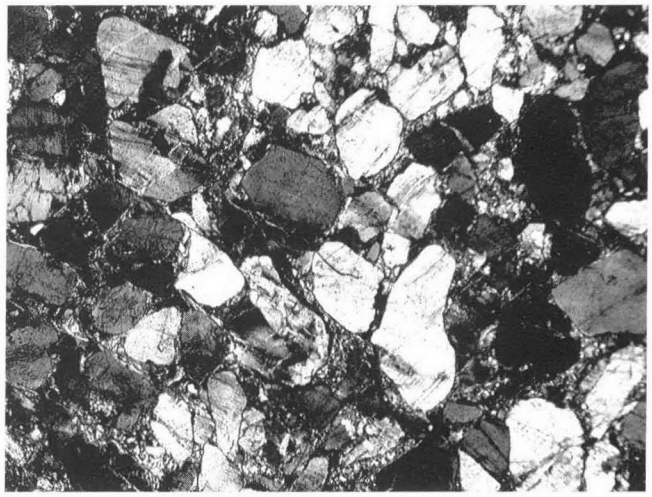


*Figure 10.15. Photomicrograph of well-rounded quartz and K-feldspar grains in an epiclastic sandstone in the Warrumba Volcanics. Field of view approximately 4 mm. (GR 620220 mE 6255270 mN) (O.L. Raymond photograph)*

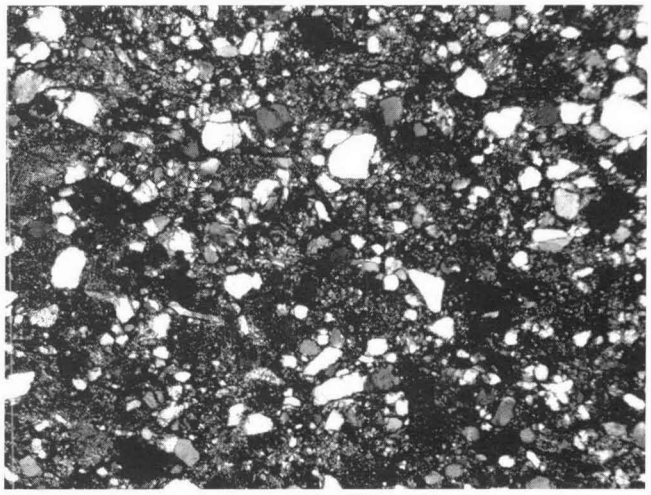


*Figure 10.16. Photomicrograph of an angular quartz–lithic sandstone from the base of the Warrumba Volcanics. Field of view approximately 4 mm. (GR 618610 mE 6249650 mN) (O.L. Raymond photograph)*

## Coomaloo Ignimbrite Member (Drwc) *nov*

The Coomaloo Ignimbrite Member mainly comprises a quartz–K-feldspar–plagioclase-phyric, variably welded, ignimbrite. It is similar in hand specimen to the Curumbenya Ignimbrite of the Dulladerry Volcanics. The unit also contains some quartz–K-feldspar–plagioclase-phyric (with or without biotite) volcanic rocks and vitric ash tuff.

The predominant rock type in the Coomaloo Ignimbrite Member is ignimbrite, which typically contains 10% to 15% of phenocrysts of quartz, K-feldspar and sodic plagioclase. The quartz phenocrysts are generally slightly more abundant than either of the feldspars, with a grainsize from 0.1 mm to 2 mm for the quartz and plagioclase (typically <1.5 mm). K-feldspar crystals range up to 6 mm, but are typically less than 2 mm. Phenocrysts are typically rounded and embayed euhedra, with smaller angular crystal fragments. Biotite phenocrysts are present at trace levels

and are typically strongly altered to chlorite, sericite, and iron oxides.

Devitrified tubular pumice fragments (fiamme), up to 1 cm in length, can be discerned in less-altered samples of the ignimbrite. The groundmass of the ignimbrite in the Coomaloo Ignimbrite Member is typically devitrified and recrystallised into microcystalline quartz and feldspar. Relict fragmental textures may or may not be preserved. The fiamme often exhibit spherulitic devitrification, or may be entirely silicified. Minor secondary sericite and chlorite alteration of feldspar phenocrysts is common. It is clear that while the fiamme commonly define a strong eutaxitic layering in thin section, strong welding does not occur throughout the ignimbrite. In some samples, the fiamme are not entirely flattened and some biotite phenocrysts are apparently undeformed.

The ignimbrite of the Coomaloo Ignimbrite Member contains variable amounts of lithic clasts ranging from recrystallised felsic volcanic fragments to basalt and limestone. Lithic clasts are typically less than a centimetre across and constitute less than 5% of the rock — coarser breccia units rich in lithic clasts do occur within the ignimbrite (Figure 10.17). In the area west of the Conimbla Syncline, the ignimbrite includes abundant limestone xenoliths, from a few millimetres to metres across. The xenoliths commonly weather out of the more resistant ignimbrite leaving cavities (Figure 10.18). Larger limestone clasts contain identifiable fossils described by Jones (1984), who reported the tabulate coral *Tryplasma lonsdalei* Etheridge, occasional pentamerid brachiopod fragments, and unidentified stromatoporoids from limestone near GR 627200 mE 6245100 mN. However, recent mapping could not confirm this.

Other minor rock types within the Coomaloo Ignimbrite Member include rhyolites and vitric ash tuff.

A strongly porphyritic rhyolite occurs at the base of the Coomaloo Ignimbrite Member in the nose of the Conimbla Syncline. The rhyolite contains phenocrysts of K-feldspar (typically 2 mm to 3 mm, but up to 10 mm), quartz (typically ~2 mm), and biotite (typically ~0.5 mm). Phenocrysts comprise 20% to 30% of the rock, occurring as rounded and embayed euhedra in a fine-grained, recrystallised quartz groundmass, which shows no relict eutaxitic or fragmental textures.

The vitric tuff in the Coomaloo Ignimbrite Member is composed of minor quartz, K-feldspar, and plagioclase phenocrysts (up to 2 mm) in a fine-grained matrix of unwelded, devitrified, angular glass shards (0.05 mm to 0.3 mm). Minor lithic and vitric tuffs also occur in the core of the northern part of the Gooloogong Anticline. Those rocks contain K-feldspar and quartz crystal fragments and rhyolitic lithic clasts up to 10 mm in a devitrified microcystalline groundmass. The occurrence of these tuffs in the core of the Gooloogong Anticline suggests that they underlie the lava flow rocks of the Walloy Rhyolite Member.

*Figure 10.17. Cobble- to boulder-sized lithic clasts in a ?co-ignimbrite breccia in the Coomaloo Ignimbrite Member of the Warrumba Volcanics. (GR 627130 mE 6244880 mN) (O.L. Raymond photograph)*

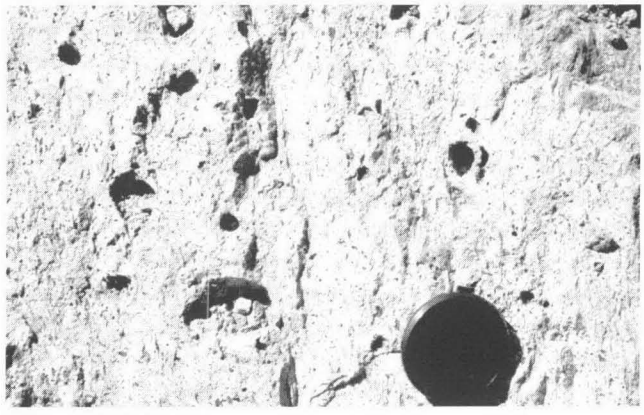


*Figure 10.18. Cavities caused by weathering out of limestone xenoliths from the quartz–feldspar-phyric Coomaloo Ignimbrite Member of the Warrumba Volcanics. (GR 624660 mE 6245600 mN) (O.L. Raymond photograph)*

The magnetic susceptibility of the Coomaloo Ignimbrite Member is typically very low ($\sim 20 \times 10^{-5}$ SI), although it may range as high as $1000 \times 10^{-5}$ SI. Count rates for all three radioelements (K, Th, U) are high and produce a bright white colour on RGB images.

**Adelargo Member** (Drwa) *nov,* after Colwell (1974)

The Adelargo Member consists of alkali basalt (mugearite), trachyandesite (benmoreite), and trachyte (Colwell, 1974). The basalts and andesites are typically very fine-grained and occasionally vesicular. They are aphyric, to less commonly porphyritic, flow rocks. A trachytic texture is commonly developed in a very fine-grained groundmass of albitised plagioclase, minor clinopyroxene and opaque iron oxides. The trachyandesites contain substantial interstitial alkali feldspar in the groundmass. Some strongly porphyritic volcanic rocks contain up to 15% euhedral andesine laths up to 10 mm in length (Figure 10.19). Colwell (1974) reported rare, partially altered olivine in some basalts. The trachytes contain oligoclase phenocrysts rimmed by sanidine in a groundmass of fine-grained sanidine laths and opaque iron oxides. Fine-grained secondary chlorite is commonly developed in the groundmass and vesicles of the volcanic rocks.

The magnetic susceptibility of the Adelargo Member is very high (up to $5900 \times 10^{-5}$ SI; with an average around $1200 \times 10^{-5}$ SI). The mafic volcanic rocks produce a prominent anomaly in aeromagnetic data, which contrasts strongly with the weakly magnetic felsic Warrumba Volcanics and the Hervey Group. The magnetic anomaly of the Adelargo Member is significantly wider than the thickness of the unit, but still provides a useful marker horizon for interpretation of fold and fault geometries, both outcropping and buried.

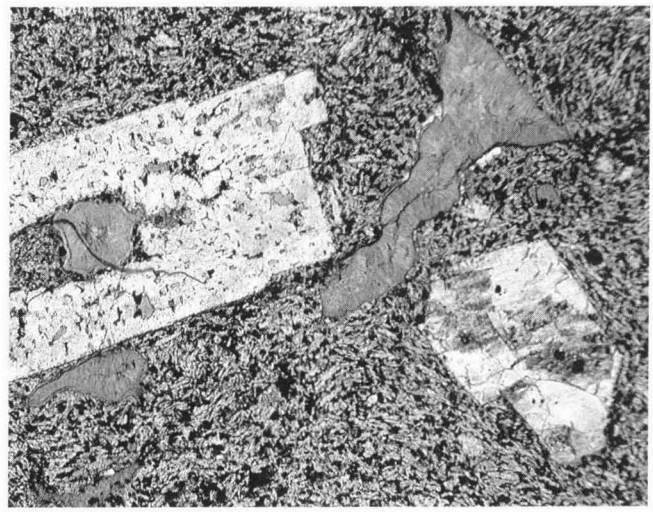


*Figure 10.19. Irregular chlorite-filled vesicles and plagioclase phenocrysts in a basalt of the Adelargo Member of the Warrumba Volcanics. Field of view approximately 4 mm. (GR 620930 mE 6258630 mN) (O.L. Raymond photograph)*

# 11. LATE DEVONIAN

## **Hervey Group** (Dh) Conolly (1965b)

*Nomenclature, derivation, type locality and subdivision*

The Hervey Group (Figure 11.1), as defined by Conolly (1965b), has its type section in the Hervey Range in the Narromine 1:250 000 map sheet area (along Clagger Creek to Caloma Trigonometrical Station), where the sequence consists of some 1500 m of quartzose sedimentary rocks (Conolly *et al.*, 1969; Sherwin, 1996). However, the type sections for several of the constituent formations were defined elsewhere. Conolly (1965a) also subdivided the Hervey Group into three subgroups, but this has not been followed here.

Major problems in lithological correlation of the Hervey Group between different areas have been noted by several authors (e.g., Sherwin, 1973b, 1996; Campbell & Bell, 1977; Ritchie *et al.*, 1992; Young, 1999a). In the Grenfell 1:100 000 map sheet area, the main difficulties have arisen because of doubtful correlations across the Lachlan River originally proposed by Conolly (1965a), who recognised the Mandagery Formation as the major bluff-forming sandstone unit in the main part of Hervey Group outcrop (Grenfell 1:100 000 map sheet area). In the stratigraphic subdivision adopted below, the term Weddin Sandstone is used for this major bluff-forming sandstone unit on the southern side of the Lachlan River, and on the northern side where there is continuity of outcrop into the area of the Parkes 1:100 000 map sheet, the terminology of formations defined in the Mandagery railway type section of the Parkes Syncline is used (Bumberry, Eurow, Wingara Formations).

Sherwin (1973b) showed that the lower part of what had been mapped as Hervey Group sediments in the eastern limb of the Tullamore Syncline included siliceous volcanic rocks of Early Devonian age, separated from the overlying true Hervey Group by an unconformity. These older sediments were later assigned to the Early Devonian Trundle Group and Late Silurian-Early Devonian Derriwong Group.

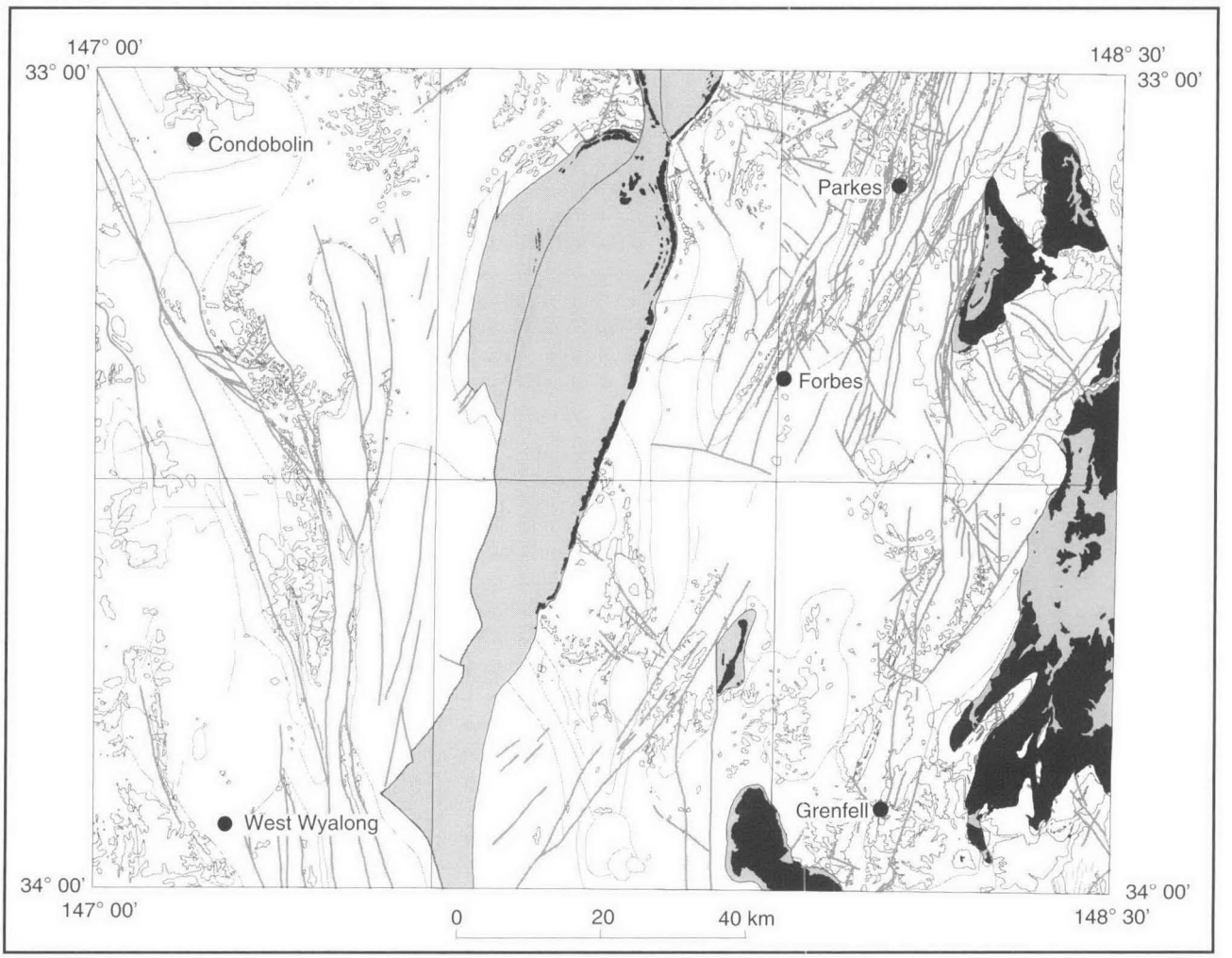



*Figure 11.1. Distribution of the Hervey Group in the Forbes 1:250 000 map sheet area. Areas shaded black represent substantial outcrop. Areas shaded grey represent distribution beneath surficial cover.*

The subdivision of the Hervey Group now recognised in the Tullamore Syncline in the Bogan Gate district is shown in Figure 11.2.

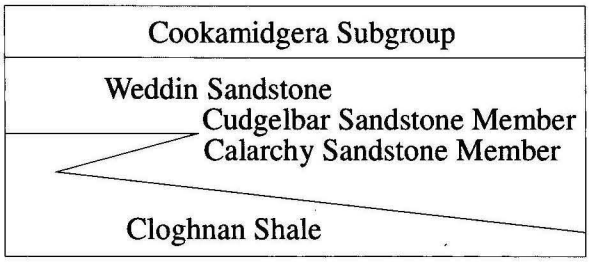



*Figure 11.2. Stratigraphic subdivision of the Hervey Group in the Tullamore Syncline, Bogan Gate district.*

## **Peaks Formation** (Dhp) after Conolly (1965a)

*Previous nomenclature*

The lower part of the Hervey Group sequence in the Weddin Range was initially identified by Conolly (1965a, pp 70-71) as the 'Bogan Gate Sandstone', but the type section for this formation lies far to the north in the Tullamore Syncline. This stratigraphic subdivision has been followed recently (e.g., Warren *et al.*, 1995, figure 4), but according to Sherwin (1996, p. 75) the term 'Bogan Gate Sandstone', as originally defined, applies to "a composite of sediments and volcanics ranging in age from Late Silurian to Mesozoic", and should no longer be used.

*Derivation of name*

The Peaks Formation is named from Peaks Creek, which forms the alluvial fill of the valley of the Gooloogong Anticline northeast of Adelargo.

*Type locality*

The type section of the Peaks Formation (formerly 'Peaks Sandstone') was defined by Conolly (1965a) along Peaks Creek on the western limb of the Gooloogong Anticline at GR 623000 mE, 6263000 mN.

*Thickness*

Conolly (1965a, p. 60) recorded the following sequence in the type section for the 'Peaks Sandstone':

| | |
|---|---|
| white and red coarse- and medium-grained sandstones and red siltstones | 46 m |
| red siltstone | 9 m |
| red coarse-grained sandstones and red siltstone and red shale | 58 m |
| red siltstone and shale | 15 m |
| TOTAL | 128 m |

Conolly (1965a) estimated a maximum thickness of some 1500 feet (450 m) in the Gooloogong Anticline, but Colwell (1974) revised this to 250 m. The thickness of bluff-forming coarse sandstones can vary considerably along strike, mainly due to facies change — e.g., in the Bumbaldry Hills along the eastern limb of the Conimbla Syncline, and at the southern end of the Keewong Anticline, where the Mogongong Conglomerate Member is developed. Jones (1984) recorded a thickness of 860 m in this area, whilst in the southeastern part of the Weddin Range a thickness of about 170 m is estimated.

*Distribution and outcrop*

As is the case in the Parkes 1:100 000 map sheet area, the basal part of the Hervey Group is often poorly exposed, mainly because of scree cover from overlying sandstones. In the type area the Peaks Formation consists of a sequence of poorly sorted red and white lithic sandstones interbedded with red siltstones and shales, the sandstone units being generally 1 m to 3 m in thickness, and lensing out over distances of up to 400 m along strike (Colwell, 1974). At GR 627340 mE 6277790 mN, there is a reported contact with the underlying Lock Lomond Granite (Conolly, 1965a; illustrated by Colwell, 1974, plate 8). There, the Peaks Formation forms a low bluff of massive red grit (and conglomerate, coarse sandstone), beneath which a single granite boulder was observed in the float of large blocks that had rolled down onto the soil cover. The adjacent road cutting 1.5 km to the south exposes the type section of the 'Gooloogong Beds' of Colwell (1974). As noted below, outcrop of Peaks Formation immediately to the north of this road cutting, which is well-exposed by recent cable line trenching, indicates that the lower 20 m of coarser red sedimentary rocks in the road cutting should be included within the upper part of the Peaks Formation.

In the valley of Warrumba Creek, the eastern flank of the Warrumba Range contains westerly dipping sandstones in the gullies west of the track at GR 626230 mE, 6268800 mN, but an easterly dipping ridge-forming white and red sandstone unit occurs east of the creek. This, presumably, is the Peaks Formation on the western limb of the adjacent Warrumba Syncline, rather than a sandstone unit within the Hunter Formation as suggested by Colwell (1974).

In many places, the Peaks Formation crops out as thick, bluff-forming, coarse sandstones, which result in conspicuous ridges — e.g., the Bumbaldry Hills along the eastern limb of the Conimbla Syncline. In other sections the ridge-forming sandstones may be reduced or absent, and in the Keewong/Brundah fold system of the Yambira Syncline area, as mapped by Jones (1984), the basal Hervey Group contact is apparently between the Hunter Formation and the underlying volcanic units.

Along the eastern limb of the Conimbla Syncline coarse pebbly sandstones form the main ridge, but massive sandstones crop out right around the fold (e.g., about 15 km to 20 km north-northeast of Greenthorpe) and the Hunter Formation is not evident as a valley within the sandstone sequence. It is possible that the Hunter Formation is missing, with the Peaks Formation grading into higher sandstones assigned to the Weddin Sandstone that occupy the core of the fold, these two formations having similar rock types. Alternatively, there could be a faulted contact between the two formations, or the Peaks Formation could

lie further east, and the basal contact with volcanic rocks has been misidentified. Field checking is required to clarify this. Also possible is the wedging out of the sandstone to the south, such that the basal contact is between the Hunter Formation and underlying volcanic rocks, as mapped by Jones (1984) in the Keewong/Brundah fold system to the west. A lithological change was noted to the south along strike, and at GR 625650 mE 6247330 mN lithology typical of the Gooloogong Member of the Hunter Formation is seen above a much thinner coarse sandstone unit. These possibilities cannot be resolved without further fieldwork.

In the region south of Keewong Creek, where Conolly (1965a) identified the Mogongong Conglomerate Member, Jones (1984) mapped a variety of rock types, including lower red bed and debris flow units. In the core of the Keewong Anticline much of the Peaks Formation shows up on aerial photographs as more finely bedded than the more typical massive coarse sandstone units of other localities.

In the Weddin Range, good sections are seen in the foothills at the southeastern end, separated from the main Range by recessive outcrop of the Hunter Formation. The basal contact with underlying Early Palaeozoic strata, which dip to the east, is well-displayed at several localities (GRs 600610 mE 6239780 mN, 6001430 mE 6239270 mN, and GR 599230 mE 6240070 mN). Prominent strike ridges of pebbly sandstone are evident on aerial photographs: at GR 599230 mE 6240070 mN the basal unit, and, at GR 600300 mE 6239780 mN and GR 600610 mE 6239780 mN, a higher sandstone unit at the top of the formation are the main ridge-formers. At GR 601340 mE 6239390 mN, vein quartz suggests faulted truncation of the Peaks Formation, but higher in the section in the Weddin Sandstone at the eastern extremity of the Weddin Range there is no evidence of faulting. Any major faulting must therefore lie further east, beneath alluvial cover.

*Description*

The lithology of the basal beds of the Peaks Formation is variable. At GR 617400 mE 6256570 mN on the nose of the Redcliff Syncline a brick-red mudstone forms the basal unit, overlain by a feldspathic red sandstone with rounded outcrop and occasional pebbles, but the actual contact is not exposed. At GR 621370 mE 6261320 mN, just north of the type section, a ridge-forming red siltstone with abundant burrowing represents the basal unit. That burrowed unit is near the tree line, with the cleared country to the east being an outcrop tract of the Adelargo Member of the Warrumba Volcanics. In the type area, Colwell (1974) noted a basal 15 m thick unit of red siltstone and shale mappable on both sides of the Gooloogong Anticline, which thickens to the southeast to reach about 50 m thickness east of 'Adelargo'. On the eastern side of the Redcliff Syncline this basal unit beneath the first sandstone outcrop is about 20 m thick at GR 618410 mE 6261190 mN. Five kilometres to the south of the type area, in the vicinity of Mogongong and Bumbaldry, the basal beds are represented by the Mogongong Conglomerate Member up to 120 m thick, above which the red mudstone unit reaches a thickness of some 90 m (Jones, 1984, figure 6.6). At the northeastern end of the outcrop across the Gooloogong Road, the Peaks Formation forms a low bluff of massive arkosic red grit, close to the contact with underlying granite.

In the Weddin Range the basal unit is unconformable on underlying Early Palaeozoic strata, at GR 600610 mE 6239780 mN, as a reddish quartz pebble sandstone or conglomerate about 3 m thick, with angular pebbles up to 20 mm across. The 'small lenses of reworked limestones' said by Conolly (1965a, p. 71) to occur in the 'Bogan Gate Sandstone' in the Weddin Range were not observed at any locality. At GR 601130 mE 6241070 mN the unconformity is well-seen in the gully on the west side of the track, where the pebbly sandstone unit is underlain by a basal red shale only 1 m thick. The section at GR 600610 mE 6239780 mN comprises an estimated 170 m of thickness to the top of the second ridge-forming pebbly sandstone, which itself is about 10 m thick. This is taken to represent the top of the Peaks Formation, and is the highest sandstone outcrop in the section before the Weddin Sandstone is encountered on the main escarpment. The intervening strata, representing the lower part of the Hunter Formation, are seen only as float of small pieces of laminated micaceous red siltstones. The middle 150 m of the Peaks Formation at this locality is interbedded red/buff siltstones and lesser mudstone (at least in outcrop), often as platy outcrop, and sometimes showing bioturbation and burrows.

*Depositional environment*

A fluvial environment with both high and low energy regimes is indicated for the Peaks Formation. Palaeocurrent direction was from the west (Conolly, 1965a) or southwest (Colwell, 1974). A local igneous source for clastic constituents is indicated, according to Jones (1984).

*Palaeontology*

A placoderm fish assemblage occurs (J. Pickett, pers. comm., 1994) in a 40 cm thick red sandstone unit at the western end of the Gooloogong Road cutting section of Colwell (1974), which is close to the top of the Peaks Formation. Identified taxa are *Bothriolepis* sp. and *Remigolepis* sp. In addition, Jones (1984) noted plant remains provisionally identified as *Protolepidodendron* in the Brundah Creek region.

*Age and relationships*

The basal formation of the Hervey Group on the Parkes 1:100 000 map sheet area, which is apparently equivalent to the Peaks Formation, was identified by Conolly (1965a) as the 'Kadina Formation', the name derived from the type section defined near Kadina Trigonometrical Station in the Hervey Range in the area of the Narromine 1:250 000 sheet (Conolly, 1965a, p. 47). The 'Kadina Formation' was one of the upper formations of Conolly's (1965a) 'Beargamil Sub-Group' (and the only named unit in the Parkes–Manildra area — Conolly, 1965a, table 1). In the type area of the Hervey Range, Conolly (1965a) included in that

subgroup the underlying Clagger Sandstone, a coarse-grained unit including red sandstones, conglomerates, and some red shales and siltstones (also see Sherwin, 1996). It is evident that (in the Grenfell 1:100 000 map sheet area) there is often a similar sequence of lower red mudstones overlain by sandstones, both of which have been included here within the Peaks Formation. A broad correlation can therefore be proposed between the Peaks Formation and both the 'Kadina Formation' and Clagger Sandstone in the type area of the Hervey Range.

Broad correlation with the Mandagery Formation is also likely, as previously proposed (e.g., Young, 1994; 1999a, figure 3). This is based on revised correlations of the 'Mandagery Sandstone' across the Lachlan River as discussed by Ritchie *et al.* (1992) and Pickett (1993a). Palaeontological evidence supports the correlation of the Peaks and Mandagery Formations, and the age of the latter, as indicated by the Canowindra fish fauna, might be older than the Famennian age previously suggested by Young (1993). A late Frasnian age for this fauna was proposed by Young (1997a, 1999a), and the fish assemblage from the upper part of the Peaks Formation may represent the same fauna. The same may apply to the fish fauna from Gingham Gap in the Hervey Range described by Hills (1936), which was probably derived from the Clagger Sandstone (Sherwin, 1996).

The occurrence of plant remains provisionally identified as *Protolepidodendron* by Jones (1984) from the basal part of the Peaks Formation suggests a possible correlation with the Merriganowry Shale Member of the Dulladerry Volcanics (Cowra 1:100 000 map sheet area), which also contains this plant, and has been assigned a probable late Middle Devonian (Givetian) age (Pickett, 1993b; Young, 1994, 1999a).

## **Mogongong Conglomerate Member** (Dhpm)
Conolly (1965a)

*Previous nomenclature*

The Mogongong Conglomerate Member was defined by Conolly (1965a, p. 60). Jones (1984) further subdivided this member into mappable lower 'Debris Flow', and upper 'Fluviatile Conglomerate' units, reflecting different modes of deposition. This subdivision is not used here.

*Derivation of name*

The name is after Mogongong railway siding and Mogongong Spring, just south of the Mid Western Highway, about 15 km east of Grenfell.

*Type locality*

The type section for the Mogongong Conglomerate Member of Conolly (1965a, p. 60) is just north of the Mid Western Highway, about 15 km east of Grenfell and about 5 km north of Mogongong.

*Thickness*

Conolly (1965a) measured a sequence of 320 feet (98 m): 37 m of massive red conglomerate, overlain by coarse pebbly sandstones, thin conglomerates and red siltstones (61 m). Jones (1984, figure 6.6) recorded a thickness of 120 m, with the unit thinning to the south. About 20 m of fluviatile conglomerate occurs at the southern end of the Yambira Syncline.

*Distribution and outcrop*

This member is restricted to the southern part of the Yambira Syncline, with the main outcrop on the northern side of the Mid Western Highway in the Brundah Falls area, and on the southern side in outcrops on both sides of Bungalong Creek. An outlier of fluviatile conglomerate, in unconformable contact with underlying Ordovician sedimentary rocks, occurs at the summit of Mount Lively south of the Grenfell–Koorawatha railway line (Jones, 1984). A significant proportion of clasts in the conglomerate from this locality are from the underlying Ordovician rocks (Jones, 1984).

*Description*

Conolly (1965a) described a thick massive conglomerate member with poor and indistinct bedding at the base, overlain by well-bedded conglomerates and sandstones. Pebbles vary in size from 12 mm to 75 mm diameter. Jones (1984) recorded angular immature clasts set in a fine red matrix in lower beds, identified as debris flow deposits, and an upper 'Fluviatile Conglomerate' units, with well-rounded gravel and pebbles, which are not clast-supported, indicating shallow water high energy deposition. Above this his 'red-bed sequence' up to 20 m thick comprises massive mudrock with some silty and fine sand interbeds.

*Depositional environment*

The angular immature clast-supported sediments recorded by Jones (1984), which conform with the 'massive matrix supported gravel lithofacies' (Miall, 1978), were interpreted as debris flow deposits. Fluvial deposition (shallow water high energy) in the upper 'Fluviatile Conglomerate' unit is indicated by the well-rounded gravel and pebbles, which are not clast-supported, with the massive mudrock probably representing overbank deposits, in which Jones (1984) identified well-developed pedotubules at some horizons, indicating subaerial exposure.

*Palaeontology*

At Brundah Falls, Jones (1984) recorded plant impressions identified as *Cordaites* sp. *cf. C. australis*, and *Protolepidodendron* sp.

*Age and relationships*

The age and relationships for the Mogongong Conglomerate Member are as discussed for the Peaks Formation.

## **Boulton Formation** (Dho) *nov*

*Previous nomenclature*

This name Boulton Formation is used for the basal formation of the Hervey Group in the northeast portion of the Forbes 1:250 000 map sheet area, to replace 'Kadina Formation' as used by Conolly (1965a). The 'Kadina Formation' was the only named formation recognised by Conolly (1965a) within his lower 'Beargamil Sub-Group' for the Parkes–Manildra area (Conolly, 1965a, table 1), but its type section is near Kadina Trigonometrical Station in the Hervey Range in the Narromine 1:250 000 map sheet area (Conolly, 1965a, p. 47). Here, the 'Beargamil Sub-Group' also includes the underlying Clagger Sandstone, a coarse-grained red unit including reddish to purple sandstones, conglomerates, and some red shales and siltstones (Sherwin, 1996). Conolly (1965a, pp. 41, 46) cited as the 'type section for the Beargamil Sub-Group' his measured section "one half mile due east of Beargamil Dam on the western flank of the Bumberry Syncline", where "two to three hundred feet of basal red conglomerates, red arkoses and lithic sandstones rest with a marked angular unconformity on acid volcanics and tuffs of probable Lower Devonian age". Elsewhere (Conolly, 1965a, p. 55) this type section was also referred to as the "Kadina Formation immediately to the west [*sic*] of Beargamil Dam" but since his map shows granite immediately west of the dam, with 'Bolten Formation' [sic] to the east, this is assumed to be an error. Remapping east of the dam has confirmed that the base of the Hervey Group is separated from the dam by both granite and Dulladerry Volcanics, so this should be disregarded as a type section for the 'Beargamil Sub-Group'.

The name 'Kadina Formation' was presumably applied in the Parkes–Manildra area because of an assumed correlation with the type locality, but Conolly's (1965a) intentions are unclear as published, because the basal formation of the Hervey Group is also named 'Bolten Formation' on his map (Conolly, 1965a, figure 8). This name was derived from the section described as "red siltstone and shale unconformably overlying older Palaeozoic green shales of probable Silurian age" at "Mount. Bolten on the eastern limb of the Parkes Syncline" (Conolly, 1965a, p. 55). This informal name, 'Bolten Formation', has priority, and was used on the 1972 Forbes 1:250 000 geological map sheet (Brunker, 1972). However, it may be confused with another unit, the 'Boltons beds' (Silurian) in the Tantangara region of New South Wales (C. Brown, pers. comm., 1995), so a new spelling is proposed here.

Here, the correct spelling given on the Parkes 1:100 000 topographic map is adopted to define a new Boulton Formation as the basal formation of the Hervey Group in the Parkes 1:100 000 map sheet area of the Forbes 1:250 000 map sheet area.

*Derivation of name*

The name Boulton Formation is from Mount Boulton (635 m), about 2 km south of the Mandagery crossing on the Orange–Broken Hill railway line, which forms the easternmost exposure of the Hervey Group in the Parkes Syncline.

*Type locality*

Mount Boulton provides the type section of 'red siltstone and shale unconformably overlying older Palaeozoic green shales' as measured by Conolly (1965a, p. 55) through the basal part of the Hervey Group in the Parkes Syncline.

*Thickness*

The type section for the 'Kadina Formation' (now Boulton Formation) at Mount Boulton was given a thickness of 350 feet (107 m) by Conolly (1965a, p. 55). In the 'type section for the Beargamil Sub-Group' specified by Conolly (1965a), the Boulton Formation (his 'Kadina Formation') had a measured thickness of 60 m to 90 m.

*Distribution and outcrop*

The basal part of the Hervey Group is often poorly exposed, mainly because of scree cover from overlying sandstones. The lowermost outcrop of Hervey Group observed to the east of Beargamil Dam on the Bindogandra fire trail at GR 629100 mE 6337080 mN is a basal red grit with rounded quartz pebbles to 10 mm across, and subrounded lithic fragments up to 20 mm across. Elsewhere in the Bumberry Syncline the basal Hervey Group was observed at GR 628900 mE 6323950 mN where similar red grits and conglomerates, plus red siltstones, are exposed in association with underlying Moura Formation sedimentary rocks in a gravel scrape. Along the southern limb at GR 634750 mE 6324300 mN a kaolin quarry in deeply weathered red mudstone immediately overlies basal conglomerates, but underlying sedimentary units are covered by alluvium.

At the telephone line south of The Dungeons road cutting, the basal beds of the Hervey Group are covered by sandstone scree, as on the eastern limb of the Parkes Syncline at GR 627500 mE 6324700 mN. To the west along the road, following the Sydney–Broken Hill railway line, the first good outcrop of Hervey Group rocks is a grey quartzite. However, gamma ray spectrometric data indicate that the outcrop extends north to the road from Mount Boulton, and at GR 628650 mE 6323180 mN buff mudstone exposed on the south side of the road 2.1 km west of the Mandagery turnoff dipping to the west is assumed to represent the Boulton Formation.

At GR 627500 mE 6324700 mN, above a quarry in the Moura Formation, scree from the sandstone ridge covers a recessive unit of reddish brown mudstone (excavated from rabbit burrows). The ridge-forming unit is made up of yellowish brown siltstones and fine sandstones (light grey when fresh), which is assumed to correspond to the basal sandstone unit of the Mandagery Formation in its type section. Gamma ray spectrometric data indicate that this unit (and presumably the underlying Boulton Formation) pinches out about 5 km along strike north of the railway line. To the north of this the base of the Hervey Group is a unit that can be traced to the south in apparent continuity

with a sandstone horizon within the type section of the Mandagery Formation. At the northern extremity, on the Parkes–Orange road, only light grey quartz sandstones are exposed, although outcrop pattern on aerial photographs suggests another recessive middle unit in the ridge to the south of the road. Following previous mapping, a basal equivalent of the Boulton Formation is inferred along the northern half of this northern limb of the Parkes Syncline, but without age control it could equally well be considered a lateral equivalent of the finer grained interval within the type section of the Mandagery Formation.

Good exposures of the basal Hervey Group and marked angular unconformity with underlying Moura Formation are seen at Mount Boulton. There, at GR 631050 mE 6320330 mN, readings of 10° dip towards 335° above the unconformity, and 43° dip towards 320° below, are similar to those previously published by Powell *et al.* (1980, figure 7). Down dip to the west of Mount Boulton, the gamma ray spectrometric data suggest discontinuous Hervey Group outcrop, with the Mount Boulton exposure forming an outlier from the main outcrop of the Parkes Syncline. However, although outcrop is poor, exposures of the Boulton Formation were observed near GR 629060 mE 6320490 mN, with colluvium with sandstone float to the north, and green siltstone at GR 629410 mE 6320390 mN. It is presumed, therefore, that the basal Hervey Group has been eroded to a very thin or colluvial cover over the volcanic rocks in this area (i.e., transparent on gamma ray spectrometric images).

*Description*

In the type area for the Boulton Formation, the basal 10 m of the formation is exposed in the gully at GR 631050 mE 6320330 mN. The basal unit consists of about 3 m of dark grey pebble conglomerate with angular pebbles and shale and mudstone clasts up to 25 mm across, overlain by lithic sandstone and grit in 150 mm to 300 mm thick beds interbedded with maroon mudstones (1 m to 2 m thick). Above this is some 5 m of friable red mudstone, at the top of which is another dark grey and maroon unit that contains some bands of calcareous nodules. At GR 630690 mE 6320260 mN the lowest exposure at the top of the gully is friable red mudstone, overlain by massive red and purple siltstones, which crop out as large blocks. Some beds are mottled and show evidence of bioturbation. Small channel fills 0.15 m deep by 0.5 m wide are the only sandstones in this unit, which is overlain by a fine ridge-forming sandstone, the same lithology as observed at GR 627500 mE 6324700 mN above the Symington quarry.

*Depositional environment*

A low energy fine-grained tidal flat or overbank depositional setting is suggested for the Boulton Formation. Minor stream channels were apparently present.

*Palaeontology*

No fossils have been recorded from the Boulton Formation, although there is some evidence of biological activity in the form of worm burrows and other minor bioturbation. A fossil locality was noted by Williams (1977, figure 1) as a fossiliferous marine unit beneath the 'Mandagery Sandstone'. However, remapping indicates that the fossiliferous horizons represent the lower part of the overlying Mount Cole Formation (previously 'Pipe Formation', Conolly, 1965a).

*Age and relationships*

The age of this basal formation of the Hervey Group in the northeastern portion of the Forbes 1:250 000 map sheet area is probably constrained to the Givetian–Frasnian interval (Middle to Late Devonian). To the southeast, (Bathurst 1:250 000 map sheet area), the Merriganowry Shale Member (included in the top of the Dulladerry Volcanics beneath the Hervey Group by Pogson & Watkins, 1998) contains a late Givetian fish and plant assemblage (Pickett, 1993b; Young, 1994, 1999a). That provides an older age limit to the Boulton Formation. The Canowindra fish fauna in the top of the Mandagery Formation was previously assessed as Famennian (e.g., Young, 1993), but new evidence of marine influence indicates that it may be late Frasnian (Young, 1997a, 1999a; Young & Turner in press).

The Boulton Formation can be considered broadly equivalent to other basal Hervey Group formations — the Clagger Sandstone and 'Kadina Formation' in the Hervey Range in the Narromine 1:250 000 map sheet area, and the Peaks Formation (Young, 1999c). Sherwin (1996) has recently noted a locality at the southern end of the Hervey Syncline where crinoid debris in a recessive outcrop characteristic of the 'Kadina Formation' indicates a marine environment of deposition. In the Hervey Syncline the base of the Hervey Group is represented by the Clagger Sandstone, which contrary to Conolly's (1965a) interpretation, is not confined to the northern part of the syncline, but extends to the southern end, where it forms prominent dip scarps (Sherwin, 1996). Assuming that evidence for marine deposition in the Parkes and Hervey Synclines represents a transgressive event, and can therefore be correlated, the 'Kadina Formation' in its type area might relate to a higher horizon (Mandagery–Mount Cole Formation transition) in the northeastern part of the Parkes 1:250 000 map sheet area, in which case, the Boulton Formation would be equivalent only to the basal Clagger Sandstone of the Hervey Group type section.

## **Mandagery Formation** (Dhm, Dhma) after Conolly (1965a)

*Previous nomenclature*

The Mandagery Formation was originally defined as the 'Mandagery Sandstone' by Conolly (1965a)

*Derivation of name*

Mandagery is an aboriginal word widely used in the area of the Forbes 1:250 000 map sheet. It is applied in the vicinity immediately east of the Parkes Syncline, to a major sandstone ridge in the adjacent Molong 1:100 000 map sheet area to the east, and to Mandagery Creek, which

flows in a southwesterly direction across the southeastern part of the Parkes 1:100 000 map sheet, and through the town of Eugowra.

*Type locality*

The type locality of the Mandagery Formation is within in the Parkes Syncline, about 4 km to the west of the Mandagery railway crossing. Conolly (1965a, p. 55) stated that the type section "was measured along the main western railway line to Parkes near Mandagery Railway Station". The base and top of the Mandagery Formation were defined, respectively, by the first and last white sandstones above the underlying formation ('Kadina Formation' of Conolly, 1965a; or Boulton Formation), and below the overlying formation ('Pipe Formation' of Conolly, 1965a; or Boulton Formation).

*Thickness*

Conolly (1965a, p. 55) recorded a measured thickness for the Mandagery Formation in the type section of almost 2250 feet (700 m). However, as mapped here, assuming an average dip of 20°, the formation seems thicker than measured by Conolly (1965a), at least along the road, where dips have been measured in the 20° to 30° range (*cf.* 25° from Conolly, 1965a; 21° given by Powell *et al.*, 1980). The upper part of the formation is exposed in the creek just south of the railway line at GR 626400 mE 6323450 mN. From the published map (Conolly (1965a, figure 8), the upper boundary crosses the road near GR 626000 mE 6323600 mN, where the road descends to the flats of the recessive Mount Cole Formation, but gamma ray spectrometric data show a distinct change further east, at about GR 626700 mE 6323600 mN, by which the Mount Cole Formation is readily recognised. Within these limits, a thickness of up to 900 m is indicated.

Conolly (1965a, p. 55) also noted that the Mandagery Formation (his 'Mandagery Sandstone') thins to the north, south, and east away from the type area. However, these thickness comparisons are not reliable, because gamma ray spectrometric data show that the formation was misidentified in the adjacent Bumberry Syncline, which, at its closest, is less than 5 km east of the type section. The original map (Conolly, 1965a, figure 8) shows most of the area occupied by the Bumberry Syncline to consist of an extensive outcrop of Mandagery Formation. However, it is clear from the gamma ray spectrometric data that the mapped area includes three formations (Mandagery, Mount Cole, and Bumberry Formations), and much of the thickness attributed to the Mandagery Formation is that of the Bumberry Formation. Along the southern extremity of the Parkes Syncline, there is evidence that the Mandagery Formation thins out against the underlying granite.

*Distribution and outcrop*

In the type locality the Mandagery Formation is well exposed in railway cuttings, and along the road between Cookamidgera and Mandagery just south of the railway line — where it forms dominant strike ridges that are readily identified on gamma ray spectrometric images. It can be traced as a strike ridge to the north and south in the Parkes Syncline, where at the southern extremity it is clearly exposed and appears to thin out against the underlying granite, with facies change to finer siltstones making it difficult to distinguish from the underlying and overlying finer-grained units (Boulton Formation and Mount Cole Formation). As noted above, the Mandagery Formation was misidentified in the original map for the Bumberry Syncline, and is much narrower in outcrop than shown by Conolly (1965a, figure 8; also Brunker, 1972). However, it is still readily identified in outcrop and on a gamma ray spectrometric image. The Mandagery Formation is also less clearly developed in the Eugowra Syncline, where the Bumberry Formation tends to be the main bluff-forming sandstone, although originally it was mapped in this area (Conolly, 1965a, figure 8).

*Description*

The type section for the Mandagery Formation begins with a unit of massive white and red sandstones 45 m thick, overlain by fine-grained white sandstones and siltstones (90 m), and green and red siltstones and shales with some white sandstones (73 m). From the published map (Conolly, 1965a, figure 8), the base of the Mandagery Formation can be assumed to be represented by the massive finely laminated light grey quartzites exposed beside the road just east of the cattle grid near GR 627600 mE 6323700 mN. About 500 m west, friable red mudstone exposed in a gravel excavation on the south side the road, presumably represents a level within the finer units of the overlying 163 m interval recorded for the type section, of which red siltstones form only a minor part (Conolly, 1965a, figure 6). Gamma ray spectrometric data clearly show this fine-grained unit, which can be traced along the northern limb (Dhma on map), the outcrop decreasing in thickness (possibly due, partly, to steepening of the dip), as does the underlying sandstone unit, which pinches out about 5 km along strike north of the road. It appears from the gamma ray spectrometric data that the basal Hervey Group unit along the northern half of the northern limb is continuous to the south with a sandstone horizon within the type section of the Mandagery Formation. However, as noted above, a basal equivalent of the Boulton Formation is inferred, following previous mapping. The approximate base of the Mandagery Formation ('Sandstone') on Conolly's map (Conolly, 1965a, figure 8) on the road 4 km west of Mandagery railway crossing is a hard grey quartzite with small mudclasts. The gamma ray spectrometric data show a unit within the Mandagery Formation with a similar colour intensity to the overlying Mount Cole Formation in outcrop seen to the west around the bend in the road where it swings to the northwest, with red and green mudstones exposed on the road edge.

Towards the southern end of the Parkes Syncline the Mandagery Formation is clearly exposed and appears to thin out against the underlying granite, with a facies change to finer siltstones making it difficult to distinguish from the underlying and overlying finer-grained units (Boulton

Formation and Mount Cole Formation). This is the area where Williams (1975) identified a fossiliferous lithological 'subunit A' of the Boulton Formation resting unconformably on granite, considered to underlie typical 'Mandagery Sandstone'. The section at GR 620100 mE 6311500 mN shows this fine-grained unit in contact with the Eugowra Granite, but there is an overlying fine-grained and recessive sequence right across the valley, with no marked sandstone outcrop until the slope of the Eurow Range to the west — which is formed by the overlying Bumberry Formation. The basal Bumberry Formation slope can be traced continuously to the north to the Mandagery railway type section. The Mandagery Formation is therefore interpreted to be absent in this section, with the basal fossiliferous unit considered instead to be equivalent to the lower part of the Mount Cole Formation.

In the Bumberry Syncline there are exposures in The Dungeons road cuttings, and to the south. The lowest exposure just above Bindogundra Creek is a massive sandstone in the road gutter. At GR 630200 mE 6329000 mN the last steep slope down to the bottom of the outcrop shows yellow blocks of sandstone, grey when fresh, and the Boulton Formation is apparently missing or covered by scree. Above this massive unit (forming a 'waterfall' in the gully), is a more reddish unit, with some cross-bedding, and large load casts. Units at GR 629800 mE 6328750 mN show a fish bed assumed to approximate the top of the Mandagery Formation, because it coincides with the gamma ray spectrometric image boundary.

*Depositional environment*

A high energy fluvial environment is indicated for the deposition of the Mandagery Formation, presumably in a coastal plain setting. There is also some circumstantial evidence from the overlying Mount Cole Formation for a marine influence at the top of the Mandagery Formation.

*Palaeontology*

*Bothriolepis* and *Remigolepis* plates were found at GR 629800 mE 6328750 mN, which, according to the gamma ray spectrometric data, approximates to the top of the Mandagery Formation. Both genera are well known from the Canowindra fossil fish fauna (Bathurst 1:250 000 map sheet area), which also occurs near the top of the Mandagery Formation.

*Age and relationships*

A late Frasnian age has been proposed for the Canowindra fish fauna (Young, 1999a), which would place the Mandagery Formation in the Frasnian. Possible equivalents are the Clagger Sandstone in the Hervey Range (although a higher sandstone has been identified as Mandagery Formation in that sequence, but the correlation is questionable; Sherwin, 1996), and the Peaks Formation in the southeastern portion of the Forbes 1:250 000 map sheet area (Young, 1999c).

## **Hunter Formation** (Dhh) after Conolly (1965a)

*Previous nomenclature*

The Hunter Formation is equivalent to the 'Hunter Siltstone' of Conolly (1965a) and (in part) to the 'Bogan Gate Sandstone of Conolly (1965a).

*Derivation of name*

The Hunter Formation is named from Hunter Creek, where Conolly (1965a, p. 61) defined the type section (for the 'Hunter Siltstone').

*Type locality*

The type section of Conolly's (1965a) 'Hunter Siltstone' was measured on the eastern limb of the Gooloogong Anticline in the valley of Hunter Creek, about 20 km northwest of Grenfell.

*Thickness*

Conolly (1965a, p. 61) calculated a thickness of about 330 m ("one thousand feet of red siltstone with occasional fine-grained red sandstone and shale members") from the width of outcrop and average dip, and a maximum thickness of 1600 feet (490 m) was estimated (Conolly, 1965a, figure 4, column K) in the section near the Lachlan River just off the northeastern corner of the Grenfell 1:100 000 map sheet area. In the region of the Redcliff Syncline and Gooloogong Anticline the Hunter Formation maintains a thickness of at least 150 m (Colwell, 1974), whereas in the southern part of the Yambira Syncline it reaches some 450 m thickness (Jones, 1984).

At the southeastern end of the Weddin Range, width across the recessive valley between the Peaks Formation and Weddin Sandstone suggests a thickness for the Hunter Formation of some 200 m, based on dip measurements varying from about 35° to 20° up the sequence. Previously, Conolly (1965a) recorded a thickness of some 248 m of 'Bogan Gate Sandstone' beneath the Weddin Sandstone in that area, which presumably includes both the Peaks Formation and the Hunter Formation equivalents as recognised here.

*Distribution and outcrop*

The 'Hunter Siltstone' was identified and mapped by Conolly (1965a), as a thick sequence of red siltstones and shales that "forms prominent valleys between the strike ridges of the Mandagery and Peaks Sandstones" (p. 61). As such it is rarely observed, except when capped and preserved by overlying sandstones whence it can form prominent outcrops. Thus, the red colour of the northwest-facing escarpment at Redcliff Mountain is due to an extensive exposure of Hunter Formation, protected from erosion by overlying cliffs of Weddin Sandstone. Immediately to the north, where the overlying sandstones have been lost, the Hunter Formation outcrop is represented by a wide valley with little exposure, which occurs mainly as scattered float derived from the more resistant siltstone interbeds. It is noteworthy that gamma-ray spectrometric survey data indicate a high radiogenic

mineral content for this formation, which is clearly defined within the Hervey Group sequence by its light colour, although sometimes difficult to distinguish from underlying volcanic rocks.

The Hunter Formation forms extensive but mainly recessive outcrops capped by Weddin Sandstone in the cores of the Redcliff and Yambira Syncline. Farther east it forms a conspicuous valley around the axis of the Broula Anticline. On the western limb of the Conimbla Syncline the Hunter Formation apparently thins to the south, although lithology typical of the Gooloogong Member is seen at GR 629690 mE 6247200 mN. Up the eastern limb of this syncline the entire outcrop from the base of the sequence to the fold axis is of sandstone lithology, so the Hunter Formation may be missing due to facies changes. However, faulting, or an incorrectly interpreted contact with underlying volcanic rocks are alternative interpretations, for which field checking is required. According to Jones (1984), in the Yambira Syncline area the Hunter Formation overlies the Peaks Formation conformably on the western side, but to the east extends out over the basal debris flow unit (Mogongong Conglomerate Member) to lie directly on the underlying volcanic rocks. It is possible, therefore, that the same applies along the southeastern flank of the Bumbaldry Hills, where the Peaks Formation may be absent because the sandstone lithology wedges out to the south. However, further east, on the eastern limb of the Broula Anticline, the Hunter Formation is readily identified as another distinctive valley between the Peaks Formation and Weddin Sandstone, this sequence apparently being truncated around the fold axis by faulting. As noted above, the position of the basal Hervey Group contact needs field checking in this area.

The Hunter Formation has not previously been identified in the Weddin Range, although the lower part of the sequence initially identified by Conolly (1965a, p. 71) as the 'Bogan Gate Sandstone' presumably included the strata assigned here to the Hunter Formation. The formation is generally difficult to observe because of its recessive outcrop, and the extensive sandstone scree from the overlying Weddin Sandstone. However, the valley between the foothills at the southeastern end and the main range is typical of the often recessive outcrop of the Hunter Formation at other localities. At GR 600610 mE 6239780 mN, the top of the Peaks Formation is a ridge-forming pebbly sandstone, which is overlain by scattered float of small pieces of laminated micaceous red siltstone on a shallow dip slope leading down into the valley, formed in the fine-grained rocks of the lower part of the Hunter Formation. The resistant sandstones and conglomerates of the Weddin Sandstone form the steep cliffs capping the main range, but the lower flanks and even the steeper middle parts of the northeast-facing escarpment are also formed by fine friable red and green mudstones typical of the Hunter Formation at other localities. These outcrops are almost completely obscured by a scree cover of sandstone and conglomerate, including many large blocks and boulders. Actual outcrops occur in erosion gullies at least half way up the scarp and near the base of the overlying Weddin Sandstone at GRs 600490 mE 6239090 mN, 600270 mE 6239120 mN, and 598550 mE 6239220 mN. Elsewhere the friable mudstone typical of the Hunter Formation may be rarely observed well up the scree slope in the excavations of rabbit burrows, attached to roots of fallen trees, etc.

*Description*

The Hunter Formation was originally described by Conolly (1965a, p. 61) as follows:

> "The Hunter Siltstone is a thick sequence of red siltstones and shales and a lesser proportion of fine-grained red sandstones conformably overlying the Peaks Sandstone and underlying the Mandagery Sandstone. It forms prominent valleys between the strike ridges of the Mandagery and Peaks Sandstones."

Because the formation tends to be recessive, rock types are often not discernable, but finer grained sedimentary rocks predominate. In the core of the Redcliff Syncline on 'Arkingarrie' at GR 618570 mE 6259260 mN, typical Hunter Formation rock types crop out with red mudstones containing abundant burrows, and minor buff siltstone interbeds. To the north (about 1 km to 2 km) the extensive exposure and float of fine siltstone and mudstone are interrupted by a low ridge of fossiliferous arkosic fine sandstones at GR 618410 mE 6261190 mN, which contain fish fossils. Further north, at GR 619490 mE 6260610 mN, this sandstone is seen to lie on the fold axis, with two dip measurements in the same outcrop about 7 m apart of 28° to the east and 48° to the west (both striking 040°). Because of its position in the fold axis the stratigraphic level of this fossiliferous sandstone unit is difficult to estimate. Similar lithology was observed at GR 622990 mE 6252350 mN on the axis of the Yambira Syncline, and at GR 624340 mE 6256910 mN on the Yambira Road in the valley of Hunter Creek (type locality). Generally, the red siltstone lithology in beds up to 50 cm thick are most typical. Yellow and olive-grey siltstones occur near the top of the sequence in the vicinity of Redcliff Mountain, and were separated as a separate member by Jones (1984). However, this subdivision is not followed here.

An extensive exposure of Hunter Formation is seen on the northwest-facing escarpment at Redcliff Mountain (e.g., near GR 624100 mE 6266100 mN). This outcrop extends to the north into the valley of the headwaters of Warrumba Creek. A more resistant white and red sandstone unit identified by Colwell (1974) to the east of this creek is reinterpreted here as the basal Peaks Formation on the western limb of the adjacent Warrumba Syncline (it dips to the east), which is juxtaposed against the same formation dipping to the west in a probable faulted contact.

*Depositional environment*

A low energy, shallow-water environment for the Hunter Formation is indicated by the fine-grained sedimentary units, presumably overbank or lacustrine deposits as suggested by Colwell (1974). The presence of lingulid brachiopods associated with fish and plant remains in the

Gooloogong Member might indicate brackish water, perhaps related to marine transgression into a coastal flood plain environment. Circumstantial evidence of a second phase of marine influence at the top of the Hunter Formation (also with abundant fish remains) might be suggested on the basis of a sandy shore environment indicated by the *Skolithos* ichnofacies identified in basal beds of the overlying Weddin Sandstone.

*Palaeontology*

Fossil assemblages have been found at the base, near the middle, and at the top of the Hunter Formation — as summarised by Young (1997a). Four assemblages may be present (A-D):

*Assemblage A.* The lowest occurrence (GR 627060 mE 6276190 mN, in the Gooloogong Member type section), first reported by Colwell (1974), includes lingulid brachiopods (first reported by Jones, 1984), plant remains, and fish plates referred to the placoderm *Groenlandaspis* sp. The latter have tubercular ornament, so are not conspecific with those from the higher *Grenfellaspis* horizon described by Ritchie *et al.* (1992).

*Assemblage B.* From the middle part of the Hunter Formation at GR 619240 mE 6260270 mN *Bothriolepis* sp. and a phyllolepid indet. occur about 2 km south of the original *Grenfellaspis* locality at Redcliff Mountain. Of biostratigraphic significance is the phyllolepid plate, a taxon not recorded in the higher *Grenfellaspis* horizon. This is fauna 3 of Young (1999a, figure 5). In the Yambira Syncline (GR 622990 mE 6252350 mN) there may be another occurrence of this fauna (Young, 1997a). A new fossil fish locality at GR 593880 mE 6243530 mN in the Weddin Range may belong to Assemblage B, or to Assemblage C. *Bothriolepis* sp. is the only genus identified at this locality so far (Young, 1997a).

*Assemblage C.* This is a poorly known occurrence from the middle part of the Hunter Formation, from where Colwell (1974, plate 15) illustrated an ADL plate of *Groenlandaspis* sp., which lacks tubercular ornament, and therefore may be conspecific with the species from the *Grenfellaspis* fauna at the top of the formation. It is assumed therefore to be a younger horizon than Assemblage B.

*Assemblage D.* The upper part of Hunter Formation has yielded the *Grenfellaspis* fish fauna of Ritchie *et al.* (1992), recorded from various localities in the Grenfell 1:100 000 map sheet area. GR 625910 mE 6264260 mN is the locality for new material collected from the Eagle's Nest locality of Ritchie *et al.* (1992). The faunal list given below, modified from Young (1993, p. 251), is based on collections from this and other localities, including the original locality at the southern end of Redcliff Mountain. The *Bothriolepis* and *Remigolepis* from the *Grenfellaspis* fauna were described by Johanson (1997).

Acanthodii: ischnacanthid *gen. nov.*

Placodermi: *Grenfellaspis branagani* Ritchie *et al.*, (1992)

*Bothriolepis grenfellensis* Johanson (1997)

*Remigolepis redcliffensis* Johanson (1997)

*Groenlandaspis* spp.

Osteichthyes: ?*Eusthenodon* sp.

?*Ctenodus* sp.

porolepiform gen. nov.

*Age and relationships*

Correlation of the Hunter Formation with the Mount Cole Formation in the Parkes 1:100 000 map sheet area (previously 'Pipe Formation' in the Manildra–Gooloogong area; Young, 1999b) has been proposed for the lower part of the Hunter Formation. Young (1999a) suggested that the change to fine-grained deposition in both sequences may have resulted from a marine flooding event, which caused brackish water conditions indicated by the lingulid brachiopod assemblages found at various localities, including the Gooloogong Member type section (Assemblage A above). Also possible is correlation with the 'Kadina Formation' in the Hervey Syncline (Narromine 1:250 000 map sheet area), from which Sherwin (1996) has recorded crinoid ossicles, indicating marine conditions. Assemblage B above is fauna 3 of Young (1999a, figure 5), assigned to the early Famennian, and Assemblage D above has been assigned to the late Famennian (Young, 1993, 1999a, figure 5). The latter is correlated with the uppermost part of the Bumberry Formation, where a locality (at GR 631680 mE 6289100 mN) on the western limb of the southern part of the Eugowra Syncline has yielded the only known articulated specimen of *Grenfellaspis branagani.*

## **Gooloogong Member** (Dhhg) after Colwell (1974)

*Previous nomenclature*

The Gooloogong Member of the Hunter Formation was mapped as the 'Gooloogong Beds' by Colwell (1974, p.28).

*Derivation of name*

The Gooloogong Member (of the Hunter Formation) is named from the town of Gooloogong.

*Type locality*

The type section for the Gooloogong Member, defined by Colwell (1974, figure 13), is in the road cutting on the Gooloogong–Grenfell road, 7 km west of the town of Gooloogong.

*Thickness*

Colwell (1974) assigned the complete exposed section in the road cutting on the northern side of the road to the 'Gooloogong Beds'. The 96 m exposure is limited by lack of outcrop at both ends. However, it is evident from normal field outcrop immediately to the north of the road cutting that the lower 20 m of coarser sedimentary rocks, which are predominantly of reddish colour, should be included within the upper part of the Peaks Formation. Consequently, the type section of the Gooloogong Member

is here restricted to the upper 80 m of Colwell's (1974, figure 13) stratigraphic section.

*Distribution and outcrop*

The type section is a good exposure of some 80 m of easterly dipping buff sandstones and siltstones, with minor components of red siltstone, shale and fine-grained sandstone. Generally these beds are poorly outcropping and difficult to observe, and they were recognised only after the road cutting was constructed in the early 1970s. Colwell (1974) considered the unit to lens out rapidly to the south along the Redcliff Syncline, but the poor outcropping characteristics mean that this assessment may not be reliable over large areas. A considerable thickness (possibly partly due to faulted repetition) of typical buff sandstones/siltstones identified as the Gooloogong Member occurs immediately above the Peaks Formation in roadside exposures and gravel scrapes along the Bumbaldry Fire Trail.

To the west of the Conimbla Syncline along the Major West Road (e.g., localities near GR 629000 mE 6251000 mN), fine buff sandstones and siltstones and red mudstones are observed in the core of a small syncline, which may be faulted against the underlying Warrumba Volcanics to the west. However, the map of Jones (1984) interpreted the Hunter Formation to lie in unconformable contact with the volcanic units around the axis of the Kangarooby Anticline, and further field work is required to check this contact. Similar lithology is seen as far south along strike as GR 629650 mE 6247330 mN, where lithology typical of the Gooloogong Member was observed in a dam excavation.

*Description*

The type sequence includes buff sandstones and siltstones, with minor components of red siltstone, shale and fine-grained sandstone. Sandstone interbeds are less than 2 m thick, and coarser sandstones such as seen in the underlying Peaks Formation are completely absent. Ripple marks, medium-scale cross-stratification, fine laminations, and burrowing and other evidence of bioturbation (tracks and trails) are displayed in the predominantly buff central part of the type section, and along the Bumbaldry Fire Trail.

*Depositional environment*

The fine laminations and ripple marks, tracks and trails and extensive burrowing in some layers suggests a shallow-water environment, presumably with estuarine brackish water on the evidence of the lingulid brachiopods. The association of lingulids with plant remains and placoderm plates also occurs in the southern part of the Parkes Syncline and at Nyrang Creek (Cowra 1:100 000 map sheet area).

*Palaeontology*

Lingulid brachiopods, plant stems, and fish plates occur in the type locality for the Gooloogong Member (Young, 1997a).

*Age and relationships*

The similarity in the lingulid–plant–placoderm association in the fossils that occur in the southern part of the Parkes Syncline and at Nyrang Creek, suggests correlation with the lower part of the Mount Cole Formation of Young (1999b). The fish remains are assumed to indicate a Frasnian (Late Devonian) age, and this horizon possibly relates to the late Frasnian marine transgression identified in other areas (Young, 1999a; Young & Turner, in press).

## Mount Cole Formation (Dhl) *nov*

*Previous nomenclature*

Conolly (1965a, p. 56) described a measured section (480 m thickness) of 'Pipe Formation' north of Nyrang Creek near Belubula Trigonometrical Station. (Mount Cole). Conolly (1965a, p. 57) had also referred to the same interval as 'Nyrang Formation'. However, that name is preoccupied, having already been used as the 'Nyrang Sandstone Member' by Pickett (1982) for a member of the Silurian Wallace Shale in the Cheesemans Creek district (C. Brown, pers. comm., 1995).

Conolly's (1965a) usage of the term 'Pipe Formation' was based on the assumption that this often recessive formation in the Parkes 1:100 000 map sheet area is a correlative of the 'Pipe Formation' in its type locality in the Hervey Syncline. Similarly, he applied the term 'Kadina Formation' (defined in the Hervey Syncline) to the basal formation of the Hervey Group in the Parkes–Manildra area, and the term 'Mandagery Sandstone' (defined in the Parkes Syncline) to a similar prominent sandstone unit in the Hervey Syncline. As noted by Sherwin (1996), it is uncertain how reliable such correlations are over long distances. Whilst there is little reason to proliferate stratigraphic names when lithological correlations are uncertain, there is some palaeontological evidence that they are incorrect (discussed below), so it is appropriate to propose a new formation name with its type locality in the Manildra–Parkes area.

*Derivation of name*

The Mount Cole Formation is named after Mount Cole north of Nyrang Creek, where Conolly (1965a) recorded a well-exposed section of the unit.

*Type locality*

The nominated type section for the Mount Cole Formation is the 1050 feet (320 m) interval of red siltstone and green and buff shale with minor white sandstone in the Mandagery railway section of Conolly (1965a, figure 10a), which he identified as 'Pipe Formation'. The Nyrang Creek section (Conolly, 1965a, figure 10b) is thicker, but it is appropriate to specify a type section that has a demonstrable stratigraphic relationship to the type sections of overlying and underlying formations defined in this area.

*Thickness*

The 344 m thick type section may be compared with the 820 feet (250 m) type section reported by Conolly, 1965a,

p. 51) of the 'Pipe Formation' measured near Caloma Trigonometrical Station, northern end of the Hervey Syncline (Narromine 1:250 000 map sheet area). Conolly (1965a) recorded a maximum thickness near Goimbla Trigonometrical Station of some 610 m.

*Distribution and outcrop*

Conolly (1965a, p. 50) identified the poorly outcropping 'Pipe Formation' as being "easily traced on aerial photographs' cropping out in valleys between Mandagery Formation and 'Caloma Sandstone' On the original maps much of the whole sequence in the Bumberry Syncline was erroneously interpreted to represent only the 'Mandagery Sandstone' and 'Pipe Formation'. However, gamma ray spectrometric data clearly show within this outcrop the presence of a unit equivalent to the recessive 'Pipe Formation', which in the Parkes Syncline forms the deep valley of poor outcrop between the type sections of Mandagery and Bumberry Formations. The recessive unit identified by Conolly (1965a) as 'Pipe Formation' is in the Eurow Formation, which overlies the Bumberry Formation (as in the Parkes Syncline).

On the northeastern limb of the Parkes Syncline the Mount Cole Formation forms a valley of poor outcrop between sandstones of the underlying Mandagery and overlying Bumberry Formations, which shows up clearly on gamma ray spectrometric images. On the road south of the railway line between the Mandagery Formation and Bumberry Formation type sections the Mount Cole Formation forms a broad valley. The colour change in gamma ray spectrometric images recorded near the road occurs slightly lower in the sequence than the uppermost conspicuous sandstones, mapped by Conolly (1965a) as the top of the Mandagery Formation. Massive sandstones are also exposed in a nearby gully, with the colour change in the gamma ray spectrometric image located about 200 m to the east, suggesting that the geochemical change (reduction in radiogenic minerals) occurred within the upper Mandagery Formation. Generally, the gamma ray spectrometric image approximately shows the boundary between the Mandagery and Pipe Formations, but poor outcrop often limits the precise location of lithological change.

Good exposures of the Mount Cole Formation in the Parkes Syncline are generally limited to creeks and gullies, but the formation is traceable on gamma ray spectrometric images. It is also present as a valley from the type section to the extremity of the southeastern limb of the sequence, where it apparently lies directly on the granite. That unconformity was first a mapped by Conolly (1965a) as a complete section with 'Mandagery Sandstone' overlying 'Kadina Formation'.

The upper part of the Mount Cole Formation is often obscured by scree from the basal Bumberry Formation, which is clearly seen on the gamma ray spectrometric image as a prominent marker well up the slope. The Mount Cole–Bumberry Formation transition is well seen at GR 626030 mE 6322260 mN, in the cleared slope adjacent to the northern side of the railway line, where about 15 m of interbedded green and red mudstones forms a sharp contact with the first massive sandstone of the basal Bumberry Formation.

In the Bumberry Syncline the Mount Cole Formation is less obvious in aerial photographs, but is again very clear on the gamma ray spectrometric images, extending the length of the northern and eastern limbs. Good exposures are encountered in The Dungeons road cuttings on the main Parkes–Orange road, and in the telecommunication cable trench to the south (near GR 630000 mE 6328900 mN).

*Description*

In the headwaters of Bartleys Creek, immediately south of the type section, the basal strata of the Mount Cole Formation are poorly exposed. However, the middle part has good outcrops of red mudstone, with calcareous bands and common fish fossils, as described by Williams (1975).

The basal beds of the Mount Cole Formation are seen at the southern end of the Parkes Syncline, where they lie directly on the Eugowra Granite. Williams (1975, 1977) followed Conolly's (1965a) interpretation that this was a complete section with 'Mandagery Sandstone' overlying 'Kadina Formation' in unconformable contact with the Eugowra Granite. However, Williams (1975, p. 33) identified a distinct lithological 'subunit A' of buff–green siltstones, which he considered to underlie typical Mandagery Formation, and unconformably overlie the Eugowra Granite. This unit contains a faunal assemblage of plants, bivalve molluscs, and lingulid brachiopods indicating a brackish or marginal marine environment. At GR 620100 mE 6311500 mN there is a contact of granite with this fine-grained unit, which has many trace fossils in a lithology similar to the lower part of the Mount Cole Formation observed in The Dungeons road cutting through the Bumberry Syncline. This section displays red bioturbated mudstone (worm burrows, etc.) near the base, overlain by finely bedded red siltstone with small-scale cross-bedding, and large (20 mm x 10 mm) patches of fine mudclasts, with some soft interbedded mudstones, which are considered to be transitional beds from the upper Mandagery Formation. Above are greenish mudstones and shales, displaying ripple marks, as seen also at GR 630150 mE 6328100 mN; although exposures there are obscured by sandstone scree and float from the overlying formation. However, in gullies the green siltstones, with sandy interbeds up to 100 mm, thick can be observed.

At GR 630200 mE 6329000 mN the upper Mount Cole Formation is exposed as slabs of bedded siltstone, some with tracks and traces, interbedded with reddish siltstone and shale. This may be compared with the uppermost beds exposed in the vicinity of the type locality. An atypical 1 m thick hard quartzite is exposed in the gully south of the road about 50 m from the culvert, but above this are at least three exposures of red mudstone in the gully (about 5 m apart), separated by alluvium. The highest outcrop is scree adjacent to the northern side of the railway line, where about 4 m thick unit of very friable red mudstone lies immediately beneath the first massive sandstone

representing the base of the Bumberry Formation. The mudstone is interbedded and underlain by green siltstones up to 50 cm thick, with sole marks, and various red and green siltstones and shales. Plant fragments, bioturbation, and fish remains occur near the base of this exposure, representing about 15 m of section at the top of the Mount Cole Formation.

*Depositional environment*

Fossil evidence indicates a brackish water to marine influence for the lower part of the Mount Cole Formation, and an estuarine or tidal flat environment is possible.

*Palaeontology*

Conolly (1965a, p. 56) reported lepidodendroid plant remains as the only fossils from his 'Pipe Formation' (now Mount Cole Formation in the Manildra–Parkes area), but the horseshoe crab *Kasibelinurus amicorum* Pickett came from the formation in The Dungeons road cutting. This locality, assumed by Pickett following Conolly (1965a) mapping to belong to the Mandagery Formation, has also yielded plant remains, including *Leptophloeum australe* (Pickett, 1993a, p. 281). Plant remains (including *Leptophloeum australe*), fish plates, bivalve molluscs, and the inarticulate brachiopod *Apsilingula parkesensis* Williams have been recorded from the southern extremity of the Parkes Syncline, in the lower part of the section resting unconformably on the Eugowra Granite. Williams (1975) considered broken fish plates to be ubiquitous within the 'Pipe Formation', and many horizons in the valley south of the type section contain bone fragments. Mudstone at GR 626190 mE 6322050 mN has yielded osteolepid and holoptychiid crossopterygian scales, and bones of the placoderms *Groenlandaspis*, *Remigolepis*, *Bothriolepis*, and a phyllolepid. At GR 626070 mE 6322260 mN, near the top of the Mount Cole Formation (about 15 m stratigraphically below the basal Bumberry Formation) plant stems and burrowed horizons are associated with large antiarch remains (probably *Remigolepis*), fragments of *Groenlandaspis*, *Bothriolepis*, a phyllolepid, and crossopterygian remains.

*Age and relationships*

Young (1999a; Young & Turner, in press) proposed a late Frasnian age for the fossiliferous interval representing the Mandagery Formation–Mount Cole Formation transition, on the assumption that it represents the late Frasnian maximum transgression identified using conodont and other evidence from elsewhere in eastern Australia (e.g., Pickett, 1972; Young, 1995). Rather than the 'Pipe Formation' in the Hervey Syncline, a correlation with the Clagger Sandstone–'Kadina Formation' transition can be proposed, on the evidence of marine fossils in the latter (Sherwin, 1996). To the south (southeastern portion of the Forbes 1:250 000 map sheet area), correlation with the Peaks Formation–Hunter Formation transition is supported by fossil content of the Gooloogong Member (Young, 1999c).

## **Bumberry Formation** (Dhb) after Conolly (1965a)

*Previous nomenclature*

Conolly (1965a) used the name Bumberry Formation for all the sections of the Hervey Group in the Grenfell 1:100 000 map sheet area with the exception of the Weddin Range, but with some difficulty. The two lithologically similar sandstone units (Mandagery Formation, Bumberry Formation) were supposedly distinguished in the type section through the Parkes Syncline by the intervening valley of the recessive 'Pipe Formation'. However, in the Gooloogong–Grenfell region the Bumberry Formation was mapped as lying directly above the Mandagery Formation (also termed 'Mandagery Sandstone' by Conolly, 1965a), so criteria for distinguishing these two lithologically similar formations is unclear. These sequences have now been reinterpreted to be equivalent to the Weddin Sandstone.

In revision of Hervey Group stratigraphy for the Grenfell 1:100 000 map sheet area (Young, 1999c), the term Bumberry Formation was used only for the area north of the Lachlan River, where there is continuity of outcrop in the Parkes 1:100 000 map sheet area.

*Derivation of name*

According to Conolly (1965a) the Bumberry Formation is named for the locality (village) of Bumberry, about 20 km east of Parkes.

*Type locality*

The type section of the Bumberry Formation occurs in the Mandagery railway section of the Sydney–Parkes railway Conolly (1965a, p. 57). The type section is a sequence of four fining-upward cycles, each with pebbly white sandstones at the base, interbedded red siltstones and white sandstones in the middle part, and fine red siltstones and shales towards the top (Conolly, 1965a, figure 10 and p. 57). Conolly (1965b) provided information on the petrology of the Bumberry Formation.

*Thickness*

Conolly (1965a, p. 57) recorded a measured thickness of about 700 m in the type section, and commented that in a section in Nyrang Creek the uppermost of the four cycles, if present, was "... so thick that it must be considered as part of the Cookamidgera Sub-Group". Thus the definition of the boundary with the overlying Eurow Formation is unclear. The thicknesses of up to 1050 m attributed by Conolly (1965a) to the Bumberry Formation in the Kangarooby Anticline area to the south are now included within the Weddin Sandstone.

*Distribution and outcrop*

The Bumberry Formation produces prominent sandstone ridges stratigraphically above the recessive valleys of Mount Cole Formation. The base of the Bumberry Formation is well defined by gamma ray spectrometric data in the type area, and in outcrop. The basal sandstone forms a prominent marker on the gamma ray spectrometric image

along the southeastern limb of the Parkes Syncline, traceable to the south from the type section, and placed well up the slope on the western side of the valley formed by the Mount Cole Formation. Of the four fining-upward cycles identified by Conolly (1965a) in the type section of the Bumberry Formation only the lower one is evident on the gamma ray spectrometric image, with a distinct marker horizon representing the finer upper part of the first cycle. The transition to the Eurow Formation is also unclear on the spectrometric image, with the finer upper part of the lowest cycle shown by a distinct marker horizon that can be traced along the northern limb, and also to the south. Exposures of the Bumberry Formation are more extensive near the fault offset on the southeastern flank of the Parkes Syncline, due to shallower dip and/or thickening of the unit. South of the fault the lower fine-grained interval is unclear on the spectrometric image, as are the higher cycles of the Bumberry Formation, including the transition to the overlying Eurow Formation.

At the southern end of the Parkes Syncline, the nose of the fold is faulted out in the Bumberry Formation as shown by Powell *et al.* (1980). A shallow northwesterly dip adjacent to the fault contact with the steep easterly dipping western limb of the syncline can be seen on aerial photographs. Powell *et al.* (1980, figure 5) showed the whole of the Late Devonian sequence truncated to the west by another fault, but gamma ray spectrometric data indicate that Hervey Group units extend almost to the Parkes–Eugowra road immediately south and around 'Ferndale' homestead, where they are obscured by alluvium. This implies that the strong fault scarp forming the western boundary of the Eurow Range is a normal fault within the Late Devonian, rather than a reverse fault separating Devonian rocks from Ordovician as interpreted by Powell *et al.* (1980).

Conolly (1965a, p. 55) misidentified the Mandagery Formation (his 'Mandagery Sandstone') in the Bumberry Syncline, which, at its closest, is less than 5 km from the Mandagery Formation type section. Conolly (1965a, figure 8) showed most of the core of the Bumberry Syncline to be an extensive outcrop of Mandagery Formation. However, the Mount Cole Formation is very clear on the gamma ray spectrometric data, overlain by an extensive outcrop tract of Bumberry Formation. Thus, the sedimentary structures and palaeocurrent information ascribed to the Mandagery Formation, which were described and illustrated by Conolly (1965a, p. 56; plate 2, plate 3, figures 2 and 3), are all within the Bumberry Formation.

On the western limb of the Bumberry Syncline the basal Bumberry Formation forms the highest relief as the ridge-forming unit of the main range (Bumberry Ridge and Billygoat Ridge, including Bindogundra Trigonometrical Station at over 640 m). Aerial photograph interpretation of outcrop suggests four cycles, as in the type section, with the spillway of Lake Endeavour Dam approximating to the top of cycle 2, and the middle and upper reaches of the lake approximating to cycles 3 and 4. Cycle 4 is distinguishable on the spectrometric image by its lighter colour. Similar lithology of the basal Bumberry Formation is observed near GR 631100 mE 6326400 mN, where the upper Mount Cole Formation has extensive exposure in the valley eroded out of the core of the syncline. The four cycles are not evident in outcrop pattern south of the Parkes–Orange road because of the shallow dip near the fold axis.

The Bumberry Formation flanks both sides of the valley of Nanami Creek, as a southern extension of the Eugowra Syncline. Along the western limb of this syncline the Bumberry Formation forms the prominent outcrop of the Barwigie Hills, which is truncated to the west by faulting against the Milandra Granite (e.g., GR 631700 mE 6291790 mN). Along the eastern limb it forms another row of hills extending from just north of the Cowra–Eugowra railway line to the Canowindra–Eugowra road, where it occupies the core of a major anticlinal structure. Further east it is overlain by the finer-grained strata of the Eurow Formation.

*Description*

At GR 626030 mE 6322260 mN, there is a good exposure of the base of the type section in the cleared slope adjacent to the northern side of the railway line, where the upper 15 m of interbedded green and red mudstones at the top of the Mount Cole Formation is exposed. The first massive sandstone of the basal Bumberry Formation is well-exposed through the fence. It is a well-bedded quartzite (50 mm to 100 mm beds) with some cross-beds, and which forms large blocks in outcrop. The finer, upper part of the lowest cycle in the type section can be seen as recessive outcrop on the eastern slope of the hill when viewed to the north across the railway line. Lithological characteristics can be observed to the south at GR 624500 mE 6321500 mN, an exposure in a gravel scrape on the western side of the road, where friable red mudstone with some less weathered larger blocks are overlain by flat slabs of yellow–buff sandstones with sedimentary structures (including cross-bedding, and parting lineation). Typical lithology of associated massive quartzites, showing parting lineation and other sedimentary structures, is seen at that locality in blocks unearthed during trenching for an underground cable line. The same lithology was observed at GR 631150 mE 6326450 mN higher in the sequence. Interbedded fissile red–purple mudstone in this lower unit is exposed at 624850 mE 6321350 mN as a very friable gravel in the road cutting of the Cookamidgera–Eugowra road, underlain by massive maroon siltstones, some layers with fine laminations, others with extensive bioturbation in the form of lighter-coloured burrowings.

The four major cycles identified in the type section are evident on aerial photographs at the southern end of the Parkes Syncline, where the Bumberry Formation is truncated by faulting. However, in the Bumberry Syncline the cycles are less clear. At GR 630550 mE 6328425 mN, near the base of the formation, platy yellow sandstone or quartzite crops out as flagstones 100 mm to 200 mm thick (also seen on upper section of the cutting, east of Bindogundra Creek, exposed in an excavation on the south side of the road. At GR630200 mE 6329000 mN the basal

Bumberry Formation (according to interpretation of gamma ray spectrometric data) is present along a steep track at the end of the electricity transmission line clearing as white sandstone blocks and slabs with parting lineations, and rare *Leptophloeum*. This bed can be traced on aerial photographs to The Dungeons road cutting section above (east of) Bindogundra Creek.

The lithology of the upper part of the Bumberry Formation is seen in the small bluff at GR 631150 mE 6334800 mN, with outcrops of similar lithology to GR 624500 mE 6321500 mN in the Parkes Syncline. These resistant cross-bedded sandstones are traceable on aerial photographs to the north as the ridge-forming unit of Billygoat Ridge, including Bindogundra Trigonometrical Station, which is the highest point within the northern part of the Bumberry Syncline. This resistant sandstone sequence (estimated thickness using aerial photographs about 170 m) has its upper beds in the spillway of Lake Endeavour Dam. That outcrop is illustrated by Conolly (1965a) as Mandagery Formation. These cross-bedded sandstones, which include lag deposits containing impressions of fish fragments (including antiarchs, and rare phyllolepids), continue around the shore of the lake, and a ridge running back up to the intersection with the road to 'Top Valley' represents the top of the sandstone sequence, although part of this was mapped by Conolly (1965a, figure 8) as his 'Pipe Formation'. The upper sandstones of the Bumberry Formation are well-exposed north of Lake Endeavour, the highest outcrop at GR 631450 mE 6337100 mN being a light grey to buff fine friable sandstone with mudclasts, evidence of burrowing, bioturbation, etc. Generally, these upper beds are more lithic than the white sandstones exposed in the spillway of Lake Endeavour Dam.

To the south of the Parkes and Bumberry Synclines, the Bumberry Formation is predominantly a coarse-grained unit (in the area of the Grenfell 1:100 000 map sheet). The four fining-upward cycles identified by Conolly (1965a) in the type section are not evident that far to the south.

The lowest beds observed at GR 631700 mE 6291790 mN (faulted to the west) are laminated buff siltstones with festoon cross-bedding, which are lithologically similar to the Gooloogong Member of the Hunter Formation to the south. These are interpreted as a finer-grained interval near the base of the Bumberry Formation. Higher in the section, through the Barwigie Hills, rock types include coarse cross-bedded feldspathic grit (GR 631770 mE 6292010 mN), and laminated cross-bedded sandstones (GR 632160 mE 6292070 mN), the former resembling rock types in the Peaks Formation, and the latter rock types in the Weddin Sandstone, the assumed broad correlative of the Bumberry Formation across the Lachlan River.

At some localities higher in the sequence (e.g., GR 632130 mE 6290980 mN) laminated cross-bedded sandstones are interbedded with burrowed red mudstones (generally recessive; and observed only as chips in the soil). Conolly (1965a) identified a small outcrop of basal Eurow Formation at the top of the Barwigie Hills sequence, but this section is interpreted here to represent the uppermost fine cycle of the Bumberry Formation. At those localities (GRs 631680 mE 6289100 mN and 631830 mE 6289390 mN) a red mudstone unit (containing fish, plant remains, and abundant burrowing) in quarries is overlain by a 40 m thick section with two prominent sandstone horizons separated by a fine-grained interval (no outcrop). The upper bed of coarse red sandstone (7.5 m thick) is the highest outcrop in that valley, and is assumed therefore to represent the top of the Bumberry Formation. Exactly the same sequence is seen at GR 634440 mE 6290880 mN on the eastern limb of the Eugowra Syncline, the intervening valley occupied by the overlying recessive Eurow Formation being devoid of outcrop.

Further south, along the eastern limb, a lower fine-grained interval of the Bumberry Formation is exposed in the core of the Nanami Anticline at GR 633010 mE 6286280 mN (red mudstone), with overlying laminated cross-bedded quartzites at GR 632830 mE 6286310 mN. Interbedded sandstones and siltstones crop out along the northern bank of the Lachlan River (between eastings 631390 mE and 631710 mE along approximate northing 6281650 mN), faulted out the west. This folded and faulted section is assumed to represent the finer-grained upper part of the Bumberry Formation. At GR 633140 mE 6288970 mN a syncline axis in a pipe-rock (*Skolithos*) resembles that ichnofacies observed in the basal part of the Weddin Sandstone.

On the eastern limb of the Nanami Anticline near GR 634830 mE 6289060 mN interbedded cross-bedded laminated sandstone and red mudstone units (the latter non-outcropping) apparently represent the gradational upper boundary of the Bumberry Formation. At GR 635130 mE 6288970 mN a highly cleaved phyllitic mudstone was observed in a dam-wall excavation, and further east the sequence is dominated by similar highly cleaved fine-grained sedimentary rocks, assigned here to the Eurow Formation.

*Depositional environment*

The fining-upwards cycles in the Bumberry Formation are interpreted to represent channel fill, point bar and overbank depositional settings in a large fluvial system. A fluvial/coastal plain or near-shore moderate energy environment is indicated by the predominant cross-bedded sandstone rock types.

*Palaeontology*

Lepidodendroid and fish plate remains were recorded by Conolly (1965a, p. 57) from the Bumberry Formation, but localities were not specified, so they could refer to any part of the Manildra–Gooloogong region. New fossil occurrences (Parkes 1:100 000 map sheet area) listed by Young (1997a) include Leptophloeum at GR 630200 mE 6329000 mN and a diverse fish and invertebrate fauna associated with large plant stems at GR 632580 mE 6336550 mN from within the Bumberry Formation.

A new locality of the *Grenfellaspis* fish fauna first described by Ritchie *et al.* (1992) was discovered in red

mudstone forming an upper recessive unit near the top of the Bumberry Formation in a gravel quarry on the western limb of the Eugowra Syncline (GR 631680 mE 6289100 mN). Continuity of outcrop along strike to the north establishes the stratigraphic position of this new fish horizon as approximating the upper Bumberry Formation–lower Eurow Formation interval (as mapped in the Parkes 1:100 000 map sheet area).

*Age and relationships*

The diverse fish, invertebrate and plant assemblage from GR 632580 mE 6336550 mN is assemblage 4 in the biostratigraphic scheme of Young (1999a, figure 5), which has been assigned a middle Famennian age. A *Grenfellaspis* fish fauna at the top of the Bumberry Formation (Grenfell 1:100 000 map sheet area) indicates a late Famennian age (Young, 1999b). Thus the Bumberry Formation can be considered middle-late Famennian (Late Devonian) in age, and may be equivalent to the upper part of the Hunter Formation and the lower part of the Weddin Sandstone in the Hervey Group south of the Lachlan River (Grenfell 1:100 000 map sheet area).

## **Eurow Formation** (Dhe) after Conolly (1965a)

*Previous nomenclature*

The Eurow Formation was one of four formations within the 'Cookamidgera Sub-Group' of Conolly (1965a, table 1), above which in excess of 300 m of undifferentiated sedimentary rocks were estimated in the Mandagery railway section (Parkes 1:100 000 map sheet area (Conolly, 1965a, figure 10). Although Pogson & Watkins (1998) proposed a 'Cookamidgera Formation' containing a lower 'Eurow Member', the name Eurow Formation has been retained as a formation by Young (1999b), as seems appropriate for a sequence over 600 m thick.

*Derivation of name*

Conolly (1965a, p. 57) stated that the type area "... occupied by the fine-grained red beds of the Eurow Formation ... forms the headwaters of Eurow Creek", presumably an alternative name for the Bartleys Creek, which flows to the west through Cookamidgera. The name is also used for the Eurow Mountains (formed by the basal Bumberry Formation), a major range reaching 644 m along the southeastern flank of the Parkes Syncline.

*Type locality*

There has been confusion about the type locality of the Eurow Formation. Conolly (1965a, p. 57) stated that the "type section was measured in the Bumberry Syncline, the centre of which is occupied by the fine-grained red beds of the Eurow Formation". However, his map (Conolly, 1965a, figure 8) did not show this formation occurring in the core of the Bumberry Syncline, and therefore it may be that the reference to "Bumberry Syncline" was in error, and instead should have referred to the "Parkes Syncline". This is supported by Conolly's statement (1965a, p. 46) that the type section for the Cookamidgera Subgroup was measured in the centre of the Parkes Syncline. Since the Eurow Formation is a named unit that was recognised by Conolly within this Subgroup (Conolly, 1965a, table 1), it might be presumed that that type section also applies to the Eurow Formation.

*Thickness*

Conolly (1965a, p. 57) estimated a thickness of at least 630 m in the type section, and at least 610 m "where the Nangar Anticline pitches to the south near Gooloogong".

*Distribution and outcrop*

The Eurow Formation is typically a recessive unit with poor outcrop and hence forms valleys stratigraphically above ridges of the Bumberry Formation. This is the case in its major outcrop areas in the core of Parkes Syncline, and in the eastern part of the core of the Bumberry Syncline. In general, the only exposure observed is red mudstone in the soil cover, and along graded roads (although this is often transported from elsewhere as fill or roadmetal. The Eurow Formation has also been mapped in the core of the Eugowra Syncline.

The Eurow Formation in the Forbes 1:250 000 map sheet area has been identified only on the northern side of the Lachlan River, in essentially the same outcrop tract as originally mapped by Conolly (1965a, figure 8). It is also present in the valley of Nanami Creek (in the Eugowra Syncline), but there are no exposures in the mapped part of this valley. Conolly (1965a) identified a small outcrop of basal Eurow Formation on the western side of the Nanami Road, but this section is considered to represent the uppermost fine cycle of the Bumberry Formation.

To the east of the Nanami Anticline, the Eurow Formation forms extensive outcrops on Mount Gooloogong and Nanami Sugarloaf, where the prominence of outcrop seems partly due to the strong vertical cleavage, which has apparently rendered the fine siltstone and mudstone more resistant to weathering.

*Description*

Massive redbeds of dark grey and maroon siltstones and red mudstone and shale of the Eurow Formation may be seen in gravel quarries, but are often not exposed except in areas of rapid erosion — such as in the core of the Eugowra Syncline at GRs 636550 mE 6300360 mN and 636430 mE 6300360 mN, and to the south at GRs 635630 mE 6295930 mN, 636300 mE 6295290 mN, and 636520 mE 6296640 mN. More typical small exposures are seen at GRs 634270 mE 6297130 mN and 634230 mE 6292440 mN. Worm burrows are abundant in some horizons.

The upper part of the formation is in the southern Parkes Syncline east from GR 620230 mE 6316750 mN, where flaggy bioturbated maroon siltstones underlie the massive quartz sandstones at the top of the ridge forming the Wingara Formation. Within the Bumberry Syncline the basal beds of the Eurow Formation overlying upper sandstones of the Bumberry Formation crop out as red

mudstone on the east side of the road at an outcrop mapped by Conolly (1965a, figure 8) as 'Pipe Formation'. The southern extension of this outcrop is generally covered by soil and sandstone float to the south and along the Parkes–Orange road), but at GR 634900 mE 6328250 mN a bedded outcrop of red mudstone was observed dipping gently to the east, as does another bedded outcrop to the north at GR 632580 mE 6336550 mN. These orientations indicate that the Bumberry Syncline fold axis is much further east than previously mapped.

Massive redbeds are also seen in the gravel quarries near GRs 637280 mE 6287880 mN and 635810 mE 6288188 mN. Because they are massive, bedding may be difficult to distinguish from cleavage.

Worm burrows are abundant at some horizons in these quarries. In many areas there is little or no outcrop, with only red mudchips in the soil, or friable shale observed in gullies and washouts. These massive dark maroon siltstones and mudstones contain little evidence of bedding, but burrowing may be common at some levels. Ripple marks and desiccation cracks were observed at a few localities.

*Depositional environment*

A low energy shallow-water environment of deposition as alluvial plain, overbank or lacustrine settings is suggested for the Eurow Formation. There was occasional subaerial exposure, probably in a coastal plain setting.

*Palaeontology*

The Culela fish fauna was identified near the top of the Eurow Formation near GR 637280 mE 6287880 mN, where it is, again associated with the lycopod *Leptophloeum australe* — which has apparently been commonly found in the local area (N. Campbell, pers. comm., 1997). *Leptophloeum* is also recorded from a quarry within the Eurow Formation at GR 636860 mE 6283060 mN, on the eastern slope of Mount Gooloogong. Lepidodendroid plants (presumably *Leptophloeum*) have been recorded in shales of the Eurow Formation south of Goimbla Trigonometrical Station. in the Eugowra Syncline by Conolly (1965a, p. 57).

*Age and relationships*

The identification of the Culela fish fauna near the top of the Eurow Formation indicates correlation with the Culela Member, a recessive member near the top of the Weddin Sandstone in the outcrops south of the Lachlan River. The lycopod *Leptophloeum australe* is associated in both sequences, and was also found immediately above the recessive unit forming the valley beneath the uppermost preserved sandstone unit of the Weddin Sandstone in the southern part of the Weddin Range (Marsden 1:100 000 map sheet area). *Leptophloeum* impressions may be found at various levels within the Hervey Group, but the predominance of fissile lycopod remains at the horizons discussed here suggests some significant vegetation change, perhaps caused by climatic change, or some other 'event' of potential correlation value.

A provisional latest Famennian age is indicated for the Eurow Formation, on the evidence of the Culela fish fauna (Young, 1999a, figure 5).

## **Wingara Formation** (Dhn) after Young (1999b)

*Previous nomenclature*

The unit defined as the Wingara Formation by Young (1999b) was mapped as a 'thin sandstone member within the Eurow Formation' and 'undifferentiated upper Cookamidgera Sub-Group' by Conolly (1965a) and was included within the Cookamidgera Formation by Pogson & Watkins (1998).

Conolly (1965a) named the Eurow Formation within his 'Cookamidgera Sub-Group', and the overlying 300 m of undifferentiated sedimentary rocks in the type section through the railway section across the Parkes Syncline was named the Wingara Formation by Young (1999b).

The Wingara Formation in the type area is present as a basal sandstone unit with overlying fine-grained sedimentary rocks. The name can be applied to an equivalent cross-bedded quartzite unit observed to overlie the red beds of the Eurow Formation in the hills to the north and east of Nanami Sugarloaf and near the top of Mount Gooloogong. Young (1999b) briefly discussed the identification of the new formation and the erection of a formally named unit within Conolly's (1965a) undifferentiated 'Cookamidgera Sub-Group'.

*Derivation of name*

The name derives from 'Wingara', about 9 km south of the village of Cookamidgera (Parkes 1:100 000 sheet). 'Wingara' is adjacent to the type locality of the formation.

*Type locality*

The base of the type section for the Wingara Formation is at GR 620230 mE 6316750 mN, about one kilometre northeast of 'Wingara' homestead. There, massive white sandstone and quartzite form a westerly dipping sequence in the core of the Parkes Syncline.

*Thickness*

A measured dip of 20° at the base of the type section for the Wingara Formation, reducing towards the fold axis (about 500 m to the west), indicates an estimated thickness of some 150 m to 200 m. However, the top of the unit is lost to erosion. Conolly (1965a, figure 10a) showed a minimum thickness of about 200 m above the basal sandstone unit at the top of his Mandagery railway section.

A measured section in folded sedimentary rocks at Gooloogong Trigonometrical Station passed through about 50 m of interbedded lithic siltstones and fine sandstones above a light grey and buff cross-bedded quartzite some 10 m thick (estimate). This is considered to represent the basal part of the Wingara Formation capping the Eurow Formation at this locality.

*Distribution and outcrop*

The Wingara Formation is a mappable unit around the fold axis in the southern part of the Parkes Syncline, with discontinuous westerly dipping outcrop along strike some 6 km to the northeast. There is no exposure on the western limb of the Parkes Syncline, which may be faulted. Conolly (1965a) reported another sandstone outcrop at the top of his Nyrang Creek section.

The Wingara Formation has been mapped as a massive cross-bedded quartzite unit overlying red mudstones of the Eurow Formation in the hills to the north and east of Nanami Sugarloaf. It is also identified near the top of Mount Gooloogong, with sandstones forming ridges extending north from Gooloogong Trigonometrical Station towards the Cowra–Eugowra railway line, and no doubt contributing to the preservation of the normally recessive underlying Eurow Formation in that area.

The Wingara Formation is at the top of the Hervey Group succession, and at all localities In the Forbes 1:250 000 map sheet area the upper part is lost to erosion.

*Description*

The base of the Wingara Formation is clearly exposed in the western bank of a small creek near the type locality as a massive white cross-bedded quartzite. Nearby, some large load casts were observed in a similar lithology. The upper part of the type section is more bedded, with intervals of no outcrop indicating an increase in fine-grained sediments, as also indicated in the sections of Conolly (1965a, figure 10).

Above the gravel quarry in the Eurow Formation near GR 637280 mE 6287880 mN is a light buff to grey sandstone unit 3 m to 0 5 m thick, with a characteristic massive boulder-like outcrop. This coarser-grained sequence is also observed to the south (GR 632460 mE 6286830 mN), where it is more laminar and cross-bedded, with blocky outcrop and some high angle foresets in beds up to 1 m thick. Some thin recessive units are interbedded, but are entirely scree-covered intervals. The sandstones extend south along this ridge to GR 637300 mE 6286800 mN. To the west (near GR 635610 mE 6288090 mN), the same massive unit forms a resistant cap to the hill behind a gravel quarry, and also apparently crops out across the top of Nanami Sugarloaf (aerial photograph interpretation). South of the Cowra–Eugowra railway line the same rock types were observed in the resistant ridges near GR 635200 mE 6283100 mN. At Gooloogong Trigonometrical Station, a sequence of about 50 m of interbedded recessive friable red mudstones and red and purple lithic siltstones with a "lumpy" bedded outcrop forms the axis of a syncline flanked downslope on both sides by a much cleaner massive cross-bedded quartzite. Because quarries beneath this horizon at the lower southeastern flank of the mountain on the Gooloogong–Canowindra road (GR 634970 mE 6280660 mN) reveal red mudstone rock types typical of the Eurow Formation, the overlying strata are interpreted as Wingara Formation.

*Depositional environment*

The coarser sandstone lithology suggests that during deposition of the Wingara Formation a return to a higher energy fluvial and/or sandy shore environment took place.

*Palaeontology*

No fossils have been found in the Wingara Formation, but the gravel quarry near GR 637280 mE 6287880 mN contains fossil fish remains associated with the lycopod *Leptophloeum* in the mudstones immediately beneath the Wingara Formation.

*Age and relationships*

The Wingara Formation is thought to represent the eroded top of the Hervey Group sequence for the Forbes 1:250 000 map sheet area north and south of the Lachlan River.

The occurrence of the lycopod *Leptophloeum* near the eroded top of the Weddin Sandstone in the southern flank of the Weddin Range suggests a latest Devonian age for these strata, and a similar age is assumed for the Wingara Formation.

## **Cloghnan Shale** (Dhc) Conolly (1965a)

*Type locality and previous nomenclature*

The type area for this formation is on the Narromine 1:250 000 map sheet area. Conolly (1965a) defined this unit essentially by its non-appearance and association with a depressed zone between more resistant units of the Hervey Group. Sherwin (1996) noted that virtually all the "outcrops" of Cloghnan Shale, including the type area, contain fine-grained sediments, with Early Devonian marine fossils, attributable to the Trundle Group.

Notwithstanding difficulties with the type section, the Cloghnan Shale is well entrenched in geological literature because of the vertebrate fauna it contains. The dominant rock type is more akin to a silty mudstone. Selection of a new type section is desirable even if it is nowhere near 'Cloghnan' (also spelled Clognan), from which it is named.

*Distribution and outcrop*

The Cloghnan Shale is the basal unit of the Hervey Group in the Tullamore Syncline and is interpreted to be equivalent to the Peaks Formation, which forms the basal unit of the Hervey Group east of Grenfell. The Cloghnan Shale is conformably overlain by the Weddin Sandstone, and unconformably overlies the Early Devonian Carawandool Volcanics. The Cloghnan Shale is present on the north side of Carlachy Ridge, northwest of Bogan Gate, and is present along the eastern margin of the Jemalong Ridge at the base of the eastern limb of the Tullamore Syncline south of the Parkes–Broken Hill railway line. Natural outcrops are very rare, being generally recessive and covered by colluvial scree shed from hills of the overlying Weddin Sandstone. Even quarry exposures disintegrate within a few years. Extensive exposures of the Cloghnan Shale occur in a series of gravel scrapes near the eastern end of Carlachy Range, 4.5 km northwest of Bogan

Gate. There is a further exposure on Burrawang Road where it crosses the Jemalong Ridge about 20 km west-northwest of Forbes

*Description*

The Cloghnan Shale consists of very friable interbedded reddish-purple siltstone and less abundant mudstone. The bedding is thin to medium, up to one metre in thickness. The internal structure is usually obscure but some beds are clearly laminated. Rare ?calcareous beds, generally 2 cm to 6 cm thick form a unit about 50 cm thick near GR 572150 mE 6303150 mN. The overall colour is reddish but most exposures become grey–green on and near joint surfaces. In a rare natural outcrop (GR 527130 mE 6303120 mN), well-bedded fairly featureless mudstone is interbedded with rare, indistinctly laminated siltstone and fine sandstone beds up to 10 cm thick. In the best exposures, the mudstone shows grey–green mottling. Thin- to medium-thickness, pale pink to grey, fine-grained sandstone beds have lower contacts that suggest scouring of underlying red mudstone. Some of the fine red sandstone interbeds, up to 30 cm thick, have multiple, low-angle, cross-bedded units, mostly less than 3 cm thick. Disarticulated fish plate fossils are most abundant in a highly mottled, nodular (?bioturbated) calcareous, mostly reddish-purple silty mudstone.

The mudstone exposed in scrapes northwest of Bogan Gate is well-bedded in places, and includes sandstone beds to 20 cm thick, with the mudstone grading up into sandstone. The dominantly red mudstone, typical of basal Hervey Group, is quite green in places but still generally mottled. The more isolated sandstone beds are fine-grained, brown and laminated. Some sandstone beds and greenish mudstone have irregular borings, about 3 mm in diameter, that may be tree roots. In thin section (T64477), there are slump-dismembered carbonaceous mudstone and red sandy siltstone clasts in a sparse mud matrix, with angular chips of quartz, abundant mica, and accessory magnetite, apatite, zircon and tourmaline.

In a quarry at the base of the Jemalong Ridge (GR 566800 mE 6289200 mN) the unit occurs as maroon siltstone with interbedded maroon shale and rare, thin sandstone beds.

*Environment of deposition*

The grainsize and possible tree root structures in the Cloghnan Shale suggest silty floodplain deposits in an oxidising environment. Some of the red colouration may be attributable to a source area containing reddish rocks. For example, some outcrops of the underlying Kadungle Volcanics have a notably similar reddish-purple colour. The white to greenish patches are indicative of reducing conditions but it is uncertain how much later this reduction postdates deposition.

*Boundary relationships*

The Cloghnan Shale is interbedded with, and probably encloses, the southern end of the Carlachy Sandstone Member. There is a sharp contact between the Cloghnan Shale and the overlying Cudgelbar Sandstone Member exposed in a cutting on the Burrawang Road where the surface of mudstone may have been leached before deposition of sandstone (Figure 11.3). Just north of Monumea Gap there is a very small creek exposure of Cloghnan Shale (too small to show at map scale) only a few metres above reddish purple outcrops of Kadungle Volcanics.

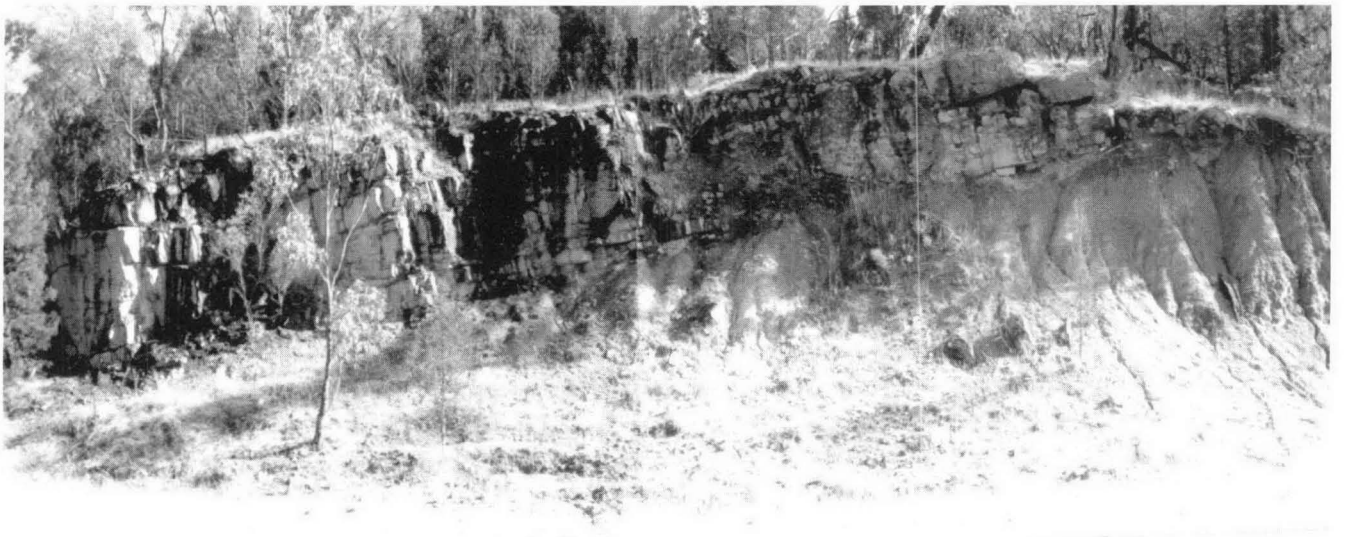


*Figure 11.3. Thick-bedded quartz sandstones of the Cudgelbar Sandstone Member overlying highly weathered Cloghnan Shale. Intense weathering and bleaching of the shale beneath the contact suggests preservation of a Late Devonian weathering profile. (GR 572740 mE 6305320 mN) (O.L. Raymond photograph)*

## **Weddin Sandstone** (Dhw) after Conolly (1965a)

*Previous nomenclature*

The Weddin Sandstone as defined in this report includes the Weddin Sandstone of Conolly (1965a),and parts of the' Mandagery Sandstone', Bumberry Formation, and Eurow Formation as defined by Conolly (1965a). The Bumberry Formation and Eurow Formation are retained for units north of the Lachlan River in the northeastern part of the Forbes 1:250 000 map sheet area.

In addition to its type locality (in the Weddin Range), the name Weddin Sandstone is applied to a considerable thickness of strata that occurs widely within the eastern part of Hervey Group outcrop south of the Lachlan River, the base of which is the major bluff-forming sandstone unit in the area. This basal unit was previously identified by Conolly (1965a) as the 'Mandagery Sandstone', but the type section of the Mandagery Formation occurs in the Parkes Syncline, some 40 km to the north. There is no reliable ground for correlation across this distance and, as noted above, the Mandagery Formation is considered instead to broadly correlate with the other major sandstone interval lower in the sequence (the Peaks Formation). Some close lithological similarities have been noted between the upper bluff-forming sandstones in the Redcliff Syncline–Broula Anticline region, and those forming the main escarpment in the Weddin Range, suggesting that the term Weddin Sandstone is better applied to these upper sandstone strata, a conclusion supported by a small number of relevant palaeontological data points (see below).

Parts of the Bumberry and Eurow Formations, recognised in the Gooloogong–Grenfell region by Conolly (1965a, figure 11) have been included within the 'Weddin Formation' by Young (1999c). Young (1999c) did not attempt subdivision of his 'Weddin Formation' based on lithology, but constituent members are now defined (e.g., by distinctive fossil fish fauna).

*Derivation of name*

The Weddin Sandstone is named for the Weddin Range, in the southwestern corner of the Grenfell 1:100 000 map sheet area. In the language of the Wiradjuri tribe, who inhabited the Lachlan River basin, the word *weedin* means 'a place to sit, stay or remain' (Kabaila, 1996).

*Type locality*

Conolly (1965a, p. 72) defined the type section of the Weddin Sandstone as a sequence that "... forms rugged sandstone cliffs 800 feet high ... near Black Spring Mountain in the Weddin Range". He stated that "... the Nangar Sub-Group cannot be subdivided into individual formations in the Weddin Range ...", but, as noted above, equivalents of both the Peaks and Hunter Formations can be recognised in this sequence. The type section thus needs to be limited to the upper part of Conolly's (1965a) measured section, presumably including the upper 1050 feet (320 m), which was said to include "several 10' to 20' thick conglomerate layers". Conolly gave a total thickness of 1500 feet (457 m) for the type section, but the sequence continues for some 5 km to the south of Black Spring Mountain, with upper strata observed in the adjacent Young 1:100 000 map sheet area. A section examined in a gully 3 km southeast of Black Spring Mountain, GR 598550 mE 6239220 mN, is summarised below. Conolly's type section is summarised here:

| | |
|---|---|
| Fine- and medium-grained white and buff sandstones with interbedded green and white siltstones | 120 m |
| Medium white sandstones, coarse sandstones interbedded with several 10' to 20' thick conglomerate layers | 200 m |
| White and red sandstones, conglomerate, but many fine red and white sandstones and siltstones | 135 m |
| TOTAL | 455 m |

However, estimation from aerial photograph interpretation suggests a considerably greater thickness than this, and it is not clear where the above type section was measured, although apparently it did not go right through the range (e.g., Conolly, 1965b, figure 2). If through the Weddin Gap (about 3 km northwest of Black Spring Mountain), then the section may not be reliable because faulting is evident in that locality. Furthermore, the structure was misinterpreted by Conolly (1965a), being a shallow syncline with axis trending about 330°, with the uppermost preserved strata occurring only in the core of the syncline in the area of the Marsden 1:100 000 map sheet. An auxiliary section in the type locality is proposed here from the eastern escarpment at GR 593450 mE 6244100 mN, running across strike at about 240° across the range and down Guinea Hen Creek on the Marsden 1:100 000 sheet, where the highest strata are preserved.

*Thickness*

The 457 m thickness for the Weddin Sandstone in the type locality given by Conolly (1965a) seems to be a considerable underestimate. Aerial photograph estimation of the thickness of a section across strike from the escarpment near Black Spring Mountain to the uppermost preserved strata to the southwest (to just south of the Forbes 1:250 000 map sheet area), suggests a thickness of 1000 m to 1200 m. This estimate is based on measured dips at both ends of the section in the range 16° to 20°. The auxiliary and more complete section to the north, crossing the range and running approximately along the gully of Guinea Hen Creek, gives an estimated thickness of about 1150 m using a dip of 15° (measured at the eastern end), or about 800 m using a dip of 10° (measured at the western end).

The Weddin Sandstone is much thinner in some localities in the area of the Grenfell 1:100 000 map sheet, where the upper part has been largely removed by erosion. It is 100 m to 400 m thick in the Warrumba Range area (Colwell, 1974), and at Mount Yambira forms a thin cap of about 20 m above the Hunter Formation (Jones, 1984). Conolly

(1965a, p. 61-62) mentioned thicknesses of his 'Mandagery Sandstone' of about 150 m to 305 m in the Gooloogong–Grenfell region, and about 910 m to 975 m thickness of his 'Bumberry Formation' to the east of the Kangarooby Anticline. Those formations are included here in the Weddin Sandstone. Thus, total thickness in the east would compare with or perhaps exceed that of the type section. No detailed new sections have been measured because structural complications mean any repetition of strata is difficult to detect.

*Distribution and outcrop*

The Weddin Sandstone forms an impressive series of rugged cliffs in the type area of the Weddin Range, reaching a height of 712 m at Weddin Mountain. To the northeast of the type area, the Weddin Sandstone forms the bluffs capping Redcliff and Yambira Mountains, although the thickness is considerably less in the flat-lying strata in the cores of the Redcliff and Yambira Synclines because much of the upper part has been lost to erosion. To the east, the Weddin Sandstone forms the sandstone ridges of the Conimbla Range, and occupies the core of the Conimbla Syncline. In the region of Pipe Clay Creek and north of Barryrenie Road, the Weddin Sandstone contains a much higher proportion of finer siltstones and mudstones than in the Weddin Range, thus resembling the correlative units on the northern side of the Lachlan River, the Bumberry Formation and Eurow Formation. In the Tullamore Syncline, north and south of Bogan Gate, the Weddin Sandstone is a prominently outcropping unit that forms ridges and mountain ranges including the Jemalong Ridge on the eastern limb of the Syncline. Other outcrop areas include the Wheoga Range, formed by the eastern limb of the Wheoga Syncline northeast of Grenfell.

*Description*

A good section was studied at GR 598550 mE 6239220 mN in a gully on the eastern escarpment beneath Weddin Mountain, where the first sandstone outcrop occurs some 30 m above one of the few high exposures of the Hunter Formation. The basal beds of the Weddin Sandstone comprise a massive grey–buff quartzite in 40 cm to 50 cm thick beds, some with abundant rounded mudclast horizons (up to 10 cm across). Pipe-rock with *Skolithos* burrows is common. This is some 30 m to 40 m beneath the first cliff-forming sandstone, also observed further east at GR 600280 mE 6239080 mN, and which is characterised by a basal scour and fill with abundant mudclast impressions. This is overlain by a massive yellow–buff fine orthoquartzite with bedding between 40 cm and 1 m thickness, some tabular cross-beds, and parting lineations, but (above the basal scour and fill) few if any pebble or mudclast inclusions. This is in contrast to the two higher bluffs forming the top of the escarpment, separated by some 20 m to30 m of scree, which comprise small cliffs of massive pebbly sandstone and conglomerate each 2 m to 3 m thick. The lower part of the Weddin Sandstone was also observed at the eastern extremity of the range (near GR 602100 mE 6237900 mN), again displaying cross-bedded sandstone and pipe-rock rock types. The lithology of the upper part of the Weddin Sandstone in this section was observed on the southern side of the Weddin Range, where buff to yellow cross-bedded sandstones with some small pebble layers crop out to boundary of the National Park.

Rock types in the northern part of the Weddin Range were observed from near GR 593750 mE 6203550 mN (base), for about 5 km southeasterly (uppermost preserved strata; Marsden 1:100 000 map sheet area). At GR 593830 mE 6243470 mN the lowest sandstone exposure is a light buff quartzite, with large tabular cross-beds at some horizons, but otherwise massive in outcrop. Again, pipe-rock was observed in the scree. The top of the sequence at GR 588820 mE 6241600 mN is a massive cross-bedded sandstone unit some 6 m thick that forms a conspicuous bluff in the core of the syncline. That sandstone forms a small plateau of flat-lying bedded sandstones with platy outcrop, which are not well exposed, This unit forms the uppermost preserved strata with an estimated thickness of 10 m to 20 m. Beneath the bluff, the scree contains much evidence of bioturbation (worm burrows, etc.) and, although poorly exposed, the valley is apparently the result of a fine-grained interval observed to the south near GR 589300 mE 6240750 mN as washouts of very friable red and green mudstone gravel.

Elsewhere the basal beds of the Weddin Sandstone were observed to show similar rock types to the type area. At Redcliff Mountain, the sandstone outcrop about 5 m above the highest exposure of the Hunter Formation is a bluff-forming massive cross-bedded sandstone, again lacking pebbles, which is succeeded some 30 m up section by a thicker massive unit (10 m to 12 m) forming the cliff at the top of the western slope. This is characterised by cross-beds in tabular sets 40 cm to 50 cm thick, and a few pebble layers. To the east, towards the core of the Redcliff Syncline, the distinctive pebbly sandstones with low angle cross-beds are encountered up sequence, as in the Weddin Range. In the Conimbla Range east of Kangarooby Creek the basal Weddin Sandstone was observed at GR 632240 mE 6262030 mN, again a massive cross-bedded sandstone with few pebbles overlying scree-covered slopes of Hunter Formation.

In the Wheoga Syncline, the Weddin Sandstone is a pink to white, medium-grained, moderately well-sorted quartz sandstone with pebbly horizons. The sandstone is commonly very thick-bedded and massive, although minor cross-bedding occurs. The pebbly horizons are thin, commonly being only the width of one or two pebbles (Figure 11.4). Pebble clasts, up to 2 cm across, are predominantly comprised of angular to sub-rounded, white vein quartz. Rare, thicker conglomerate and shale beds also occur within the sandstone. Magnetic susceptibility is very low (typically $< 10 \times 10^{-5}$ SI). Gamma ray spectrometric count rates are very low.

A distinctive pipe-rock lithology with abundant *Skolithos* burrows ranging in diameter from 10 mm to 20 mm was observed in outcrop and scree at several localities along the Weddin escarpment. That lithology apparently

characterises the basal part of the Weddin Sandstone because it disappears consistently from the scree at about the same level on traversing up the gullies. The same facies was observed in the core of the Conimbla Syncline (GR 633050 mE 6255430 mN), and also in an outcrop assigned to the basal part of the equivalent Bumberry Formation north of the Lachlan River at GR 633170 mE 6281350 mN. Scree at GR 634970 mE 6280660 mN also shows the same rock type.

*Figure 11.4. A layer of white quartz pebbles in a poorly-bedded quartz sandstone of the Weddin Sandstone in the Wheoga Syncline. (GR 585650 mE 6268200 mN) (O.L. Raymond photograph)*

In the northeastern part of the main Hervey Group outcrop, to the east of the Conimbla Range, the Weddin Sandstone contains more fine-grained units (siltstones and mudstones) and less sandstone and conglomerate than in the type area of the Weddin Range.

*Depositional environment*

A fluvial environment for the Weddin Sandstone has been proposed, and Conolly (1965a, p. 73) stated that palaeocurrent indicators show consistent flow from the north in the Weddin Range area. The basal part of the unit, characterised by pipe-rock of medium-grained sandstone or quartzite with abundant *Skolithos* burrows (ranging in diameter from 10 mm to 20 mm), is an uncommon lithology within the Hervey Group. The *Skolithos* ichnofacies is widely regarded as indicative of a sandy shore environment (e.g., Frey, 1975; Howard & Frey, 1984; Bjerstedt, 1987). The initiation of coarser sedimentation at the Hunter Formation–Weddin Sandstone transition may therefore have resulted from a sea level rise.

*Palaeontology*

According to Conolly (1965a, p. 73), in his Weddin Sandstone, "Fish plates ... are fairly abundant and similar to types described by Hills (1932, 1936) from the Hervey's Range", but this has not been confirmed during mapping in the Grenfell 1:100 000 map sheet area except for the Culela Member. Otherwise, only two small fragments of possible fish plates have been identified after extensive examination of outcrop, and abundant broken blocks, many with mudclast horizons that would normally reveal fossil fish remains, if present. Conolly (1965a) also noted traces of fish and plant impressions attributed to both the 'Mandagery Sandstone' (now Mandagery Formation) and Bumberry Formations in the Gooloogong–Grenfell region. Impressions of the lycopod plant *Leptophloeum australe* were found in the measured section at Yarrabunda, some 36 m above the Culela fish fauna, and small invertebrates occur at GR 635650 mE 6263840 mN. At GR 588220 mE 6241890 mN an impression of *Leptophloeum australe* was found in sandstone scree near the axis of the syncline. It is thought that the sample may have been derived from the uppermost 50 m (estimate) of the preserved section in the Weddin Range (abundant evidence of bioturbation also occurs at that locality).

Fossilised Late Devonian fish remains from the Weddin Sandstone in the Jemalong Ridge have been noted by several authors (e.g., Hills, 1932; Sherwin, 1971; Bell, 1972). They include *Bothriolepis* sp., *Holoptychius* sp., *Remigolepis* sp., *Phyllolepis* sp., and *Ichthyostega* sp. Sherwin (1973b) reported the Late Devonian plant genus *Leptophloeum* sp. from the Jemalong Ridge, about 8 km south of Bundaburrah.

*Age and relationships*

The Culela fish fauna is assigned a provisional latest Famennian age in the macrovertebrate biostratigraphic scheme of Young (1999a, figure 5, assemblage 6). Evidence from the Bumberry Formation, north of the Lachlan River, confirms a close association with abundant lycopod remains (*Leptophloeum australe*). Its occurrence very close to the preserved top of the Hervey Group in the southern part of the Weddin Range is significant, because the upper limit of *L. australe* approximates to the late Famennian *praesulcata* or *costatus* conodont zones (Mory, 1981; Pickett, 1993b, p. 281), and is not considered to extend across the Devonian–Carboniferous boundary (Young, 1995, 1996). This would suggest that the Weddin Sandstone is confined to the Late Devonian (Famennian) rather than extending into the Carboniferous, at least in its preserved part.

The Weddin Sandstone as interpreted here is considered to broadly correlate with part or all of the Bumberry, Eurow, and Wingara Formations as mapped in the area of the Parkes 1:100 000 map sheet (see below).

### Cudgelbar Sandstone Member (Dhwu) *nov*

*Type locality*

The type locality for the Cudgelbar Sandstone Member is at Cudgelbar Ridge, several kilometres west-northwest of Bogan Gate

*Previous Nomenclature*

The Cudgelbar Sandstone Member was formerly mapped as undifferentiated Weddin Sandstone. It is the upper, and probably more widespread, of two sandstone members now recognised within the Weddin Sandstone in the vicinity of Bogan Gate.

*Distribution and outcrop*

The Cudgelbar Sandstone Member forms the prominent Cudgelbar Ridge to the northwest of Bogan Gate and persists along the eastern limb of the Tullamore Syncline to the south of the Orange–Broken Hill railway line. Recognition is less reliable in the northern part of the Tullamore Syncline north of the Bogan Gate constriction. Outcrops are generally very prominent ridges with very little soil cover.

*Description*

In the type area (GR 573650 mE 6338650 mN), the Cudgelbar Sandstone Member consists of well-bedded units at least 1 m thick. Internally, the beds are massive or have indistinct low-angle cross-bedding in sets less than 20 cm thick. The sandstone is medium- to coarse-grained and pale reddish-brown to off-white. Rounded to sub-angular clasts range in size from coarse sand to pebbles, up to 6 cm in diameter, and occur both isolated and in pebbly bands. Most clasts are milky quartz but about 5% are of volcanic origin, probably from underlying Early Devonian units. In the cutting on the Burrawang Road (GR 575800 mE 6314200 mN) the basal 50 cm of sandstone is medium- to coarse-grained, massive and well-sorted. That horizon is overlain by 2 m to 3 m of milky quartz–pebble conglomerate, in which the pebbles are subangular to rounded and up to 6 cm across. Low angle cross-bedded units in the conglomerate are up to 1.5 m thick.

*Thickness*

The maximum thickness of the Cudgelbar Sandstone Member in the type area is approximately 500 m. This thickness was estimated from aerial photographs because formation boundaries are poorly exposed.

*Environment of deposition*

The coarser grainsize of the sandstone and the presence of conglomeratic bands suggest fluvial deposition in a higher-energy environment than that of the Carlachy Sandstone Member. The more resistant, siliceous nature of the beds in general indicates a lower clay content and, possibly, greater winnowing of the original fluvial sediments. There is no evidence for the buried soil horizons that are observed in lower units of the Hervey Group.

*Boundary relationships and age*

In the type area, the Cudgelbar Sandstone Member is separated from the underlying Carlachy Sandstone Member by a very thin bed of ?Cloghnan Shale. Southeast of Bogan Gate the Cudgelbar Sandstone Member has a sharp contact with the Cloghnan Shale, which, locally, has a leached upper contact (e.g., at the Burrawang Road locality).

## Carlachy Sandstone Member (Dhwa) *nov*

*Type locality*

The type locality for Carlachy Sandstone Member of the Weddin Sandstone is in the western part of the Carlachy Range, 5 km northwest of Bogan Gate.

*Previous Nomenclature*

At the type area in the Carlachy Range, Conolly (1965a) divided outcrops of the Carlachy Sandstone Member into the 'Bogan Gate Sandstone' and the 'Troffs Formation', neither of which was part of his concept of Weddin Sandstone. East of Bogan Gate, Conolly (1965a) did not differentiate this particular unit from the remainder of the Weddin Sandstone.

*Distribution and outcrop*

The Carlachy Sandstone Member is recognisable in both limbs of the Tullamore Syncline near Bogan Gate, although recognition is uncertain north of the constriction in the syncline. Southeast of Bogan Gate this Member becomes progressively thinner and cannot be recognised any farther south than an isolated outcrop 5 km north of the Lachlan River (GR 574500 mE 6310000 mN). The sandstone forms very prominent outcrops, especially to the northwest of Bogan Gate.

*Description*

Much of the Carlachy Sandstone Member resembles the Cudgelbar Sandstone Member but, in general, it is more friable, possibly indicating a higher clay content. The sandstone is fine- to medium-grained, generally well-sorted, hard to friable and laminated to massive. The colour varies from off-white to red and reddish-purple. At GR 575740 mE 6313950 mN, the sandstone is well-bedded, with bedding thickness being in the range of 5 cm to 30 cm, and groups of beds forming an overall sequence 25 m to 50 m thick. There is some small-scale cross-bedding up to 15 cm thick. The uppermost, obvious sandstone bed shows trails and possible ripples (very low relief), with the distance between crests being about 3 cm. Some beds are mottled reddish-brown to off-white, with an abrupt upward change to reddish-purple mudstone. Just below these mottled beds are bedding planes covered with possible fish plate fossils. The Carlachy Sandstone Member is much richer in fossil fish remains than the Cudgelbar Sandstone Member. At least two "pock-marked" horizons, are a characteristic feature of the Carlachy Sandstone Member. These "pock-marks" are a weathering feature, possibly marking former plant root hollows or others of uncertain origin, but they have no recognizable structure other than being vaguely spheroidal. In thin section (T64486), the well-sorted grey quartzose sandstone, with sutured silica overgrowths, contains rounded lithic fragments of metamudstone with abundant accessory feldspar, magnetite, mica, rutile, zircon, and tourmaline. The cement consists of clay and ankerite.

*Thickness*

The maximum thickness of the Carlachy Sandstone Member is about 350 m, in the vicinity of Bogan Gate. Because the base of the ridge is obscured by sandstone scree, the thickness has been estimated from aerial photographs.

*Environment of deposition*

The "pock-marking" in this sandstone is interpreted as possible root burrows. The sandstone is probably fluvial in origin but may have supported vegetation for extended periods with recognisable development of soil horizons.

*Boundary relationships and age*

Field relations indicate that the Carlachy Sandstone Member is essentially a large wedge or lens within the Cloghnan Shale. Near Bogan Gate, the Carlachy Sandstone Member is separated from the overlying Cudgelbar Sandstone Member by a very thin (less than 1 m thick) mudstone unit believed to be a split of the Cloghnan Shale. Southeast of Bogan Gate the Carlachy Sandstone Member is progressively thinner and cannot be recognized where the Hervey Group is cut by the Lachlan River.

## Culela Member (Dhwc) *nov*

*Derivation of name*

The Culela Member of the Weddin Sandstone is named after 'Culela', whose owner, Neville Fragar, was the first to discover the Culela fish fauna that occurs in this unit.

*Type locality*

The type section for the Culela Member is included in a measured section across the eastern limb of the northern extension of the Conimbla Syncline on 'Yarrabunda' (section base at GR 636430 mE 6265170 mN and section top at GR 639710 mE 6265530 mN).

*Thickness*

Some 113 m of interbedded green and red siltstones, fine buff sandstones and red mudstones form a recessive unit between ridge-forming sandstones, which define the base and top of the Culela Member. The fossil fish assemblage comes from the top of a 10 m interval of red mudstone, 77 m above the base of the Culela Member.

*Distribution and outcrop*

The Culela Member is a distinctive fine-grained unit with recessive outcrop, which tends to form valleys within the sandstones that predominate in the Weddin Sandstone. Part of the valley of Barryrenie Road is formed by the Culela Member, and its limited, or lack of outcrop apparently limits the eastern margin of Hervey Group outcrop in the Broula Anticline (east of the Forbes 1:250 000 map sheet area). It crops out to the north on 'Yarrabunda' and 'Culela'. From the type section it can be traced on aerial photographs to the north into the valley of Pipe Clay Creek, where the distinctive Culela fish fauna has also been identified. It is evident that the Culela Member occurs close to the top of the Weddin Sandstone in this area.

On both sides of the northern extension of the Conimbla Syncline, the Culela Member can be traced on aerial photographs as a recessive unit, but with the steeper dips its topographic definition is sometimes uncertain. In general, this uppermost part of the Weddin Sandstone sequence in the northeastern part of the outcrop on the southern side of the Lachlan River contains more fine-grained units interbedded with thinner sandstones than in the Weddin Range. The equivalent strata north of the Lachlan River (Bumberry and Eurow Formations) have similar predominance of fine-grained units. Where the Culela Member crosses the Barryrenie Road (between GRs 634300 mE 6259510 mN and 634660 mE 6258990 mN), the gamma ray spectrometric image indicates high K, U and Th levels (as in the Hunter Formation). However, to the east and north of this point spectrometric data are difficult to relate to the geological structure of the area as previously mapped by Conolly (1965a). This area is folded and faulted, and more detailed fieldwork is necessary to clarify the provisional outcrop pattern shown on the map.

*Description*

Typical rock types in the Culela Member are red and green mudstones and siltstones and interbedded fine sandstones. Rock types and outcrop pattern are generally similar to the Hunter Formation, but the Culela Member is clearly much higher in the sequence, and contains a different vertebrate fauna.

*Depositional environment*

A low-energy shallow-water environment is indicated by the fine-grained sedimentary units of the Culela Member. The sediments were presumably laid down as overbank or lacustrine deposits.

*Palaeontology*

The Culela fish fauna has been identified at localities GRs 635790 mE 6265930 mN, 636350 mE 6265030 mN, 635770 mE 6268440 mN, 635710 mE 6268310 mN, and 636000 mE 6259150 mN. A preliminary list of identified taxa follows:

| | |
|---|---|
| Placodermi: | large remigolepid antiarch |
| | *Bothriolepis* sp. |
| | *Groenlandaspis* sp. |
| Osteichthyes: | scales and bones (crossopterygian; ?actinopterygian) |
| Plantae: | plant remains (including. *Leptophloeum* in a higher horizon) |

*Age and relationships*

The Culela fish fauna is assemblage 6 in the macrovertebrate biostratigraphic scheme of Young (1999a, figure 5), which has been assigned a provisional latest Famennian age. The Culela Member is a recessive unit near

the top of the Weddin Sandstone and may be equivalent to the recessive unit near the top of the Weddin Range sequence identified near the axis of a syncline as a recessive valley beneath the uppermost preserved sandstone (near GR 589000 mE 6241000 mN). The lycopod *Leptophloeum australe* has been found at both localities. It is noteworthy that this lycopod is also common in the upper part of the Eurow Formation near GR 637280 mE 6287880 mN, which has also yielded the Culela fish fauna — and is, again, overlain by a sandstone unit close to the preserved top of the sequence (interpreted as equivalent to the Wingara Formation in the northeast of the Forbes 1:250 000 map sheet area). On this basis, a provisional correlation is proposed with the uppermost part of the Eurow Formation.

## **Cookamidgera Subgroup** (Dhg) Conolly (1965b)

*Previous nomenclature*

Sandstone beds within the core of the Tullamore Syncline, overlying the ridge-forming Weddin Sandstone, were placed in the Cookamidgera Subgroup by Conolly (1965a), although the type area is over 50 km the east in a separate syncline. Correlation is, thus, questionable for the reasons previously noted by Sherwin (1973b, 1996).

*Distribution and outcrop*

The Cookamidgera Subgroup is widely distributed south of Bogan Gate, concentrated along the east limb of the Tullamore Syncline, west of Jemalong Ridge (formed by the Weddin Sandstone). The large faults now interpreted near the axis of the Tullamore Syncline may have resulted in some repetition of section. The blocky to slab-like sandstone outcrops of the Cookamidgera Subgroup are more thinly-bedded than the Weddin Sandstone and much lower in relief. In many areas the Subgroup is represented by low rises and blocky float but well-defined trend lines are evident in aerial photographs.

*Description*

The Cookamidgera Subgroup is much more thinly bedded than the Weddin Sandstone Members and is finer-grained. Poor outcrop of fine- to medium-grained, deep reddish-brown sandstone on the south side of the road at GR 572300 mE 6331120 mN is thin- to thick-bedded (beds 3 cm to 30 cm). Laminated and massive beds are interbedded. At a nearby locality (GR 577080 mE 6324600 mN) the beds form very low outcrops, barely rising above the ground surface. The jointing there imparts a deceptive easterly dip to beds that actually dip to the west. The fine- to medium-grained, well-sorted reddish-brown quartzose sandstone has bedding thicknesses of about 5 cm to 30 cm, and rarely up to 50 cm, in "packages" of thicker beds about 2 m to 3 m thick, which are mostly massive but sometimes laminated. There is some suggestion of weathered out clay pellet beds. Some of the more tabular claystone fragments weather to leave hollows resembling fossil placoderm plates.

At an indistinct escarpment (GR 572980 mE 6332290 mN) on the east side of Wards Lookout, there are lines of very blocky flesh to buff, mostly medium- to coarse-grained sandstone, with rare bands of pebbles or fine conglomerate. The bedding here is up to 1 m thick and internally massive, although there is indistinct bedding in the pebbly bands. At the same locality, rare plant (?reed) stem fossils are present and a fragment of a thick, coarsely ornamented arthrodire plate has been observed.

Thin sections (e.g., T64488) show sutured overgrowths, well-sorted, red, laminated bimodal sandstone (median grainsizes 0.1 mm and 0.3 mm) and abundant accessory feldspar ($An_{45}$), mica, magnetite, apatite, zircon, rutile, tourmaline, and rounded lithic grains of volcanic chert, felsic tuff, metasiltstone, metasandstone, and mudstone in an ankerite cement.

*Thickness*

Between Bogan Gate and Goobang Creek the Cookamidgera Subgroup is unlikely to be much more than 500 m thick, based upon regional dips and outcrop width. Greater apparent thicknesses in outcrops immediately south of Bogan Gate may be due to repetition by fault slices.

*Environment of deposition*

The depositional environment of the Cookamidgera Subgroup was probably a continuation of the fluvial conditions prevalent during deposition of the Weddin Sandstone, but more seasonal in character. The significantly finer-grained sandstones are probably indicative of weaker currents. The coarser beds amid finer sands are also indicative of channels in an alluvial plain. The "reed" stems also support an interpretation of relatively stable overbank and plain deposits.

*Boundary relationships and age*

Closely parallel bedding trends in the Cookamidgera Subgroup and the Weddin Sandstone indicate conformity of the two units. North of Bogan Gate the Cookamidgera Subgroup is overlain by Mesozoic sedimentary rocks. However, south of Bogan Gate the Subgroup is overlain by (?late) Cainozoic flood plain sediments.

# 12. MESOZOIC

## Ungrouped Mesozoic Unit

### Friable sandstone and polymict conglomerate (Mz)

*Distribution*

Mesozoic sandstones and conglomerates occur about 15 km east and north of Bogan Gate, and are exposed in gravel pits (e.g., GR 585910 mE 6346980 mN) and road cuts.

*Description*

At the surface this Mesozoic sandstone and conglomerate unit appears to be a quartz-lithic pebble conglomerate, but sections show that it is predominantly sandstone, with rarer mudstone and conglomerate. Cross bedding exposed in pits and cuttings indicates a fluvial depositional environment and northerly flowing currents, consistent with the sediments having been deposited by streams flowing towards the Surat Basin depocentre to the north. Clasts in the conglomerates are generally well rounded, and include boulders of quartzite over 1 m in size, and pebbles of dark (high strain) metamorphic quartz, which do not appear to have a source in the local area.

Apatite fission track analysis of bedrock samples from the Northparkes mine area, reported by O'Sullivan *et al.* (2000) indicate Mesozoic reheating, consistent with possible deposition of around 1 km of sediment. The Mesozoic sedimentary rocks on the Forbes 1:250 000 map sheet area are interpreted as being part of this sequence, which has been mostly eroded from the area.

*Boundary relationships and age*

The Mesozoic sandstones and conglomerates unconformably overlie rocks of the Ordovician Northparkes Volcanic Group and the Late Devonian Hervey Group. Their age has been recently confirmed as Jurassic by palynology of drillhole cuttings provided by North Ltd (M. McPhail, pers. comm., 1999).

# 13. CAINOZOIC

## Ungrouped Cainozoic Units

### Weebar Hill Leucitite (Tl) *nov*

*Nomenclature, derivation, distribution and relations*

The Weebar Hill Leucitite is named after Weebar Hill near Wallaroi Creek at GR 502500 mE 6330100 mN. The name is used for leucitites crop out occur subsurface southeast of Condobolin and continue into the Cargelligo 1:250 000 map sheet area to the west.

The Weebar Hill Leucitite is the most easterly of the Miocene leucite-bearing volcanic rocks in New South Wales (Cundari, 1973), which extend in a 90 km-wide belt from Byrock to Cosgrove in Victoria (Cundari, 1989). The Leucitite forms two prominent hills, Weebar Hill and Wallaroi Hill, which rise above the surrounding alluvial plain of Wallaroi Creek. Outlying outcrops at GRs 502200 mE 6331700 mN, 503650 mE 6329950 mN, 503250 mE 6329300 mN, and 502600 mE 6327300 mN form low hills rising above the alluvial plain. The strong magnetic signature of the Leucitite, which displays clearly on total magnetic intensity images, shows that its subsurface distribution extends about 5 km from Weebar Hill and Wallaroi Hill. Two water bores drilled northeast of Weebar Hill intersected basalt below Quaternary and Cainozoic alluvium cover, at depths of approximately 20 m and 42 m.

The Weebar Hill Leucitite unconformably overlies sandstones and siltstones of the Ordovician Clements Formation. At GR 502360 mE 6330140 mN, leucitite overlies a 5 m thick iridescent terracotta-coloured, ferricrete-cemented gravel (Figure 13.1). That outcrop shows that the Tertiary Lachlan River–Wallaroi Creek alluvial system was established and depositing gravels prior to the leucitite eruptions. Overlying the Leucitite are younger Cainozoic and Quaternary alluvial deposits of the Lachlan River–Wallaroi Creek system, and Cainozoic slope colluvium. The Leucitite is interpreted to have caused the damming of Humbug Creek, forming Banar Lake, which continues as an intermittent lake to the present day.

*Type localities and thickness*

The 10 m high walls of the Condobolin Basalt Quarry at GR 509950 mE 6329950 mN, where bedded lava flows and scoria breccia are exposed, provide an excellent section and type locality for the Weebar Hill Leucitite (Figures 13.2, 13.3). Thicknesses for the Leucitite vary from <1 m at the exposed edge of flows to a maximum at Wallaroi Hill of 110 m, based on the relief above the unconformity over Wagga Group rocks. Both Wallaroi Hill and the 212 m high Weebar Hill are representative localities for intrusive centres. Erosion has diminished the original thickness of leucitite on the slopes of those volcanic centres.

*Description*

Layered volcanic stratigraphy of Weebar Hill Leucitite lava flows and flow-banded scoria flow front and/or top breccias is exposed in the Condobolin Basalt Quarry. The lava flows often have vertical columnar jointing. The leucitite weathers to form spheroidal boulders at the surface. The lava flows have high magnetic susceptibilities of $300 \times 10^{-5}$ SI to $3000 \times 10^{-5}$ SI, and the vesicular breccias have magnetic susceptibilities of $30 \times 10^{-5}$ SI - $400 \times 10^{-5}$ SI. The high potassium content, combined with low Th and U in the leucitite, produces deep pink anomalies on RGB gamma ray spectrometric images.

*Figure 13.1. Ferricrete-cemented, terracotta-coloured Cainozoic alluvium underlying Weebar Hill Leucitite. (GR 502360 mE 6330140 mN) (L. Sherwin photograph)*

*Figure 13.2. Columnar jointed, layered flows of the Weebar Hill Leucitite exposed in the Condobolin Basalt Quarry. (GR 509950 mE 6329950 mN) (M.M. Scott photograph)*

Intrusive centres can be recognised at Wallaroi Hill and Weebar Hill. Wallaroi Hill has fine- to medium-grained dykes, and ridges of interbedded lava flows and scoriaceous rocks, with the contacts between flows sloping away from the hilltop. Weebar Hill is a ridge with a

magnetic high adjacent to the 212 m spot height. This magnetic high is interpreted to be a volcanic vent.

Leucitite is an ultra-alkaline volcanic rock containing no essential feldspar (although feldspar may be present up to 10%) and has leucite ($KAlSi_2O_6$) as the essential feldspathoid (>10%). Modal analyses by Cundari (1973) have revealed that the leucitites at Weebar Hill have between 14% and 23% leucite, 38% and 42% clinopyroxene, 15% and 22% olivine, and 11% and 18% iron and titanium oxides (Figure 13.4). The leucite crystals are colourless and generally less than1 mm; clinopyroxene forms small crystals ranging from brownish salite to green diopsidic augite; olivine is magnesium-rich and forms phenocrysts 1 mm to 6 mm in diameter with minor iddingsite replacement; and magnetite is the common accessory iron oxide (Cundari, 1973; Barron, 1998). The Leucitite has a grey to black aphanitic groundmass, with vesicles containing infilling of phlogopite and blue to yellow zeolite (Barron, 1998). Other petrographic features include lensoidal segregations of K-feldspar, aegirine-augite, zoned barkevikite and magnetite, and corroded spinel–olivine xenoliths, up to 10 mm, with the spinel replaced by magnetite filaments (Barron, 1998).

*Figure 13.3. Scoria flow front and/or top breccia with fresh blue–grey boulders of lava flows in the background, Weebar Hill Leucitite, Condobolin Basalt Quarry. (GR 509950 mE 6329950 mN) (M.M. Scott photograph)*

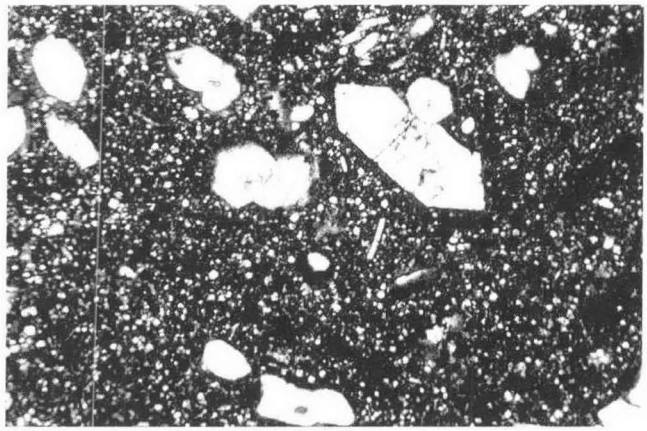


*Figure 13.4. Photomicrograph of euhedral olivine and salite phenocrysts in Weebar Hill Leucitite lava flow rock, Condobolin Basalt Quarry. (Plane polarised light 2.2mm × 3.5 mm) (GR 509950 mE 6329950 mN) (M.M. Scott photograph)*

Hard-rock aggregate was produced at the Condobolin Basalt Quarry in 1969 (Bowman, 1977a,b), but, according to the 'Milby' landowner, it ceased operation due to difficulties in crushing. Loose boulders from the quarry are still used by the Lachlan Shire Council as decorative stones in gardens in Condobolin.

*Geochemistry*

Cundari (1973) analysed four leucitite samples for whole rock geochemistry (CND-4, 6, 9, 10). Another sample (G1998/103 in the geochemistry database of the Geological Survey of New South Wales), of a grey to black aphanitic leucite flow from the Condobolin Basalt Quarry (GR 509950 mE 6329950 mN), was analysed for a greater range of elements. The leucitite has an ultramafic composition with 42 wt% to 45 wt% SiO2, 11 wt% to 12 wt% total Fe as FeO and 12 wt% to 15 wt% MgO, and high TiO2 (4 wt% to 5 wt%), CaO (9 wt%), K2O (4 wt% to 5 wt%), and P2O5 (1 wt%). There are also significantly high levels of Ag (2.8 ppm), Ce (222 ppm), Co (40 ppm to 50 ppm), Cr (359 ppm to 573 ppm), La (121 ppm), Nb (123 ppm), Nd (133 ppm), Ni (239 ppm to 520 ppm), and Zr (505 ppm to 644 ppm). The Weebar Hill Leucitite at Condobolin has similar chemistry to other leucitites in southeastern Australia, which are characterised by high Ti, Mg, K, P, H20+, Cr, Ni, Zr, Rb, Sr and Ba, and low Si, Al and Na relative to an average basalt composition (Cundari, 1973).

*Age*

Wellman *et al.* (1970) determined a K–Ar age of 12.6 ± 0.4 Ma (uncorrected), now recalculated to 12.9 ± 0.4 Ma (Middle Miocene) for a leucitite lava flow (from a ridge) at Weebar Hill.

*Environment of formation*

Cundari (1973) suggested a mantle source for leucitites in New South Wales, derived from deeper than 100 km and crystallisation at in excess of 700°C under pressures of less than 2 kb. Deep-seated crustal structures, reactivated during the late Cainozoic by faulting and differential

vertical movements, were suggested by Cundari (1973) as essential for the movement of the leucitite magma to the surface. Geological mapping, and interpretation of the Forbes 1:250 000 aeromagnetic images, suggest that the Gilmore Fault Zone has acted as a dilational conduit for the Weebar Hill Leucitite (Scott, 1999), and also for the olivine leucitite occurring 22 km along strike to the north-northwest (Suppel & Pogson, 1993).

Centred on Weebar Hill and Wallaroi Hill, an accumulated sequence of subaerial lava flows and scoria breccias form dip layers sloping away from the vents. The Leucitite flowed over the Wagga Group and Cainozoic alluvium, and into the palaeovalleys of Wallaroi Creek, Wallamundry Creek, and Humbug Creek, and towards the Lachlan River.

## Unnamed alkali olivine basalt (Tb)

*Distribution*

Alkaline olivine basalt crops out in a small area, less than 0.5 km$^2$, at the eastern boundary of the Forbes 1:250 000 map sheet area at GR 539500 mE 63008000 mN, about 15 km northeast of Eugowra. Magnetic data suggest the presence of shallow-buried basalt in Mandagery Creek, and drilling about 2 km northeast of Eugowra intersected basalt at about 60 m (Williamson, 1986).

*Description*

The unnamed Tertiary basalt in the Forbes 1:250 000 map sheet area is part of the extensive Orange Province basalts of the adjacent Bathurst 1:250 000 map sheet area. Watkins & Warren (in Pogson & Watkins, 1998) describe the olivine basalt of the Orange Province as "... blue-grey, fine grained ... with aphyric texture containing plagioclase, olivine and augite. The augite subophitically encloses plagioclase laths. Olivine occurs as subrounded microphenocrysts. Interstitial glass constitutes 20% of the rock and magnetite and ilmenite needles are abundant" (p. 273).

*Environment of deposition*

The distribution of basalts of the Orange Province shows that the lavas flowed down valleys of the Tertiary creek and river systems. Any lavas that spilled overbank from those systems have apparently been eroded away.

*Boundary relationships and age*

The exposed basalt, which overlies rocks of the Late Devonian Mount Cole Formation of the Hervey Group. Owen (1975) obtained ages of 12.5 Ma and 11.5 Ma for distal rocks of the Orange Province.

## Red sand and clay (Czd)

*Distribution*

The red sands and clays of Czd occur between Lake Cowal and Jemalong Ridge.

*Description*

This unit appears dull red on gamma ray spectrometric (RGB) images and its distribution has largely been mapped from gamma ray data. Field investigation showed that the radiometric source is highly leached sand deposits, which are the cores and planed remnants of clay-bearing sand dunes. Their origin is uncertain, but they may have been source-bordering dunes around an extensive palaeo-Lake Cowal.

*Boundary relationships and age*

Czd is surrounded by inactive Cainozoic alluvium (Cza) and is adjacent to Quaternary alluvium (Qa) and swamps (Qaw). Because Qa and Qaw are presently active, this may suggest that Czd occurs on top of the inactive Cainozoic alluvium, which must have been dry land at the time of a larger Lake Cowal-Nerang Cowal lake.

## *In situ* highly weathered granitoid (Czg)

*Distribution*

Immediately south of West Wyalong, and in an area about 15 km north of West Wyalong, *in situ* saprolite derived from granitoid forms mappable units within Cza.

*Description*

The highly weathered granitoid forms erosional plains and low-angle rises, with a veneer of residual to colluvial (sheetwash) deposits. Alluvium is locally present along watercourses. The parent rock is generally weathered to around 50 m depth, and many exposures are mottled. A lag of rounded, magnetic, ferruginous fragments is locally present, and was most probably derived from exhumation of fragments of iron-enriched saprolite — in turn, from hardened mottles, in which the goethite originally present transformed to maghemite through heat (bushfires) or biological activity. Excavations, such as at Cunningtons Lane (GR 516460 mE 6265010 mN), show yellow-brown goethite nodules that have apparently developed in the saprolite. The formation of Czg may be due to primary factors in the bedrock, such as composition, increased fracturing, etc.; or it may be developed over zones of hydrothermal alteration or greisen in the granite. On gamma ray spectrometric (RGB) images the Czg shows as being Th-rich, which is probably due to leaching of K and U.

*Boundary relationships and age*

The granitic saprolite is developed directly over the medium-grained biotite granite and granodiorite of the Silurian Ungarie Granite. It has been given a general Cainozoic age, although weathering may have been taking place since the Carboniferous (Pillans *et al.*, 1998).

## Shallow slope colluvial plains (Czr)

*Distribution*

The shallow slope colluvial plains (Czr) are widespread throughout the Forbes 1:250 000 map sheet area. They are

adjacent to and, in places, surround the colluvial sheetwash and scree (Qr) that mantle bedrock.

*Description*

The colluvial plains (Czr) occur in areas of low sculptured relief that contain defined watercourses. They form thin mantles over saprolite, commonly less than 10 m, and their composition varies according to their source bedrock. Czr is not necessarily derived from the same rocks as the underlying saprolite. Because Czr is not an in-fill deposit, weathered bedrock lies close to the surface where Czr occurs.

*Boundary relationships and age*

For mapping purposes, Czr is separated from Qr and Cza by a change in slope: the change in slope away from the pediments of Qr, and the change to horizontal toward Cza. The actual boundary relationships are onlap over Qr and generally interfingering with Cza. In a landscape that has been actively weathering and eroding, Czr has probably been forming since the Carboniferous (Pillans *et al.*, 1998), However, as the colluvium of Czr is being transported to the inactive alluvial plains (Cza), it must be younger than the onset of the process that began its formation as a mappable unit.

### Inactive alluvial plains (Cza)

The inactive alluvial plains are the most widespread of the Cainozoic units in the Forbes 1:250 000 map sheet area. They incorporate both the slightly incised stagnant depositional surface of the Lachlan River alluvial plain, and areas of low-angle undulating plains and rises underlain by saprolite. The former areas are dominated by alluvium, but the latter have a veneer of a mixture of sheetwash colluvial, residual, and alluvial deposits with variable soils. Subdivisions of the regolith-landform equivalent of this unit are shown on Gibson & Chan (1999b).

## Quaternary units

### Sand ridges (Qd)

*Distribution*

Small aeolian sand dunes (Qd) are present on the Lachlan River floodplain between Jemalong Gap and Condobolin, and about 30 km downstream from Gooloogong.

*Description, boundary relationships and age*

The sand dunes, usually no more than a few metres high, are generally not elongate, and have no preferred orientation. It is probable that they originated from locally derived sand originally deposited in levees associated with the Lachlan River. On gamma ray spectrometric RGB images they show relatively elevated K contents, due to the presence of clays mixed with the sand. They have been deposited on Quaternary flood plain sediments. The dunes are presently active, depending on the amount of stabilisation by vegetation.

### Colluvial sheetwash and scree deposits (Qr)

*Distribution*

The unit Qr mostly incorporates colluvium (sheetwash deposits) and alluvium on pediment slopes around most areas of bedrock outcrop, and around some *in situ* weathered bedrock.

*Description*

The parent material of the colluvium and scree is weathered and transported bedrock and varies according to the lithology of the bedrock source. The western slopes of some steep ridges (e.g., Jemalong Ridge, and the ridge east of Bogandillon Swamp) include aeolian sand trapped against the windward side.

*Boundary relationships and age*

The colluvium and scree overlie basement and interfinger with alluvium along creeks. As weathered and transported bedrock, the maximum age is unknown, and probably varies from place to place.

### Swamps and sump basins (Qaw)

*Distribution*

Swamps and sump basins (Qaw) occur at Bogandillon Swamp and Banar Lake, south of Condobolin and south of the Lachlan River; about 5 km northwest of Burcher; adjacent to the southeast shore of Lake Cowal; and south of the Lachlan River floodplain near Jemalong Gap.

*Description*

The dominant component of Qaw is by fine-grained sediment and grey clay soil. Large amounts of decayed organic matter are generally present. Water table levels in Qaw are frequently close to the surface, and the ground surface is, at least, seasonally wet.

*Boundary relationships and age*

The sediments of the swamps and sump basins have been deposited on Cainozoic and Quaternary alluvium and, in the case of Bogandillon Swamp and Banar Lake, Quaternary lacustrine deposits. Maximum ages for these deposits are not known.

### Lake sediments and shoreline deposits (Qal)

*Distribution*

The lake sediments and shoreline deposits (Qal) are confined to the semi-permanent lakes, Lake Cowal and Nerang Cowal

*Description*

The deposits of Lake Cowal and Nerang Cowal are dominated by fine-grained sediments with heavy clay soils. The Lake Cowal sediments vary in thickness from about

2 m to more than 100 m. The thin cover is confined to the western side of the lake, as the eastern side is a filled palaeovalley of the Bland Creek.

*Boundary relationships and age*

The lake sediments and shore line deposits are unconformable on the Ordovician Lake Cowal Volcanic Complex. Lake Cowal and Nerang Cowal are part of the Bland Creek system and, although there are no palynological age data for this system, it is probably coeval with the Lachlan River, with a maximum age for the oldest sediments of Early to Late Miocene, albeit that the older sediments are fluviatile. It is not known when the transition from fluvial to lacustrine began.

## Alluvium in active depositional plains and terraces (Qa, Qat)

*Distribution*

The alluvial units, Qa and Qat, define areas of floodplains and channels associated with modern drainage. Qa is mainly distributed along the course of the Lachlan River, extending from the northwestern corner of the Forbes 1:250 000 map sheet area to about the centre of its eastern boundary, near Gooloogong. The Bland Creek system drains north to north-northwest from about GR 550000 mE 6236800 mN, at the southern margin of the Forbes 1:250 000 map sheet area, through Lake Cowal and Nerang Cowal to the Lachlan River.

Unit Qat has been differentiated on the basis of low Th count rates, and approximates the more frequently flooded low-lying areas of the Lachlan floodplain.

*Description*

The active river deposits, Qa, are sand, gravel, and clay in varying proportions, according to the spatial and secular variations of their transporting rivers and creeks. The low-Th Qat is dominated by clayey sediments at the surface, although sands may be locally dominant.

*Boundary relationship, thickness and age*

Deposits from active watercourses may overlie units of any age. The thickness of Qa varies from less than 10 m to over 140 m (where the Lachlan River cuts the Hervey Group rocks at Jemalong Gap; GR 573000 mE 6304500 mN). Palynological dating of borehole cuttings shows that the oldest sediments of the main Lachlan palaeovalley are Early to Late Miocene (Martin, 1991), although most of the deeper palaeovalley fill is Late Miocene to Pleistocene. There are no palynological age data for the Bland Creek system, but it is probably coeval with the Lachlan River system.

## Gilgai

*Distribution*

Gilgai in the Forbes 1:250 000 map sheet area occurs mainly in flat, low-lying areas south of the Lachlan River and west of Henry Lawson Way. A small patch, less than 5 $km^2$, occurs north of the Lachlan River, about 20 km west of Bogan Gate.

*Description and relationships*

This unit represents areas with poorly drained clayey soils, where seasonal shrink-swell is the dominant soil process. They are characterised by undulating microrelief, with small depressions, holes, shelves, and mounds. Drainage is typically disintegrated. Gilgai types include crabhole, normal, linear, lattice, melonhole, and contour. King (1998) gave details of gilgai soils and their associated landscapes. Although most gilgai areas occur on stagnant alluvial plains, they also occur on some low angle slope deposits.

# 14. STRUCTURAL GEOLOGY

## Introduction

Although some 80% of the Forbes 1:250 000 map sheet area is covered by regolith, aeromagnetic data show the location and geometry, at least in plan, of the major structures and magnetically discernible units. Also, construction of a reliable solid geology interpretation for the map sheet area has allowed the ages of many of the major structures to be derived. Detailed groundwork, and U–Pb SHRIMP data have allowed refinements of the understanding of the structural development of the region, and its context within the Lachlan Fold Belt to be made. Figure 14.1 shows the principal structures superimposed on an outline of the simplified basement geology.

## Major faulting and shearing

The Forbes map sheet area is dominated by fault and shear complexes that have major north–south components to their trends. From west to east they are the:

Gilmore Fault Zone;

Marsden Thrust;

Parkes Fault Zone; and

Coolac–Narromine Fault Zone.

*Gilmore Fault Zone*

The Gilmore Fault Zone is in the west of the Forbes 1:250 000 map sheet area, which it crosses from the northwest corner to the southern boundary, near West Wyalong. The Fault Zone dips predominantly to the west, although recent unpublished seismic reflection data (R. Korsch, pers. comm., 2000) show a number of east-dipping back thrusts. These are not shown on the map cross-section as the data became available after the maps were finalised. The Fault Zone is a geometrically complicated structure showing, in plan, connecting, diverging, and rejoining splays. Although the average trend is north-northwest, individual faults may trend north–south, and connecting splays may trend northeast and northwest. The principal diverging splays cut the Fairholme Anticline. The only well-exposed part of the Gilmore Fault Zone in the map sheet area is the Booberoi Shear Zone, which is developed in some outcrops of the Siluro-Devonian Manna Conglomerate.

On a fold belt scale it extends some 600 km from the Long Plain-Indi Fault system, in southern New South Wales and Victoria, to an area east of Cobar, probably linking with the Rookery Fault. Its significance and history is not well understood. Some authors (e.g., Scheibner, 1985) describe it as a terrane boundary; others (e.g., Stuart-Smith, 1991) disagree and maintain that, although it is a regionally important structure, it is not a terrane boundary. This work concurs that it is not a terrane boundary, as turbidites of the same age and metamorphic grade occur either side of the Gilmore Fault Zone. Regardless, it is one of the structures defined as the boundary between the central subprovince and the eastern subprovince of the Lachlan Fold Belt

In the Forbes 1:250 000 map sheet area, the Gilmore Fault Zone has disrupted units ranging in age from Middle to Late Ordovician to Siluro-Devonian. The earliest movement on the Gilmore Fault Zone is inferred to have been at the end of the Ordovician or Early Silurian, during the Benambran Orogeny, when the Wagga Marginal Basin closed. Foster *et al.* (1999) obtained an Ar–Ar age from the Booberoi Shear Zone of 411 ± 2 Ma (late Early Devonian). However, they also obtained an Ar–Ar age of 405 ± 2 Ma for movement on the Indi Fault, indicating that the fault system was active for some five or six million years at this time. Given the proximity of the Gilmore Fault Zone to the Carboniferous Marsden Thrust (which could be a leading splay of the Gilmore Fault Zone) it is most likely to have had some Carboniferous reactivation. Scott (1999) has suggested that the Fault Zone provided a conduit for the Tertiary Weebar Hill Leucitite.

A movement history spanning 100 Ma, or more, implies complex overprinting of kinematic indicators. In the Forbes 1:250 000 map sheet area, kinematic indicators in the Booberoi Shear Zone show that the Early Devonian movement was transpressional with west side up and sinistral movement vectors. The respective size of the vectors is unknown. The kinematic indicators do not overprint each other, and were probably formed during the same activation. The nature of earlier movements is not known, although a closing longitudinal basin, and the submeridional folding of its sedimentary rocks, would suggest that the first movement of the Gilmore Fault Zone was, essentially, an east-directed thrusting. The part of the fault zone crossing the Silurian Burcher Greywacke does not appear to have resulted in discernible movement, at the map scale. However, this splay is recognisable in magnetic data and is associated with silicification and increased quartz veining.

The Gilmore Fault Zone has provided an important control on the location of gold mineralisation in the map sheet area, including the deposits at West Wyalong, Lake Cowal, Fairholme, and Condobolin. The fault zone probably acted as a major fluid conduit throughout its long-lived movement history.

*Marsden Thrust*

Located east of the Gilmore Fault Zone, the Marsden Thrust trends north-northeast, its trace cutting the trace of the axial plane of the Tullamore Syncline at a low angle. As a blind thrust, concealed by regolith, it has been identified only in regional magnetic data and diamond drillcore. The Marsden Thrust dips shallowly to the west. As the youngest rocks displaced by the thrust are of the Late Devonian Hervey Group, activation is most likely to have occurred in the Carboniferous Kanimblan Orogeny.

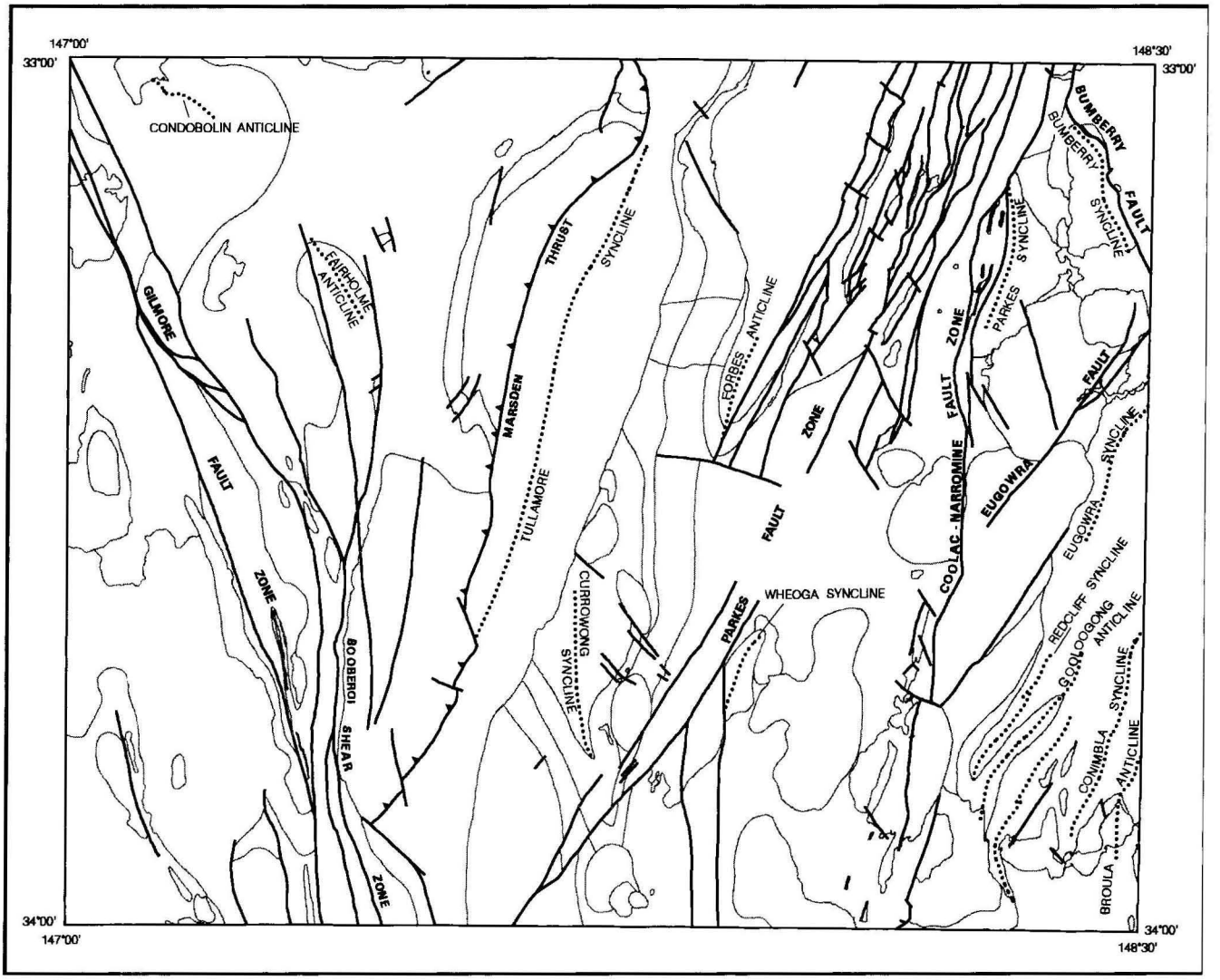



*Figure 14.1. Major structures superimposed on simplified basement geology elements in the Forbes 1:250 000 map sheet area.*

In images of magnetic data, the most obvious part of the Marsden Thrust is at the surface trace of the contact between the magnetic hanging wall rocks of the Ordovician Lake Cowal Volcanic Complex and the non-magnetic footwall rocks of the Late Devonian Hervey Group, in the southwest of the map sheet area. The general trend of the thrust is disrupted by minor northwest to north-northwest trending structures interpreted as sinistral tear faults.

*Parkes Fault Zone*

The northeast-trending Parkes Fault Zone is about 15 km wide and crosses the Forbes 1:250 000 map sheet area from the middle of the southern boundary to within 15 km of the northeastern corner. Generally steeply west-dipping, it has disrupted units ranging in age from Middle Ordovician to Late Devonian. Although the Parkes Fault Zone is apparent in magnetic data, and from mappable offsets and deformation of the units it disrupted, it has no expression in outcrop except as zones of intense strain in the Ordovician Kirribilli Formation. It acted as a controlling structure for many of the gold deposits in the Parkes–Forbes corridor, so much so that it is virtually outlined by the distribution of deposits. The Parkes Fault appears to be a major linking structure between the Gilmore Fault Zone and the Coolac–Narromine Fault Zone. As the horizontal offset of units is relatively small, at map scale, movement on the Parkes Fault Zone is interpreted to have been mainly reverse.

The age of first movement is not known, but given its proximity and connection to the Gilmore Fault Zone and the Coolac–Narromine Fault Zone, it is probable that movement initiated during the Benambran Orogeny in the Late Ordovician to Early Silurian. As the Parkes Fault Zone crosses the aeromagnetic bedding trends in the Currowong Syncline, an age for (re)activation of no more than about 400 Ma is established (these Notes). Although this age is younger than the Early Devonian movements recorded for the Gilmore–Indi system, comparison of Ar–Ar data with U–Pb data require that the errors be substantially widened. Comparison of Ar–Ar data with U–Pb data require that the external errors be added in quadrature, giving a $2\sigma$ error about $\pm 8$ Ma. Therefore, movement ages on the Gilmore Fault Zone, the Indi Fault, and the Parkes Fault Zone, quoted above, may be considered contemporaneous (see Foster *et al.* (1999) and Renne *et al.* (1998) for data).

In the northeast of the map sheet area, where the Parkes Fault Zone is linked with the Coolac–Narromine Fault Zone, reverse movement has considerably steepened the west limb of the Parkes Syncline, which is developed in rocks of the Late Devonian Hervey Group. This shows that the Parkes Fault Zone was probably reactivated in the Carboniferous Kanimblan Orogeny.

*Coolac–Narromine Fault Zone*

The Coolac–Narromine Fault Zone traverses the eastern part of Forbes 1:250 000 map sheet area and trends due north. It is part of a major structure in the Lachlan Fold Belt that extends 600 km from the Long Plain Fault, near Khancoban to the Great Artesian Basin, north of the Barwon River. At a maximum width of 5 km, it is the narrowest of the fault zones in the sheet area. Like the Parkes Fault Zone, its fault surfaces are not exposed in the sheet area and it has been mapped from magnetic data and by inference where units have been disrupted.

In the map sheet area, it is difficult to determine a movement history separate from the Parkes Fault Zone. Stuart-Smith (1989) studied the movement history of the Mooney Mooney Fault Zone, a southern continuation of the Coolac–Narromine Fault Zone. He suggested that the earliest movements occurred during the Early Silurian as either dextral or sinistral strike slip. South of the sheet area, the steeply east-dipping Jugiong Fault Zone, which links to the Mooney Mooney Fault Zone, has preserved structures showing reverse movement during the Late Silurian, and during the Middle Devonian, though the age is poorly constrained. A sinistral strike-slip of about 28 km, followed by a dextral strike slip, is inferred. Steepening of the west limb of the Parkes Syncline shows that the Coolac–Narromine Fault Zone underwent a reverse movement some time after the Late Devonian, probably during the Kanimblan Orogeny in the Carboniferous Period.

Near Grenfell, in the southeast of the sheet area, the Coolac–Narromine Fault Zone has been a control on the locus of gold mineralisation.

*Minor faults*

A number of smaller faults occur throughout the Forbes 1:250 000 map sheet area. The most important are in the east of the sheet area and form a possible northwest–northeast conjugate set. Two are named: the Bumberry Fault, trending northwest, and the Eugowra Fault, trending northeast. The Bumberry Fault dips steeply to the northeast and placed rocks of the Middle Devonian Rocky Ponds Group, in the hanging wall, over rocks of the late Devonian Hervey Group. The eastern limb of the Bumberry Syncline is considerably tightened and locally overturned against the Bumberry Fault. The Eugowra Fault largely occurs in granites of the Early Devonian Eugowra Suite, but may cut unexposed Tertiary basalts buried by alluvium of Mandagery Creek. Analyses of earthquake data show that this fault is currently active (Gibson *et al.*, 1994). A parallel fault to the Eugowra Fault occurs along the south-eastern margin of the Eugowra Batholith.

## Folding

The fold history of the map sheet area is inseparable from the history of faulting and shearing caused by compressional tectonism. The tight to isoclinal folds, formed during the Benambran Orogeny in the Late Ordovician to Early Silurian, are the principal manifestations of strain being accommodated by folding. Following this, the fold styles are generally open as most of the strain was partitioned into the faults and shear zones.

West of the Gilmore Fault Zone there are no identifiable regional folds. This may reflect the paucity of outcrop, or the lack of marker beds, in the multiply-deformed, tight to isoclinally folded beds of the Ordovician Wagga and Girilambone Groups. This folding was a response to the Benambran Orogeny that closed the marginal basins and initiated the Gilmore Fault Zone; although, some kinking and box folds in the Girilambone Group are confined to parts within the Gilmore Fault Zone and are probably a response to later fault movement. There are no identified folding effects of the Carboniferous Kanimblan Orogeny in this part of the map sheet area. The Wagga Group contains at least two generations of penetrative folds, and the Girilambone Group shows up to three generations of penetrative folds; at the map sheet scale. The Kirribilli Formation, which comprises Ordovician turbidites, mostly underwent intense shear strain, but a small area of preserved folding occurs about 25 km northeast of Forbes. The folding here occupies the core of a broad syncline. There are no age constraints on this folding, but its open style suggests they were not formed during the Benambran Orogeny.

Folding of the Siluro-Devonian and Early Devonian units is related to the Early Devonian (Emsian) deformation recorded in the Gilmore and Parkes Fault Zones. The major folds formed during this event are the Currowong Syncline and the Forbes Anticline, and the Fairholme Anticline.

The open folding affecting Late Devonian Hervey Group rocks was probably accompanied by, or slightly preceded, a reactivation of the major faults during the Carboniferous Kanimblan Orogeny. Its effect on earlier folds is not understood as there are no recognisable associated overprinting structures either in the tightly folded Ordovician turbidites or the Siluro-Devonian units. The major folds in the Late Devonian Hervey Group are the Tullamore Syncline, and smaller folds, such as the Wheoga and Sugarloaf Synclines and the Gooloogong Anticline. The Tullamore Syncline is superimposed on the Currowong Syncline.

# 15. METAMORPHISM


## Summary

A metamorphic map of the Forbes 1:250 000 map sheet area has been prepared by assessment of metamorphic mineral assemblages for 1900 samples from the map sheet area. The samples and thin sections are held in the Petrology Collection (of the Geological Survey of New South Wales) and are supported by the ROCKS database. About 50% of the map area is deficient in sample points, particularly the floodplain of the Lachlan River from Forbes westward, and a north-trending belt through Marsden.

The metamorphic map establishes broad patterns for regional metamorphic zones, with about 85% of the *resolved* area dominated by low-grade greenschist facies (zone M1: epidote/carbonate/albite). A further 10% is classified as M2 zone (prehnite/pumpellyite), restricted to the Gunningbland–Myall–Parkes and Yarrabandai districts; 5% is represented by small scattered domains with middle greenschist facies (zone M3: biotite/actinolite–tremolite); while near the middle of the western margin of the Forbes 1:250 000 map sheet area, there is an elongate domain (2% area) with retrogressed porphyroblastic ?andalusite (M4). Overlap of the metamorphic zones is involved in about 20% of the resolved area, similar to metamorphic maps over adjacent sheet areas. There are only 90 samples with two or more cleavages, but they are scattered across all metamorphic domains, and are not confined to the higher grade domains. Overall, the Forbes 1:250 000 map sheet area is generally at a lower regional metamorphic grade than the adjacent Bathurst and Dubbo 1:250 000 sheet areas.


## Introduction

This study of metamorphic grades is ongoing, with the process evolving through the production of metamorphic maps for the Bathurst (Barron, *in* Pogson & Watkins, 1998) and Dubbo (Barron, 1999) 1:250 000 sheet areas. However, because the process uses a simple spreadsheet rather than GIS, it is not yet possible to discriminate prograde from retrograde metamorphic domains, so this work must be regarded as a preliminary effort in the broader aim to prepare a metamorphic map layer for the Lachlan Fold Belt, and there will be a need to adjust domain boundaries as the work proceeds.

The original concept started with a metamorphic grade map of the Bathurst and Dubbo area (Smith, 1969). This work showed the distribution of six metamorphic grades, based on the presence or absence of key metamorphic minerals such as carbonate, albite, chlorite, prehnite, pumpellyite, actinolite–tremolite, and biotite. There was no overlap between grades shown on Smith's (1969) map, but when 2000 rocks from the Bathurst 1:250 000 sheet area were assessed in 1997 for these metamorphic grades, there was found to be such a high degree of overlap that key minerals could be grouped in pairs — such as 'biotite or actinolite'. Even with this simplifying assumption (dropping from six grades to three zones), the new metamorphic maps of the Bathurst and Dubbo 1:250 000 sheet areas still had overlap on up to 20% of the resolved map face. In some cases the overlap represented metamorphic overprinting in a sample, but in other cases probably represented finely interleaved thrust packages from different metamorphic zones. The metamorphic map for the Forbes 1:250 000 map sheet area establishes broad patterns for the regional metamorphic zones and for anomalous zones, with about 20% of the resolved area being involved in overlap.

## Treatment of data

All of the available thin sections for the Forbes 1:250 000 map sheet area were examined specifically to assess their metamorphic history based on the sequence of metamorphic assemblages (retrogression; latest prograde; relict; pseudomorphed). The identifiable metamorphic history of each rock has been coded into a character string that records the sequence of metamorphic events, and the nature of the associated stress fields (neutral, compressive or extensional). Most of the Forbes samples are from the older part of the Petrology Collection so their location details are not very precise relative to the host stratigraphic unit — it is not yet feasible to distinguish a metamorphic epoch.

- The Forbes metamorphic map is prepared from the entire metamorphic history string, not just the peak metamorphism, and five metamorphic zones are used.
- M1: clay/carbonate epidote sericite albite, both with and without foliation (the Z1 of Smith, 1969). This grade includes retrogression to chlorite or sericite.
- M2: prehnite–pumpellyite, normally without foliation (Z2 and Z3 of Smith, 1969).
- M3: actinolite–biotite, both with and without foliation (Z4 and Z5 of Smith, 1969).
- M4: porphyroblastic pale hornblende or restricted andalusite (confined to the most aluminous pelitic rock types), with foliation.
- MH: akin to the *hornfels* envelope on an intrusion, represented by the presence of metamorphic diopside or garnet, or other phases such as cordierite, andalusite, or even other higher grade hornfels assemblages (olivine, cummingtonite, etc.). These are not shown on the map.

Point maps for each metamorphic zone were produced using QuattroPro$^{R}$, particularly because of the need to use the enhanced data-label functionality available in this spreadsheet. As an aid to interpretation, each datum point was buffered by placing a circle of influence around it. This marked out domains of group influence where many points

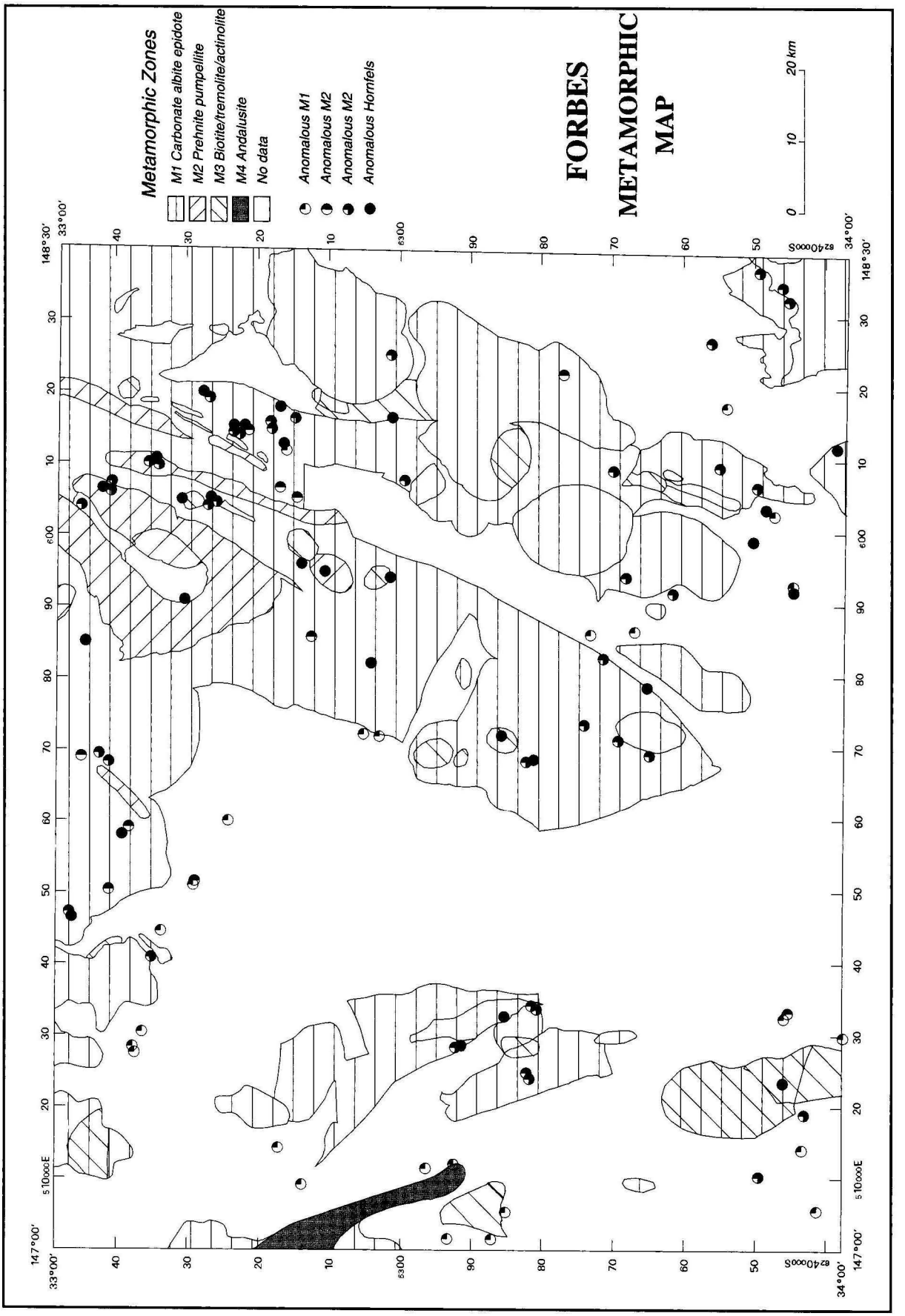



*Figure 15.1. Metamorphic map for the Forbes 1:250 000 map sheet area.*

at the same metamorphic grade overlapped due to their circles of influence. Mineral assemblages interpreted to be due to regional metamorphism were given a large influence radius of 5 km, while other assemblages that may arise out of a more local effect (hornfelsing, fault-associated alteration, etc.) were given a smaller influence radius of 1 km. Metamorphic domains (Figure 15.1) were then delineated using these buffered images overlain on the bedrock interpretive geology map. Where possible, the edges of metamorphic zones were taken to coincide with geological boundaries. Some small areas were outlined as having anomalous metamorphic assemblages, where the assemblage is higher or lower than expected, the difference not being explicable with regard to the local geology — for example, a hornfels with no known associated intrusion.

## Results and discussion

About 85% of the resolved area on the Forbes metamorphic map is dominated by low-grade greenschist facies zone M1 (carbonate–epidote–albite, etc.) assemblages. M1 is so characteristic of the Forbes sheet area that this metamorphic zone is fully mapped herein. This represents a significant change from the process used to construct the new Bathurst and Dubbo metamorphic maps (Barron, *in* Pogson & Watkins, 1998; 1999), which were generated predominantly as M2+M3 terranes, and M1 areas were not shown if the associated point pattern was not sufficiently complete to be coherent. The only M1 domains shown on the Bathurst and Dubbo metamorphic maps are within plutons or are identified as isolated anomalous regions, totalling about 10% of the map area. The Forbes metamorphic map is not like this — it shows large areas that are within the M1 metamorphic zone.

The most significant domains of the M2 zone (prehnite–pumpellyite) occur in the Gunningbland–Myall–Parkes and Yarrabandai regions, occupying about 10% of the resolved areas. In most cases these M2 areas overlap with M1, but there are three small areas in the first region where the rocks appear to be M2 zone only.

The metamorphic zones across the boundary between the Forbes metamorphic map (M1 grade on the eastern edge) and the Bathurst metamorphic map (M2 grade on western edge) do not have a satisfactory match, with most of the problem being on the Bathurst metamorphic map.

Domains in the biotite–actinolite M3 zone (Forbes metamorphic map) occur as small scattered 10 km regions occupying about 5% of the resolved area. These mostly overlap with M1 zones, but there are four small areas of no overlap, three of these in the western quarter of the map area.

Near the central portion of the western margin of the map, within the Wagga Group, there are ten samples that show retrogressed aluminous porphyroblasts. In all but one sample, these porphyroblasts lack rotation structures and were originally identified as ex-cordierite caused by unexplained heating — i.e. hornfelsing. However, field mapping showed that the samples are more than 4 km from the nearest known granitoid. Also, M. Scott (pers. comm., 1999) has indicated that the field distribution of the porphyroblastic texture is much more continuous than the few samples indicated, and that most likely the porphyroblasts represent a regional grade metamorphic zone. This is supported by D. Pogson (pers. comm., 1999) who advised that the Wagga Group to the west and north, on the Cargelligo and Nymagee 1:250 000 sheet areas, carry porphyroblasts, reaching the M4 regional grade (pale hornblende or restricted andalusite). The M4 grade Forbes samples are mainly located within an M3 zone (based on about 20 samples), supporting the transition from M3 to M4 prograde regional metamorphism within the Forbes 1:250 000 map sheet area — but M4 has subsequently retrogressed to M1.

A survey of rock samples with multiple cleavages (about 90 samples) shows that less than a third occur within M3 or M4 domains. The remainder appear in M1 or M2 domains, so metamorphic grade is not particularly related to tectonic complexity.

Many of the larger intrusions (> 1 km across) show sparse and scattered point evidence of being enveloped by a thermal aureole of 100 m (up to 500 m depending on the size and composition of the intrusion). For the sake of clarity, these MH point data are not shown on the summary map.

Many intrusions are included in the samples examined, and a metamorphic grade for the larger intrusive bodies has been assigned. In the main, this is an M1 zone, but an M3 zone is recorded over the Ungarie Granite and the southern portion of the Eugowra Granite. Both of these M3 domains are free standing, and represent strong recrystallisation of biotite or tremolite–actinolite, most likely due to a syntectonic character of these intrusions.

There are about 100 separated points shown as having anomalous characteristics on the Forbes metamorphic map. These points are too isolated to merge with the mapped metamorphic domains. In most cases the grade is higher than that expected from the surrounding area. A third of these anomalous points occur in large areas of no significant outcrop, and presumably these represent small isolated outcrops.

# 16. IGNEOUS EVOLUTION

## Forbes geochemistry database

A database of more than 360 whole rock chemical analyses was used to evaluate the igneous evolution of the Forbes 1:250 000 map sheet area and surrounding region. Most of the analyses reside in the geochemical databases of AGSO (OZCHEM) and the Geological Survey of New South Wales. A small number of analyses were also gathered from unpublished university theses. Major and trace elements was determined by a combination of XRF and ICPMS, titrimetry (FeO), and gravimetric techniques ($H_2O$, LOI).

Analyses of altered rocks, even if in the database, were not considered in this study. The altered rocks included samples with more than 5 wt% loss on ignition ($H_2O$, $CO_2$, and $SO_2$); felsic rocks with more than 79 wt% $SiO_2$ (i.e., silicified samples); and samples with alkalis (generally $Na_2O$, but also $K_2O$) obviously depleted by alteration. All analyses were recalculated to 100 wt% on a volatile-free basis.

## Interpretation of the Forbes geochemical data

Several different chemical variation and discrimination diagrams have been used to classify the igneous rocks of the Forbes 1:250 000 map sheet area. To distinguish alkaline from subalkaline igneous rocks, use can be made of the total alkalis ($Na_2O + K_2O$) *versus* $SiO_2$ plots of Irvine & Baragar (1971) and Le Maitre (1989). However, the alkali elements are commonly mobile in fold belt settings and sample positions on these plots may be affected by metamorphism and alteration. The $Zr/TiO_2$ *versus* Nb/Y plot (Winchester & Floyd, 1977) is less susceptible to alteration processes, with subalkaline rocks generally having Nb/Y ratios < 0.67. The problem of element mobility also affects the $K_2O$ *versus* $SiO_2$ plot (e.g., Le Maitre, 1989), which can be used to evaluate the tholeiitic, calc-alkaline or shoshonitic character of igneous rocks. Rocks of the Ordovician Northparkes Volcanic Group, in particular, show a broad scatter of data on this type of diagram, suggesting potassium mobility during metamorphism and alteration. Calc-alkaline suites are also discriminated from tholeiitic suites by their uniform decrease in total iron content with increasing fractionation.

MORB- or chondrite-normalised multi-element spidergram plots have also been used to characterise mafic to intermediate alkaline, calc-alkaline, and tholeiitic igneous rocks. Spidergram normalising values for mid-ocean ridge basalt (MORB) have been taken from Sun & McDonough (1989) and chondrite rare earth element (REE) normalising values have been taken from Nakamura (1974). Rocks with similar MgO and/or $SiO_2$ contents are compared to avoid the effects of fractional crystallisation. Calc-alkaline volcanic rocks typically show light rare earth element (LREE) enrichment on chondrite-normalised rare earth element diagrams, in contrast to the flat or LREE-depleted patterns of MORB or tholeiitic volcanic rocks. MORB-normalised multi-element diagrams (e.g. Figures 3.31, 3.32) compare the abundances of the relatively incompatible large ion lithophile elements (LILE; e.g., Rb, Ba, K) with more compatible elements such as the high field strength elements (HFSE; e.g., Ti, Zr, Nb, Y). Calc-alkaline and alkaline rocks typically show LILE-enriched patterns relative to MORB volcanic rocks. Pronounced negative Nb and Ta spidergram anomalies are regarded as characteristic of subduction-related magmas (Pearce, 1983).

The felsic igneous rocks of the Forbes 1:250 000 map sheet area are classified according to the S-type, I-type, and A-type classifications of Chappell & White (1992) and Collins *et al.* (1982). These groups reflect the character of the predominantly sedimentary (S-type), igneous (I-type) and refractory or residual (A-type) source material of the magmas. However, there is still considerable debate as to the origin of A-type magmas. The ASI (Aluminium Saturation Index) *versus* $SiO_2$ diagram (Figure 16.1) is a useful tool for discriminating I-type and S-type magmas. I-type magmas typically have ASI <1.1, with the ASI increasing with increasing $SiO_2$. Conversely, S-type magmas commonly have ASI >1.1, with a decreasing trend with increasing $SiO_2$. However, it is difficult to use this discriminant in highly felsic or fractionated rocks where the two trends converge at ASI ≈ 1.1.

A-type magmas generally have characteristically high $Ga/Al_2O_3$ ratios (Figure 16.2) and high levels of HFSE, REE, and other elements such as fluorine and zinc. Strongly fractionated I-type and S-type granites and peralkaline granites, however, can exhibit some of these characteristics (Figure 16.2). Distinctive mineralogy, such as hornblende and ilmenite (I-type); garnet, cordierite and muscovite (S-type); and allanite, halogen-rich apatite, fluorite, or sodic amphiboles (A-type) can also be useful in determining the affinity of felsic igneous rocks, but are not necessarily diagnostic.

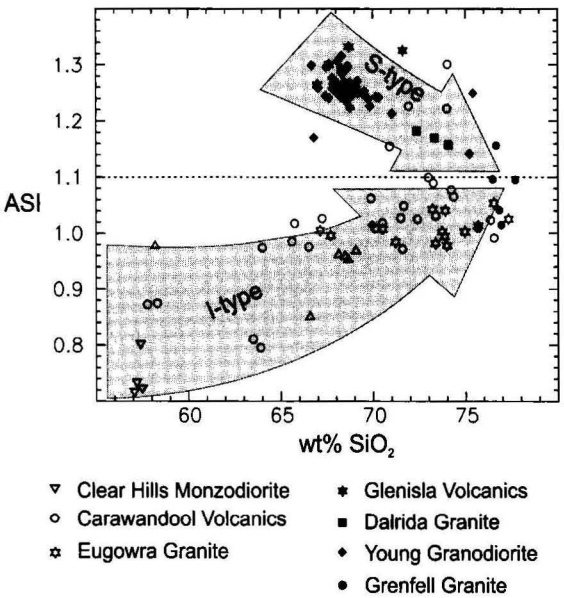



*Figure 16.1. ASI (Aluminium Saturation Index)* versus *$SiO_2$ plot of some I- and S-type igneous rocks.*

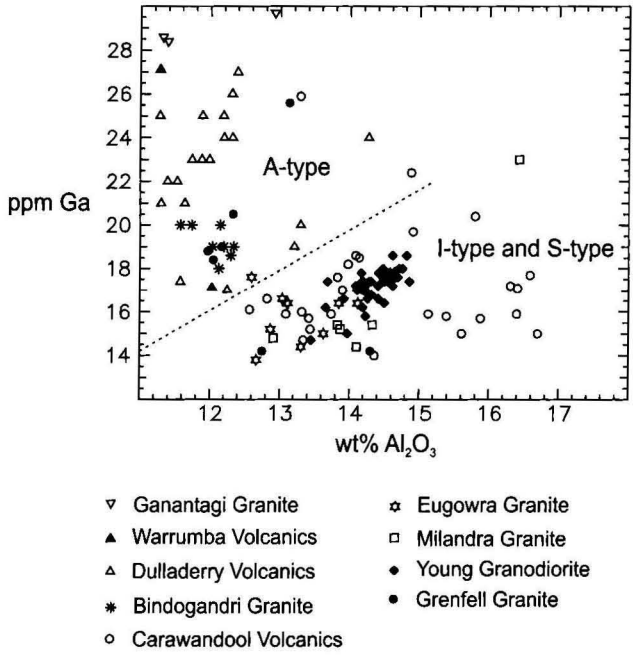



*Figure 16.2. Ga* versus *$Al_2O_3$ plot comparing A-type and I- and S-type igneous rocks. The A-type field may include highly fractionated granites (e.g., Grenfell Granite) and peralkaline granites (e.g., Ganantagi Granite).*

The fractionation and oxidation state of a magma is important for determining the probability of mineralisation associated with granites. The degree of fractionation can be estimated by ratios of elements removed or concentrated by the processes of fractional crystallisation, such as the Rb/Sr ratio (Figure 16.3). Other elements such as Ba, Th and Zr may also exhibit fractionation trends in felsic magmas (Figure 16.3). The oxidation state of a magma is estimated by the ratio of oxidised to reduced iron in the magma (Ishihara *et al.*, 1979; Blevin & Chappell, 1992) (Figure 16.4). Redox conditions of a magma can have a strong bearing on the ore metals concentrated during fractionation (Blevin & Chappell, 1992). For instance, Cu, Mo, and Au are generally associated with more oxidised magmas, with Sn and W associated with more reduced and more fractionated magmas.

## Ordovician magmatism

The Ordovician to earliest Silurian in the eastern Lachlan Fold Belt was a period of generally potassic mafic–intermediate magmatism, in a late-stage oceanic arc subduction setting (Müller *et al.*, 1992; Müller & Groves, 1993). The Early Ordovician Nelungaloo Volcanics, which are exposed in the core of the Forbes Anticline, represent the earliest phase of arc volcanism. The base of these volcanic rocks is not exposed. A hiatus in the mid-Late Ordovician, possibly due to the attempted subduction of a seamount (Glen, 1998), was followed by a major volcanic episode in the Late Ordovician. This episode included the mafic–intermediate lavas, intrusions and volcaniclastic sedimentary rocks of the Northparkes Volcanic Group, which overlie the Nelungaloo Volcanics in the northern part of the Forbes 1:250 000 map sheet area; and the Lake Cowal Volcanic Complex in the west of the Forbes 1:250 000 map sheet area.

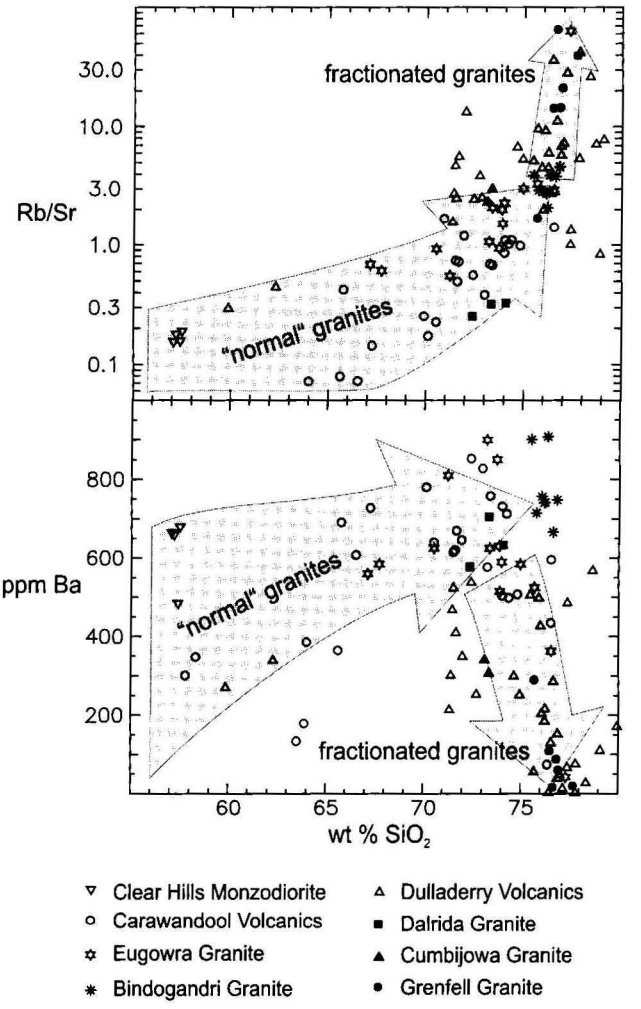



*Figure 16.3. Rb/Sr* versus *$SiO_2$, and Ba* versus *$SiO_2$ plots as measures of fractionation.*

The Northparkes Volcanic Group includes the Parkes Volcanics, Nash Hill Volcanics, Goobang Volcanics, Goonumbla Volcanics, and Wombin Volcanics. The Northparkes Volcanic Group is also intruded by several co-magmatic monzonitic intrusions in the area of the Forbes Anticline. Stratigraphic relations within the Northparkes Volcanic Group are unclear due to lack of outcrop and strong shearing and alteration in the Parkes Fault Zone. However, the Wombin Volcanics appear to be the uppermost, and most fractionated, unit within the group. The Northparkes Volcanic Group rocks typically range from high-K calc-alkaline to shoshonitic basalt and andesite compositions. Even without considering obviously altered samples of the Northparkes Volcanic Group, there is considerable scatter from low to very high $K_2O$ contents, indicating significant mobility of potassium during regional metamorphism and hydrothermal alteration. Analyses of extrusive and intrusive rocks from the Lake Cowal Volcanic Complex around Lake Cowal show less scatter, and are generally less potassic (calc-alkaline to high K calc-alkaline). The Lake Cowal Volcanic Complex also includes more felsic granodioritic rocks, not seen in other

Ordovician calc-alkaline suites of the northern Lachlan Fold Belt.

In general, the Northparkes Volcanic Group and Lake Cowal Volcanic Complex rocks are very similar to the other Ordovician arc volcanic rocks of the Molong High (e.g., the Cabonne and Kenilworth Groups). They are characterised by variably potassic, low-$TiO_2$ and Zr compositions with pronounced negative Nb anomalies on multi-element spidergrams, consistent with mantle-derived, calc-alkaline, subduction-related magmatism.

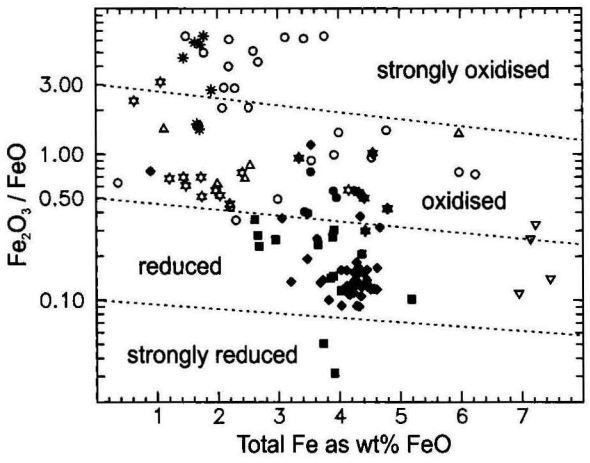



*Figure 16.4. $Fe_2O_3/FeO$ versus total Fe as FeO plot as a measure of oxidation state. The field boundaries are taken from Champion & Heinemann (1994) (after Ishihara* et al., *1979, and Blevin & Chappell, 1992).*

Contemporaneous with the Ordovician arc magmatism were two regions of basaltic magmatism of very different character to the calc-alkaline suites. The Brangan Volcanics in the Grenfell area, and the Narragudgil Volcanics south of Wyalong show tholeiitic, MORB-like affinities. The Narragudgil Volcanics consist of fine- to medium-grained basalts metamorphosed to greenschist or locally to amphibolite grade (Duggan & Lyons, 1999). The basalts have distinctive MORB-type chemical signatures on multi-element spidergrams, including flat REE patterns and relative depletion in LILE (Duggan & Lyons, 1999). The data collected in this study support suggestion by Warren *et al.* (1995) that the Narragudgil Volcanics are similar to mafic rocks of the Jindalee Group, although comparisons are limited by the sparse and incomplete nature of published geochemical data (especially trace element data) for the Jindalee Group.

The Brangan Volcanics are included in the Jindalee Group (these Notes), along with the Wambidgee Serpentinite, in the Forbes 1:250 000 map sheet area southeast of Grenfell. The Brangan Volcanics are relatively primitive (MgO ~7 wt%) olivine tholeiites, with relatively high HFSE ($TiO_2$ ~1.8 wt%) and similar flat REE patterns to the Narragudgil Volcanics. Recent palaeontological identifications from cherts within the Brangan Volcanics (Percival, 1999c) indicate that the Brangan Volcanics are of Middle to Late Ordovician age. The Brangan Volcanics and Jindalee Group probably represent the spreading centre of an inter-arc rift between the Northparkes–Lake Cowal and Molong volcanic arcs. The Kirribilli Formation and Mugincoble Chert represent the contemporaneous deepwater sediments deposited into that inter-arc basin. The Narragudgil Volcanics may represent the spreading ridge of a back-arc basin (Wagga Marginal Basin), into which the sediments of the Wagga and Girilambone Groups were deposited.

Minor probable Late Ordovician ultramafic rocks also occur in the Forbes 1:250 000 map sheet area, but crop out very poorly. The Kars Ultramafic Intrusive Complex occurs at the northern margin of the Forbes 1:250 000 map sheet area, where an incompletely zoned intrusive complex, defined by aeromagnetic data and drilling, extends into the Narromine 1:250 000 map sheet area (Downes & Burton, these Notes). The complex consists of mixed olivine pyroxenite, peridotite, minor dunite and a coarse pegmatite phase, and is related to the Late Ordovician Alaskan-type series of ultramafic complexes such as Fifield in the Narromine map sheet area (Sherwin, 1996). Several other smaller unnamed ultramafic bodies are interpreted to either intrude or be faulted into the Girilambone Group along the Gilmore Fault Zone. The relationship, if any, between the ultramafic rocks and the mafic–intermediate rocks of the Forbes 1:250 000 map sheet area is unclear, but they may represent the primitive mantle magmas, from which the latter were derived.

## Early Silurian magmatism

Recent work suggests that the major (Benambran) deformation in the Late Ordovician to Early Silurian reflected collision of the Late Ordovician volcanic arc with its back-arc basin (Glen, 1998). There followed a marked change in the style and composition of magmatism. Thickening of the crust during deformation resulted in a major crustal heating event. Huge volumes of predominantly felsic magmas were intruded, and extruded, in the Lachlan Fold Belt through the Silurian and Devonian Periods.

Early Silurian magmatism in the west of the Forbes 1:250 000 map sheet area occurred primarily west of the Gilmore Fault Zone, and in the far east of the area, east of the Coolac–Narromine Fault Zone. In the east, the S-type felsic volcanic rocks of the Douro Group were extruded. The small volume of these volcanic rocks in the Forbes 1:250 000 map sheet area represents only the western edge of a large belt of early Silurian S-type ignimbritic volcanic units (i.e., Canowindra, Hawkins, and Laidlaw Volcanics), which extend from near Wellington, in the north, to the Canberra region, in the south. The volcanic rocks were sourced from subvolcanic plutons, such as the Cowra Granodiorite near Cowra. In the Forbes 1:250 000 map sheet area, the Douro Group is represented by the Illunie and Glenisla Volcanics. The Glenisla and Illunie Volcanics

are both primarily rhyodacitic ignimbrites, with abundant coarse-grained phenocrysts of quartz, plagioclase and biotite. Garnet and cordierite also occur, but the cordierite is generally completely altered. The presence of limestone and sedimentary lenses within the Illunie Volcanics indicates they were erupted in a submarine environment. In general, alteration of the Illunie Volcanics limits the value of geochemical interpretation. However, the less-altered Glenisla Volcanics are unfractionated S-types, with high ASI, low Sr — and they are weakly to moderately oxidised (Figure 16.4).

In the region west of the Gilmore Fault Zone, the Ordovician Wagga Group metasediments were intruded by the Ungarie Suite (Chappell *et al.*, 1991) of S-type granitoids and associated volcanic rocks, and the I-type Bland Diorite. SHRIMP U–Pb zircon dating indicates that the majority of this magmatism was tightly constrained to the Llandovery, with minor intrusions as young as Wenlock. The Ungarie Suite includes the Ungarie Granite, Charcoal Tank Granite, Cookaburragong Granodiorite, and the Ugalong Dacite. The S-type granites are typically reduced, unfractionated intrusions that contain muscovite, biotite and cordierite. However, several isolated outcrops are hornblende-bearing and have I-type geochemical characteristics of higher CaO and Th, and lower Rb and Y. It is possible that these outcrops represent a separate intrusive phase, although this is not evident on the basis of either regional magnetic or SHRIMP U–Pb zircon age data. The Charcoal Tank Granite is distinctive in that its margins are gradational with the migmatitic metasediments it intrudes. Its anomalously low CaO, low $Na_2O$, and low Sr geochemistry also suggests that the granite is derived locally from melting of the surrounding sediments and has moved little from its place of original melting.

The Ugalong Dacite, which occurs at the northern margin of the Ungarie Granite, has the same Llandovery age as the adjacent granite. However, the dacite may not be co-magmatic with the granite, having significantly lower MgO, Sr and Cr overall, and higher $Al_2O_3$, CaO and $Na_2O$ in more mafic analyses. The dacite is also a predominantly oxidised magma relative to the more reduced Ungarie Granite (Figure 16.4). The more porphyritic examples of the Ugalong Dacite are similar to the Douro Group volcanic rocks further east, with abundant phenocrysts of plagioclase, resorbed quartz and biotite. The Ina Volcanics, which occur in the Burcher area east of the Gilmore Fault Zone, are younger than the Ugalong Dacite, but have similar mineralogy and S-type geochemistry and may be related to the Billys Lookout Granite.

The I-type Bland Diorite is a poorly-outcropping diorite–tonalite complex immediately north and east of Wyalong. The Bland Diorite intruded the Narragudgil Volcanics and U–Pb SHRIMP geochronology gives an Early Silurian (Llandovery) age for the intrusion. Also intruded into the Narragudgil Volcanics is a suite of andesite and diorite dykes. The dyke rocks show similar geochemical characteristics to the Bland Diorite, including identical trace element enrichment patterns at the same $SiO_2$ content, and are clearly petrogenetically related to it.

The mid-Silurian Young Granodiorite crops out from the south-east corner of the Forbes 1:250 000 map sheet area for over 120 km to the south. It is a very large, mainly unfractionated, reduced S-type granitoid (Figures 16.1, 16.2, 16.4). Numerous analyses of the granodiorite show that it has a remarkably uniform composition for such a large intrusion. In detail, however, rock types range from a predominant biotite granodiorite to aplite, and textures range from porphyritic to equigranular. The granodiorite is similar in many respects to the Ungarie Suite granites in the west of the Forbes 1:250 000 map sheet area.

## Late Silurian to Early Devonian — the Jemalong Trough

In the Late Silurian, a north–south trending rift zone and associated marine incursion, the Jemalong Trough, developed in the Bogan Gate–Wirrinya region. Sedimentary and volcanic units of the Derriwong Group and Ootha Group filled the initial rift, which transected Ordovician Northparkes–Lake Cowal arc rocks. Melting of this mafic igneous basement resulted in extrusion of the predominantly felsic Byong Volcanics of the Derriwong Group near Bogan Gate. The 'Milpose Volcanics', as described by Krynen *et al.* (1990) east of Bogan Gate, are now interpreted to be the eastern extension of the Byong Volcanics. The contemporaneous Yarnel Volcanics of the Ootha Group are probably a distal equivalent of the Byong Volcanics deposited to the west of the initial rift. The volcanic rocks have a generally I-type trend on an ASI *versus* $SiO_2$ plot (Figure 16.1), but there is much scatter in the available major and trace element data, suggesting some element mobility during regional metamorphism. The Byong Volcanics are predominantly unfractionated, strongly oxidised, plagioclase-phyric, high-K rhyolites and dacites with very low levels of LILE (such as Th and Rb). The Yarnel Volcanics are extremely felsic, rhyolitic vitric ash tuffs. Minor basalts in the Byong Volcanics show similar multi-element spidergram patterns to the Ordovician arc volcanic rocks, suggesting derivation from a similar mantle source.

The Kadungle and Carawandool Volcanics of the Trundle Group unconformably overlie the Derriwong and Ootha Groups, but are interpreted to have been deposited in the same Jemalong Trough setting, as the marine environment shallowed or even became subaerial. Some epithermal style alteration occurs within the Carawandool Volcanics. Although outcrops of the Kadungle and Carawandool Volcanics are separated by some 50 km of younger cover rocks, regional aeromagnetic data suggest that the two units may be continuous at depth. They are predominantly rhyolitic to dacitic lavas and volcaniclastic units with minor basalt and andesite, similar to the underlying Byong Volcanics. The felsic rocks of the Carawandool Volcanics are unfractionated, oxidised I-types (Figures 16.1, 16.2, 16.4) with high to very high Zr and $TiO_2$, and very low Th and Rb. These features are also shown by the Bundaburrah

Granodiorite, which intruded and may be petrogenetically related to the Carawandool Volcanics. There are, however, some differences in their compositions. The Kadungle Volcanics have higher $Na_2O$, very low CaO and $K_2O$, and have an unusually low V composition. A single εNd analysis of a basalt from the Carawandool Volcanics returned a strongly positive value of +8.1 (Raymond & Sun, 1998), indicating a primitive mantle source for the basalt.

All analysed volcanic rocks of the Jemalong Trough have characteristic I-type, low LILE, compositions, particularly low in Rb and Th. These similarities suggest derivation from melting of a single source, most probably Ordovician arc volcanic rocks. The minor basalts were derived from tapping of the upper mantle by the rifting. The low Rb and Th characteristics of the rift volcanism are also replicated in post-tectonic Devonian granitoids that intruded after inversion of the rift basin around 400 Ma. These include the Berendebba, Wirrinya, Dalrida, and Ganantagi Granites, which form a north–south corridor of elliptical intrusions, and the dyke-like Porters Mount Quartz Diorite. Their composition suggests continued melting of the Ordovician basement through the Early to Middle Devonian. The low LILE abundances persist even though the intrusions' compositions range from S-type (Dalrida and ?Berendebba Granites), to I-type (Porters Mount Quartz Diorite), and refractory A-type (Wirrinya and Ganantagi Granites) compositions. The εNd composition of an alteration breccia associated with the Porters Mount Quartz Diorite (+6.5; Wyborn & Sun, 1993) was previously thought to indicate an Ordovician age for that intrusion. However, it is now clear that some early Devonian magmas had similar compositions to those produced in the Ordovician (Raymond & Sun, 1998) and may have similar metallogenic potential.

## Other Early Devonian magmatism

The Caragabal Granite, intruded, during the earliest Devonian, into the Kirribilli Formation just east of the Jemalong Trough, is an oxidised I-type granite with high levels of HFSE (such as Ti, Zr, Nb and Y), but without the low Rb and Th levels of Jemalong Trough igneous rocks. Some analyses of this granite suggest a minor degree of fractionation, but in general it is an unfractionated pluton. The granite is associated with some minor gabbroic intrusions at its southern margin, but does not appear to be related to any other felsic intrusions.

The earliest Devonian Bogalong Suite, west of Grenfell, includes the Mortray Hill Granite Complex and Milroy Granite. The Bogalong Suite consists of non-magnetic, reduced, variably fractionated S-type granites. The granites contain significant tin mineralisation with common tourmaline alteration and development of marginal greisens. It is probable that the Bogalong Suite granites are exposed near the top of the intrusions, and that the northern parts of batholith are currently covered by a thin veneer of Kirribilli Formation. Three isolated outcrops of a clinopyroxene-bearing tonalite occur with the Bogalong Suite granites. It is not clear why these small bodies of such distinctly different composition and obviously I-type source rock occur within this fractionated S-type batholith.

The late Early Devonian in the Forbes 1:250 000 map sheet area is represented by a major plutonic event in the east of the sheet area that produced large volumes of I-type, and minor S-type, granitoids. The I-type granitoids mainly occur east of the Coolac–Narromine Fault Zone and comprise the Eugowra Suite, a major component of the high temperature Boggy Plain Supersuite (Wyborn *et al.*, 1987). The Suite contains the Eugowra, Lords, Milandra, and Lock Lomond Granites, and the Clear Hills Monzodiorite. The individual plutons range widely from mafic to very felsic compositions, with only the Lock Lomond Granite and parts of the Eugowra Granite showing signs of fractionation (Figure 16.3). On the whole, the suite is relatively strongly magnetic and of oxidised composition. The notable exception is the Clear Hills Monzodiorite, which is a moderately reduced and relatively weakly magnetic intrusion despite its rather mafic composition (Figure 16.4). The S-type Cumbijowa Granite occurs west of the Coolac–Narromine Fault Zone just to the west of the Eugowra Suite, and is a non-magnetic, reduced, and moderately fractionated pluton. The I-type Coonambro Volcanics occur at the northern margin of the Eugowra Suite. They are unfractionated, hornblende-bearing, I-type andesites to rhyolites, and may represent an extrusive phase of the Eugowra Suite.

The Broula Granite, which occurs on the southeastern boundary of the Forbes 1:250 000 map sheet area, intruded the Young Granodiorite, and could be as young as Middle Devonian. The granite is a magnetic, largely elliptical pluton, with a composition unique to the region. The Broula Granite is extremely high in U, Th, and K and, hence, has a very high gamma ray spectrometric count rates. It also contains very high levels of HFSE, such as Zr and Nb. Despite these extreme chemical characteristics, the granite appears not to be fractionated and suggests an extremely refractory source rock.

The Warrangong Volcanics occur south of the Broula Granite, and are tentatively correlated with the Pragian age Black Range Group, which includes the Mountain Creek Volcanics to the southeast of the Forbes 1:250 000 map sheet area. The Warrangong Volcanics range from rhyolite to dacite and andesite in composition, and include lava flow rocks and ignimbrites. Their hornblende- and clinopyroxene-bearing mineralogy indicates an I-type origin. They are intruded by the Crowther Monzodiorite, which may be comagmatic, but there are no geochemical data from the Warrangong Volcanics to verify this. Many thin, andesitic to dacitic dykes, possibly derived from the Warrangong Volcanics, intruded the adjacent Young Granodiorite. However, a single geochemical analysis of one of these dacitic dykes shows S-type characteristics, which suggests that it may not be related to the I-type Warrangong Volcanics.

## Middle to Late Devonian magmatism

A marked change in igneous activity occurred in the eastern Lachlan Fold Belt in the Middle Devonian when A-type felsic to bimodal volcanism occurred in subaerial continental rift settings at widely spaced locations. The formation of an extensional regime may have resulted from the relaxing of the compressional stresses of late Early Devonian deformation. The Boyd Volcanic Complex on the south coast of New South Wales, and the Dulladerry and Warrumba Volcanics in the central west of New South Wales are examples of this type of volcanism.

Only a small part of the Dulladerry Volcanics occurs in the northeastern corner of the Forbes 1:250 000 map sheet area. They extend north to Tomingly and east towards Manildra. The volcanic units are predominantly rhyolitic ignimbrites and lava flows, and epiclastic sedimentary rocks, with minor intercalated dacite, andesite, and basalt. The Warrumba Volcanics, east of Grenfell, similarly comprise of rhyolitic lava flow rocks and ignimbrite, with a thin basaltic layer at the top of the sequence. The main ignimbrites in each volcanic sequence, the Curumbenya and Coomaloo Ignimbrite Members, are remarkably similar in being strongly welded, having abundant small quartz and K-feldspar phenocrysts, and having only a minor lithic component. The generally fine-grained nature of these ignimbrites suggests a particularly explosive eruptive episode.

Chemically, the volcanic rocks have the characteristically high $Ga/Al_2O_3$ ratios (Figure 16.2) and very high HFSE contents of A-type magmas. The Dulladerry Volcanics also display evidence of fractionation in their variably low Ba content and high Rb/Sr ratio (Figure 16.3). This evidence of fractionation is considered unusual for A-type magmas (Whalen *et al.*, 1987), although it has been invoked in A-type magmas near Temora (Wormald & Price, 1988). The apparent scarcity of fractionation and the low water content of A-type magmas has resulted in them being considered poorly prospective for mineralisation. However, epithermal alteration, sometimes with gold mineralisation, occurs in each of the Dulladerry, Warrumba, and Boyd Volcanics.

The Dulladerry Volcanics are thought to be comagmatic with the Bindogandri Granite. This high silica, granophyric granite is a high-level, subvolcanic pluton with miarolitic cavities. Its $Ga/Al_2O_3$ ratios are high (although not as extreme as the Dulladerry Volcanics; Figure 16.2) and it has high levels of HFSE, Zn, and F. Trace fluorite also occurs in the granite. The Grenfell Granite has been dated as Middle Devonian (L. Black, pers. comm., 1998). It is a non-magnetic, weakly oxidised, and strongly fractionated granite of possible A-type composition. The adjacent Schneiders Granite is an extremely fractionated, aplitic granite and possibly represents a late-stage fractionate derived from crystallisation of the Grenfell Granite. The extent of fractionation of the Grenfell Granite and Schneiders Granite (Figure 16.3) means that geochemical methods of determining their source rock character are inconclusive (Figure 16.1). Although the Grenfell Granite plots in the A-type field on a $Ga/Al_2O_3$ diagram (Figure 16.2), fractionated I- and S-type granites can also plot in that field.

Other granites of A-type and peralkaline compositions include the Wirrinya and Ganantagi Granites (Figure 16.2). Neither of these granites has constraints on their age other than that they intrude Early Devonian rocks. They have been tentatively placed in the Middle Devonian due to the prevalence of A-type and peralkaline magmatism at that time in the eastern Lachlan Fold Belt. The A-type Wirrinya Granite approaches peralkaline compositions (Al/(K+Na) = 0.9) and does not crop out apart from a couple of small apophyses and dykes marginal to the main body — as defined from regional magnetic data. The small peralkaline Ganantagi Granite prominently crops out west of Bogan Gate, but is essentially non-magnetic. Both the Wirrinya and Ganantagi intrusions are high-level, granophyric granites with miarolitic cavities. The Wirrinya Granite contains minor sodic hornblende and minor fluorite filling the cavities. The Ganantagi Granite contains abundant late-crystallising aegirine-augite and arfvedsonite, as well as calcite in cavities.

## Carboniferous to Cainozoic magmatism

Following the Middle Devonian, igneous activity virtually ceased in the area of the Forbes 1:250 000 map sheet. The extensive Carboniferous felsic plutonism in the area of the Bathurst 1:250 000 map sheet did not progress west of Orange. However, some east–west trending dolerite dykes south of Condobolin are interpreted to be of Carboniferous age.

Minor mafic volcanism of Miocene age occur in the vicinity of the eastern and western margins of the Forbes 1:250 000 map sheet area, as part of the extensive continental mafic volcanic episode in eastern Australia during the Tertiary. In the east of the map sheet, a narrow valley-fill olivine basalt flow, which flowed some 50 km from its source at Mount Canobolas, near Orange, is present beneath recent alluvial sediments in the Eugowra area. In the west, the Weebar Hill Leucitite extruded southwest of Condobolin, forming a layered pile of lava flows, scoria, and breccias. The ultramafic lava contains clinopyroxene, olivine, Fe–Ti oxides, and leucite crystals enclosed in a glassy groundmass. Cundari (1973) suggested a mantle source at depths greater than 100 km for the leucitite, with intrusion along deep-seated crustal structures, such as the Gilmore Fault Zone, which were reactivated in the Tertiary.

# 17. GEOPHYSICS

## Airborne Geophysical Surveys

The National Geoscience Mapping Accord (NGMA) airborne geophysical data have been integral to the completion of the second edition of the Forbes 1:250 000 geological map sheet.

In 1993 the Australian Geological Survey Organisation (AGSO), as part of the NGMA program, acquired approximately 50 000 line kilometres of airborne magnetic and gamma ray spectrometric data over the Forbes 1:250 000 map sheet area. The airborne geophysical survey was designed to provide assistance for the regional mapping program. The survey was flown at a ground clearance of 100 m and a line spacing of 400 m, with some infill at 200 m. The coverage over the prospective Ordovician volcanic sequences in the Parkes 1:100 000 map sheet area, the northern two thirds of that map sheet area (north of latitude 33° 20' 2.2" S) was flown at the infill line spacing of 200 m.

The data were acquired for three main reasons:

- to assist with the second edition geological mapping of the Forbes 1:250 000 map sheet area;
- to promote exploration by providing a high quality and consistent dataset at low cost; and
- to identify extensions to areas thought prospective for economic mineral deposits.

### Survey specifications

Advances in geophysical instrumentation, navigation and data capture have made possible the routine collection of comprehensive medium- to high-resolution regional magnetic and gamma ray spectrometric data — with interline spacing of 400 m to 200 m. Such resolution can allow individual geological units to be resolved. Availability of those data greatly assisted the regional geological mapping of the Forbes 1:250 000 map sheet area.

The airborne survey specifications are summarised below (Franklin, 1993):

| | |
|---|---|
| Date of survey | 2 March 1993 to 9 May 1993 |
| Flight line spacing | 200 m and 400 m |
| Mean terrain clearance | 100 m |
| Flight line direction | East–west |
| Tie line direction | North–south |
| Sample interval | |
| Magnetic data: 0.1 second (approximately 7 m) | |
| Gamma ray spectrometric data: 1.0 second (approximately 67 m) | |
| GPS/Doppler/altimeter/VLF: 1.0 second (approximately 67 m) | |
| Temperature/barometric pressure: 1.0 second (approximately 67 m) | |
| Survey magnetometer | Geometrics G833 helium magnetometer (boom-mounted) |
| Base station magnetometer | Geometrics G866 magnetometer |
| Gamma ray spectrometer | Exploranium gamma ray spectrometer (GR820 spectrum processor) and two DET1024 spectrometer crystal detectors, total volume of 33.56 litres |
| Navigation | Ashtech XII "Ranger" GPS receivers and Ashtech "Ranger" differential processing software (The lines flown at 200 m spacing used a real time radio link.) |
| Flight path recovery | Vertically mounted video camera |
| Data acquisition | Digital, using AGSO ARGUS software |

Survey kilometres (including tie lines) totalled 49 055 km — 38 887 km at 400 m spacing and 10 168 km at 200 m spacing.

### Data processing and presentation

Field data were collected and reduced to located data using the AGSO ARGUS (now Intrepid) software package. Grids were then generated with the minimum curvature algorithm. ERMapper image processing software was used for the production of data images and facilitated on-screen interpretation of data. Stereo presentations of datasets were also completed with the 3D capabilities of ERMapper and this allowed different datasets to be compared and correlated. Combinations included draping the gamma ray spectrometric data over the 3D surfaces of the topography and the magnetic data.

### Interpretation

Tenison Woods (1983) completed an interpretation of the regional aeromagnetic and gravity data for the Forbes and Narromine 1:250 000 map sheet areas. The study was based on the regional 1.6 km interline aeromagnetic data and on the 11 km x 11 km gravity data acquired by AGSO (then the BMR) in the 1960s. Although superseded by the latest mapping, Tenison Woods (1983) report gave a general overview of the geological history of the major rock units and their relationship to major geophysical features.

Prior to the recent field mapping, and after release of the 1993 airborne survey, a geophysical overview was completed over selected areas. This established the relationship between major rock units and large-scale geophysical anomalies and indicated areas requiring follow-up ground surveys (Watson, 1995, 1997).

The integration of field mapping with geophysical data is iterative. Preliminary models for an area were initially proposed using available geological and geophysical data. They were then tested in the field, revised, and complemented with geophysical modelling. As the mapping team moved into unmapped areas, the new interpretations were used to adjust developing geological models. Thus many unit names and boundaries were not fixed until near the end of the mapping process. Geologists and geophysicists were both involved in this process, with many interpretations being completed in the field by the geologists.

Large tracts of the area of the Forbes 1:250 000 map sheet have sparse to non-existent outcrop and geophysical data often indicate the continuation of units that may crop out on either side of large intervals of alluvium. Thus the geophysical data constitute a particularly important mapping tool, and many boundaries with sparse outcrop were directly interpreted from geophysical data.

### Standard images

Four images formed the *standard image suite* used for most interpretations: total magnetic intensity (TMI); first and second derivatives of TMI; single-channel gamma ray spectrometric data; and ternary gamma ray spectrometric data. Geological data and other geophysical images have also complemented those images.

*Total magnetic intensity (TMI) with sun-angle illumination*

A sun-angle illumination filter can significantly highlight lower-amplitude linear magnetic anomalies. It is especially effective in enhancing features with trends transverse to the sun illumination direction. In the Forbes 1:250 000 map sheet area, the prevailing geological trend is north–south thus, sun illumination from the east proved particularly effective.

*First and second vertical derivatives of TMI*

The vertical derivative process enhances anomalies of the shorter wavelength (high frequency) or near-surface magnetic features. Images of either the first or second vertical derivative magnetic data can be particularly useful in tracing magnetic unit boundaries and structural features. The derivative process does not distort the shape of anomalies but can tend to emphasise high frequency noise in areas of low amplitude anomalies. The first vertical derivative narrows the apparent width of anomalies to more closely match the actual width of the source. The second vertical derivative further narrows the apparent anomaly width but can further emphasise high frequency noise. With weaker anomalies being enhanced, and the dynamic range of stronger anomalies decreased, the derivative process enhances subtle anomalies.

*Single channel gamma ray spectrometric data*

To solve particular problems, the total count, K, Th, and U (channel) data were displayed either separately or in combination. Images were completed as pseudocolour, greyscale, or through colour lookup tables. Some units can be very effectively mapped with single-channel gamma ray spectrometric data.

*Ternary gamma ray spectrometric data — K, Th, U*

In the generation of a ternary image of gamma ray spectrometric data, the primary colours red, green and blue (RGB) are sequentially assigned to the concentrations of the radioelements K, Th and U. The values of each of K, Th and U are separately imaged to the brightness of a single colour (K = red, Th = green, U = blue) and then combined to generate a ternary RGB spectrometric image. This very versatile image contains information on all three elements and provides another base for geological mapping. Throughout the area there can be variable concentrations of K, Th and U and thus there can be differing proportions of colours. For example, yellow (red and green) represents high concentrations of K and Th; magenta (red and blue) represents high concentrations of K and U; cyan (blue and green) represents high concentrations of U and Th; and white (red, blue and green) represents high concentrations of all three radioelements.

For the Forbes gamma ray spectrometric dataset the approximate range in counts per second (cps) for K ranged from 0 to 500 cps; Th from 0 to 400 cps; and U from 0 to 70 cps. In creating images, the range of the three colours is divided into 256 steps.

## Geophysical Overview

### Magnetic data

Aeromagnetic data for the Forbes 1:250 000 map sheet area (Figure 17.1) are dominated by a large magnetic complex in the centre and west of the image. To the north of the map sheet area, this teardrop-shaped area of high magnetic intensity extends over the width of the Condobolin and Bogan Gate 1:100 000 map sheet areas and narrows to a point near 147° 20' E, 33° 50' S. With only sparse outcrop, the sources of these anomalies have been interpreted as a broad assemblage of mineralised Ordovician volcanic rocks. Anomalies developed over shallow, younger, volcanic units overprint the magnetic anomalies from the Ordovician rocks.

West of the zone of high magnetic intensity, a zone of low magnetic intensity corresponds to a tract of turbidites and S-type granites. The rocks in this area generally show low levels of magnetic susceptibility. However, some horizons produce weak but discrete anomalies of up to 10 nT. With the help of sun-angle filters, images were generated that

highlighted these weak but discrete anomalies. This process has proved to be particularly useful for defining structural markers.

East of the area of high magnetic intensity there is another zone of high strain. In that area, the non-magnetic sedimentary rocks and magnetic volcanic rocks have been faulted and sheared into a succession of thin fault slices. At the northern end of this zone, the magnetic response is relatively strong, due to a large proportion of volcanic units with moderate to high magnetic susceptibility. To the south there are fewer volcanic units, hence, the zone is less magnetic and consists almost entirely of non-magnetic sedimentary rocks intruded by small granite bodies.

In the eastern zone, significant magnetic anomalies are interpreted to be caused by the Devonian I-type magnetic granites and by the Middle Devonian Rocky Ponds Group of volcanic units. The sedimentary, metasedimentary, and volcanic rocks, and the S-type granites lying between the magnetic volcanic rocks and I-type granites, are generally weakly magnetic.

In most areas where the overall magnetic intensity is low, small amounts of magnetite are present within particular stratigraphic horizons. Images of (sun-angle) filtered data enhance the low amplitude (10 nT) anomalies and can be used to determine structural features. Sandstones of the Late Devonian Hervey Group are an exception as they appear to contain little magnetite and, thus, yield anomalous areas of extremely low amplitude (<1 nT).

Much of the Forbes 1:250 000 map sheet area is covered by alluvium and interpretation of the magnetic data helped indicate the subsurface distribution of many units. For example, in the central north of the map sheet area, high-amplitude magnetic anomalies (>300 nT) indicate the subcrop of basalt horizons within the Early Devonian Kadungle Volcanics (Trundle Group). The sparse outcrop of this unit is limited to small areas of float but the magnetic data clearly indicate that its width is approximately 5 km and that it extends for at least 50 km.

Magnetic anomalies that have no surface geological expression are outlined in magenta on the Forbes 1:250 000 geological map.

## Gamma ray spectrometric data

The gamma ray spectrometric method is an excellent tool for surface mapping because its limited depth of investigation (approximately 30 cm) records what is present in outcrop or shallow subcrop. Rock units may even be mapped from their surficial weathered products, provided the weathered material has not been transported. The gamma ray spectrometric method also assists in the mapping of differences within the transported material. Thus, the method has application for both bedrock mapping and for mapping the regolith.

The brightness of the colours on the RGB gamma ray spectrometric ternary image (Figure 17.2) can help to indicate the extent of outcrop in the Forbes 1:250 000 map sheet area. In the east and north of the map area, the gamma ray spectrometric anomalies are representative of the underlying rock units and can effectively be used for geological mapping.

Distinct gamma ray spectrometric anomalies are produced by: the Rocky Ponds Group (high in K, Th, and U); the Hervey Group (low in K, Th, and U, except where the rocks are derived directly from the locally underlying Rocky Ponds Group); the Ordovician volcanic rocks (can be either high in K or low in all three elements); the Devonian and Silurian granites (generally high in K, Th, and U, but with K dominating in some areas); and the Silurian sedimentary rocks of the Forbes Group (moderate K and Th concentrations).

Outcrop in the central third of the Forbes 1:250 000 map sheet area is very poor as most of the area is covered by alluvium from the Lachlan River and its tributaries. The Lachlan River and its tributaries have wide flood plains and for much of the centre and west of the map sheet area, the alluvium obscures the response from the underlying rock units. Over the flood plain there is considerable variation of the gamma ray spectrometric signature, which may indicate successive stages in the formation of the flood plain. Some small but distinct areas of outcrop within the flood plain include: a prominent ridge of Late Devonian Hervey Group rocks with an approximate north-northeast strike (distinctively low K, Th, and U); the Early Devonian Carawandool Volcanics (high K, Th, and U); the Byong Volcanics (high K, Th, and U); the Caragabal Granite (high K, Th, and U); and shales and phyllites of the Kirribilli Formation and Derriwong Group and Ootha Group, which invariably have high concentrations of K, Th, and U.

The Lachlan River has transported significant volumes of alluvium containing moderate to high levels of K and Th (intense red and green in RGB images), with K being the dominant transported radioelement. Within the flood plain it is possible to subdivide the recent active sediments from the stable sediments because the recent active sediments appear to be poorer in Th and richer in K.

The western third of the Forbes 1:250 000 map sheet area contains extensive areas of transported cover. Studies of the gamma ray spectrometric data have greatly assisted the regolith mapping. Limited bedrock mapping is also possible, but the large amounts of transported material restrict the geological mapping in the northern and southern areas. In particular, the gamma ray spectrometric data highlight the following bedrock features: the Wagga Group in the southwestern corner of the map sheet area (high in K, Th, and U, but highly variable concentrations); the Burcher Greywacke (moderate to high K, Th, and U concentrations with K and Th dominant); the Girilambone Group (moderate to high K, Th, and U concentrations); the Early Devonian Yarra Yarra Creek Group (very low K, Th, and U concentrations); and the Manna Conglomerate (high K concentration).

## Gravity data

In 1993, as part of the NGMA program, AGSO upgraded the regional 11 km x 11 km gravity data acquired in the 1960s to an irregular 4 km x 4 km grid. Calibrated barometers provided the height control and stations were located from topographic map sheets.

The most prominent features on the Forbes 1:250 000 map sheet area gravity image (Figure 17.3) are two sub-parallel positive gravity ridges, approximately 300 gravity units (g.u.) above background. They trend in a north-northeast direction and continue to the north onto the Narromine and Nyngan 1:250 000 map sheet areas. Further to the east, two similar but lower amplitude ridges (approximately 150 g.u. above background) occur in the Dubbo and Bathurst gravity images. Recent mapping indicates that the likely sources of the positive gravity ridges in the Forbes 1:250 000 map sheet area are belts of Ordovician volcanic rocks. The major mineral occurrences at Cowal, Northparkes and Fairholme lie within those units and the large extent of the gravity features probably indicates extensive areas (approximately 800 km$^2$) that are likely to be prospective for economic mineralisation. Modelling using the gravity data indicates that the volcanic units may extend to depths of approximately 2000 m to 2500 m.

Other features in the gravity data include a major gravity low in the east of the Forbes 1:250 000 map sheet area (Figure 17.3). This response is approximately 200 g.u. to 300 g.u. below the regional background and is due to the absence of Ordovician volcanic rocks. Other gravity lows are associated with granites in the east and southeast of the map sheet area.

## Geophysical signatures in the Forbes map sheet area

The following descriptions are subdivided according to the legend for the simplified basement geology (see Forbes 1:250 000 map sheet legend). Within each major subdivision, selected units have been described by their geophysical characteristics. Some units cannot be resolved using the airborne survey data because they are too limited in extent to produce discrete geophysical anomalies. Specific references to individual image figures are generally not made in the following descriptions.

*Tertiary basalts*

On TMI images, an outcrop of Weebar Hill Leucitite at about 15 km southwest of Condobolin shows as an area of variable magnetic intensity, with moderate amplitudes that show a distinctive mottled pattern typical of basalt flows. The magnetic susceptibility of the basalt varies between $300 \times 10^{-5}$ SI and $3000 \times 10^{-5}$ SI, with typical values closer to $3000 \times 10^{-5}$ SI. The magnetic data significantly extend the mapped outcrop extent of this unit.

Generally the Weebar Hill Leucitite has a high K content and on the gamma ray spectrometric RGB image it shows as a deep pink response. This is in contrast to the gamma ray spectrometric signature expected of other basaltic or ultramafic rocks, which generally have low K, Th and U contents and hence would show as dark areas on RGB images.

At the eastern margin of the Forbes 1:250 000 map sheet area, a zone of discontinuous high frequency magnetic anomalies is interpreted to correspond to thin valley-fill basalt flows beneath Quaternary alluvium.

*Late Devonian sedimentary rocks*

The Late Devonian Hervey Group sedimentary rocks are characterised by very low magnetic susceptibilities ($<10 \times 10^{-5}$ SI). The subtle magnetic anomaly pattern produced by these rocks is distinguished by its extreme lack of internal variation and sun-illuminated images show a particularly bland magnetic zone. This response implies that there is very little magnetite in the rocks.

The typical gamma ray spectrometric signature of the Hervey Group is as expected for materials with very low levels of radiation. On the ternary gamma ray spectrometric RGB images these quartz-rich sedimentary rocks appear as a diagnostic near-black colour. An exception occurs in the southeastern part of the Forbes 1:250 000 map sheet area where the Hervey Group overlies the felsic volcanic units of the Rocky Ponds Group. In that area, the Hervey Group has locally been derived from the underlying volcanic rocks and the basal units show relatively high radioelement concentrations.

*Middle Devonian felsic to mafic volcanic rocks*

The main units of the Rocky Ponds Group in the Forbes 1:250 000 map sheet area are the Dulladerry Volcanics and Warrumba Volcanics. The group shows variable magnetic anomalies of low to high amplitude. In particular, the magnetic anomalies over the Dulladerry Volcanics increase in magnetic intensity towards the northeast of the map area. Of 85 samples measured for magnetic susceptibility, 42 measurements are less than $100 \times 10^{-5}$ SI, with most of the remainder (37) less than $1000 \times 10^{-5}$ SI. Only five samples recorded a magnetic susceptibility over $1000 \times 10^{-5}$ SI, with a maximum of $2400 \times 10^{-5}$ SI. Basalts of the Adelargo Member of the Warrumba Volcanics produce a narrow, high intensity magnetic anomaly — which helps to define the geometry of a fold to the northwest of Grenfell.

On the RGB ternary gamma ray spectrometric image the predominantly felsic volcanic rocks of the Rocky Ponds Group show as a mixture of bright white (high K, Th, and U), yellow (high K and Th), and green (high Th) indicating variable concentrations of K, Th, and U. Regions of lower gamma ray count rates that show as dark green (moderate Th) and blue–green (moderate Th and U) correspond to areas of relatively flat topography and are typical of deep sandy soil.

*Devonian intrusions*

Devonian intrusions in the area of the Forbes 1:250 000 map sheet are divided into I-type, S-type, and A-type granites (Chappell & White, 1992). S-type granites are generally reduced and non-magnetic and are unlike the

commonly more oxidised and strongly magnetic I-type granites. Magnetite is dominant in I-type granites, and ilmenite is dominant in S-type granites (Blevin, 1996).

Examples of typical S-type granites that produce no observable magnetic anomalies include the Cumbijowa Granite southwest of Forbes and the Mortray Hill Granite Complex. Both are highly felsic and reduced granites. The Mortray Hill Granite Complex has a strongly magnetic contact aureole developed in the Kirribilli Formation around its eastern margin. The Cumbijowa Granite has a subtle magnetic aureole. In contrast, the S-type Dalrida Granite north of Wirrinya is more oxidised and has a distinctive zoned and elliptical magnetic anomaly.

In areas of outcrop, all S-type granites have strong gamma ray spectrometric signatures and give K-dominant signatures on their colluvial slopes.

Devonian I-type granites are extensive in the east of the Forbes 1:250 000 map sheet area. The Eugowra Suite granites have low to moderate magnetic susceptibilities, ranging from about $50 \times 10^{-5}$ SI to $1500 \times 10^{-5}$ SI (average $730 \times 10^{-5}$ SI from 12 readings), although the Milandra Granite has higher values (range $600 \times 10^{-5}$ SI to $2000 \times 10^{-5}$ SI). They are generally oxidised and produce magnetic anomalies with moderate to high intensity. The anomalies clearly indicate their distribution beneath alluvial cover. In contrast, the Clear Hills Monzodiorite is reduced and has a relatively weak magnetic signature. It appears concentrically zoned with a very weakly magnetic core. The magnetic data show prominent linear features that are faults within the granites. The Eugowra Granite and Lords Granite produce very intense gamma ray spectrometric anomalies, indicating relatively high K, Th and U concentrations. At the edges of the granites where the colluvial sediments mask the outcrop signature, the gamma ray spectrometric anomaly pattern is less intense, with K being dominant. The Milandra Granite exhibits a mid-bright red colour on RGB ternary spectrometric images, which indicates low radioelement concentrations, with K being dominant.

*Early Devonian sedimentary and volcanic rocks*

Despite limited outcrop, the Early Devonian sedimentary and volcanic rocks of the Tullamore Syncline and Currowong Syncline can be mapped by their geophysical signatures. The volcanic units are often highly magnetic and long linear magnetic features outline much of the Tullamore Syncline. To the west of the Tullamore Syncline and in an area with almost no outcrop, long narrow magnetic highs show the position of basalts within the Kadungle Volcanics of the Trundle Group. In the Currowong Syncline, the Carawandool Volcanics produce moderate to high amplitude magnetic anomalies with its eastern flank showing considerable internal banding. The strong magnetic linears are due to thin basalt horizons within the predominantly weakly to moderately magnetic felsic volcanic pile.

The Early Devonian volcanic rocks have an RGB ternary gamma ray spectrometric signature of white to orange indicative of moderately high levels of Th and U, with a distinctive high level of K.

*Siluro-Devonian sedimentary and volcanic rocks*

The sedimentary and volcanic rocks of the Derriwong Group and Ootha Group generally possess very low values of magnetic susceptibility ($<20 \times 10^{-5}$ SI). Images of the magnetic data show low amplitude anomalies without any high frequency component.

The gamma ray spectrometric anomalies over the Derriwong and Ootha Groups commonly show low K, Th, and U concentrations. Th typically dominates and gives a dark green colour on the RGB images although K counts may be elevated where the rocks are composed of clasts derived from the Girilambone Group. This may reflect the poor outcrop and deep soils developed over subcrop, which subdue the gamma ray spectrometric signature. As with other sedimentary sequences, shales and siltstones contain significant fine-grained clay and mica and are generally high in K, Th, and U.

*Silurian sedimentary rocks*

The Silurian Forbes Group and Burcher Greywacke both possess low magnetic susceptibilities — 75 measurements range from 0 to $310 \times 10^{-5}$ SI, with an average of $31 \times 10^{-5}$ SI. They show low magnetic amplitude anomalies without any high frequency response.

In the northern part of the Forbes 1:250 000 map sheet area the RGB ternary gamma ray spectrometric data over the Forbes Group show a distinctive yellow colour that indicates moderate K and Th concentrations. Part of the signature of the Forbes Group is obscured by high concentrations of K in the alluvium, which has probably been transported from the nearby volcanic units. In the western part of the Forbes 1:250 000 map sheet area, the Burcher Greywacke shows a similar yellow colour that again indicates high concentrations of K and Th, but in other areas it is generally obscured by alluvium.

*Silurian felsic volcanic rocks*

In the southeastern corner of the Forbes 1:250 000 map sheet area, the weakly magnetic Illunie Volcanics show no aeromagnetic anomaly. Its high felsic composition results in a moderately strong gamma ray spectrometric signature in K, Th and U and is particularly high in K. It is distinguished from the Warrumba Volcanics (in the same area) that have a much stronger gamma ray spectrometric signal, but it does have a very similar spectrometric signature to the Young Granodiorite.

In the western portion of the Forbes 1:250 000 map sheet area, the Ugalong Dacite and Ina Volcanics produce a low-amplitude magnetic anomaly pattern that is intersected by a small number of strongly magnetic, linear dyke-like anomalies. Measurements of magnetic susceptibility from both units range from $10 \times 10^{-5}$ SI to $50 \times 10^{-5}$ SI, with occasional values up to $1000 \times 10^{-5}$ SI. On the ternary gamma ray spectrometric RGB image the outcrop of

Ugalong Dacite appears as white and thus is relatively high in K, Th, and U.

*Silurian intrusions*

The Silurian S-type intrusions about the southwestern and the southeastern corners of the Forbes 1:250 000 map sheet area have reduced compositions and produce only low-amplitude magnetic anomalies. They can be mapped in some areas by their magnetic contrast with the adjoining rocks — some more magnetic, others less so.

Although the outcrop of Ungarie Granite is sparse, it is distributed over a large part of the West Wyalong 1:100 000 map sheet area. It may be mapped by its quieter magnetic character and by linear magnetic anomalies at its boundary. The granite generally has a low magnetic susceptibility, ranging from $3 \times 10^{-5}$ SI to $100 \times 10^{-5}$ SI (34 samples) with an average of $47 \times 10^{-5}$ SI. One small group of four samples from two sites exhibit a moderate magnetic susceptibility, ranging from $410 \times 10^{-5}$ SI to $530 \times 10^{-5}$ SI.

Approximately 6 km east of West Wyalong, the I-type Bland Diorite shows as a high-amplitude magnetic anomaly and this strong response clearly defines its extent. Fourteen measurements of magnetic susceptibility yielded a moderate average of $340 \times 10^{-5}$ SI within a range of $45 \times 10^{-5}$ SI to $1400 \times 10^{-5}$ SI. On RGB ternary gamma ray spectrometric images the Bland Diorite shows as a distinctive black area and thus its K, Th, and U contents are very low.

*Ordovician–Silurian sedimentary and volcanic rocks*

The Cotton Formation in the northern part of the Forbes 1:250 000 map sheet area shows low amplitude magnetic anomalies. Measured magnetic susceptibilities are low and are typically less than $20 \times 10^{-5}$ SI. Its K, Th, and U concentrations are also low and produce low-amplitude Th anomalies with little contribution from either K or U. This gives a dark green colour on the ternary gamma ray spectrometric RGB image. Much of the outcrop area of the Cotton Formation is covered by alluvium that exhibits more intense colours, hence higher concentrations of K, Th, and U, which mask most of the subtle dark green gamma ray spectrometric response from bedrock.

Poorly outcropping sedimentary rocks of the Jingerangle Formation generally have very low magnetic susceptibilities (less than $20 \times 10^{-5}$ SI), and lie within a north–south zone containing north–south trending interbedded magnetic volcanic units. As outcrop is extremely poor, it is not possible from the airborne data to determine its K, Th, and U contents.

*Ordovician intermediate–mafic volcanic rocks, intrusions and sedimentary rocks*

The Ordovician volcanic and intrusive rocks produce high-amplitude linear magnetic anomalies. Measurements of magnetic susceptibility are generally high and range from $300 \times 10^{-5}$ SI to $3000 \times 10^{-5}$ SI. Some parts of the volcanic units have low magnetic susceptibilities of $5 \times 10^{-5}$ SI and have probably been affected by alteration.

Gamma ray spectrometric anomalies over the Ordovician volcanic rocks show as red on the ternary image and imply relatively high concentrations of K with low concentrations of Th and U. This response may indicate either high-K magmatic chemistry or the degree of potassic alteration. However, the Nash Hill Volcanics show a different response to the rest of the Northparkes Volcanic Group because they exhibit a distinctive green colour on RGB images of the ternary gamma ray spectrometric data. This would indicate relatively high concentrations of Th with low concentrations of K and U.

*Ordovician tholeiitic volcanic rocks and chert*

The Brangan Volcanics, Narragudgil Volcanics, and Wambidgee Serpentinite exhibit characteristic linear magnetic anomalies with high to moderate amplitude. These mafic volcanic rocks and cherts are black on the RGB ternary gamma ray spectrometric image, which indicates very low K, Th, and U concentrations.

*Ordovician ultramafic rocks*

Although the Kars Ultramafic Intrusive Complex crops out poorly in the Forbes 1:250 000 map sheet area, it produces a high amplitude magnetic anomaly that is easily distinguished from the surrounding weakly magnetic sedimentary rocks.

*Ordovician metasedimentary rocks*

The Kirribilli Formation has low magnetic susceptibilities ranging from $10 \times 10^{-5}$ SI to $50 \times 10^{-5}$ SI, which correspond to weak magnetic anomalies. However, within this unit, linear moderately magnetic anomalies that represent narrow bands of more magnetic rocks have a high magnetic susceptibility of approximately $1600 \times 10^{-5}$ SI.

The gamma ray spectrometric anomaly over the Kirribilli Formation is also partly banded, with moderate K, Th, and U concentrations. Mid-bright yellow bands (moderate K and Th), dark bands (low K, Th, and U), and bright yellow bands (high K and Th) reflect the variable quartz-rich to lithic composition of the unit. The anomaly pattern confirms the north–south trend of this unit.

Girilambone Group metasedimentary rocks in the western part of the Forbes 1:250 000 map sheet area have very low magnetic susceptibilities (less than $10 \times 10^{-5}$ SI), with higher values ($200 \times 10^{-5}$ SI) recorded for the cherts. The rocks give low amplitude magnetic anomalies and show a striking contrast when they abut the highly magnetic Ordovician volcanic units. When the Girilambone Group is in contact with either the weakly magnetic Burcher Greywacke or the weakly magnetic Wagga Group, neither can be distinguished from the Girilambone Group.

For the northern outcrops, the K, Th, and U contents of the Girilambone Group are generally low with a relative slight increase in the Th concentration. Further south, near Burcher, the gamma ray spectrometric responses are higher, with K, Th, and U showing moderate to relatively high concentrations.

On images of the magnetic data, the Mugincoble Chert shows as a linear magnetic anomaly with moderate amplitude. Although field magnetic susceptibility readings are generally less than $20 \times 10^{-5}$ SI, sparse and narrow bands of ferruginised chert give values in excess of $10\,000 \times 10^{-5}$ SI. Magnetic modelling by Watson (1995) indicate that the single magnetic anomaly over the Mugincoble Chert could be due either to a single dyke-like body or to a number of narrow vein-like bodies. The highly siliceous siltstones and cherts of the Mugincoble Chert yielded a very low gamma ray spectrometric signal.

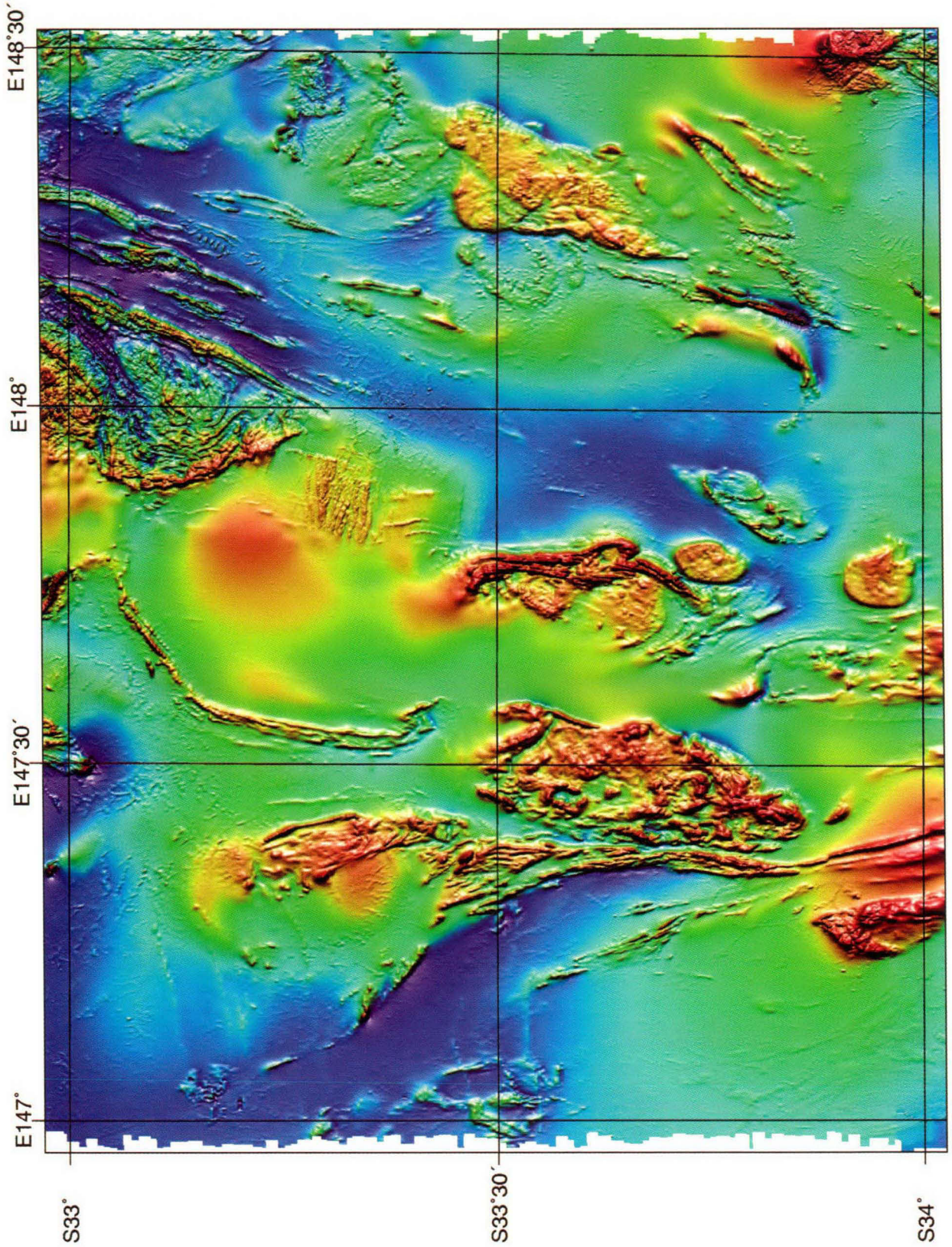



*Figure 17.1. Forbes 1:250 000 map sheet area TMI (Total Magnetic Intensity) data presented as a shaded (illuminated from the east) pseudocolour image. Scale 1:750 000.*

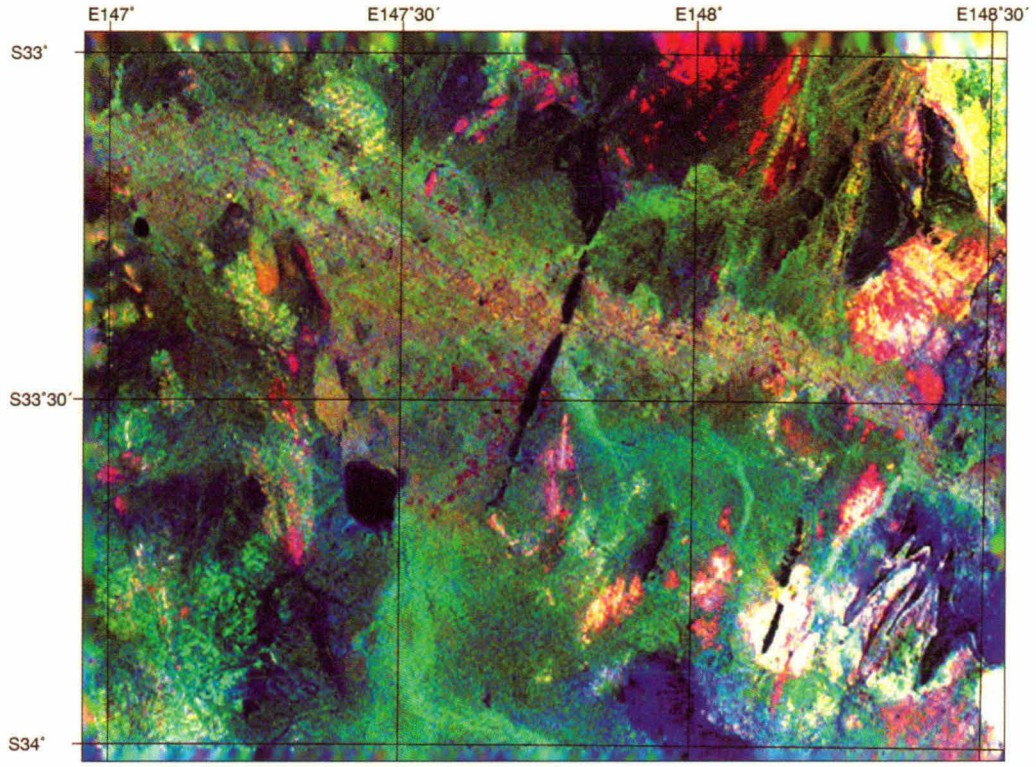



*Figure 17.2. Forbes 1:250 000 map sheet area gamma ray spectrometric data presented as a ternary RGB image, where red indicates K, green Th, and blue U. Scale 1:1 200 000.*

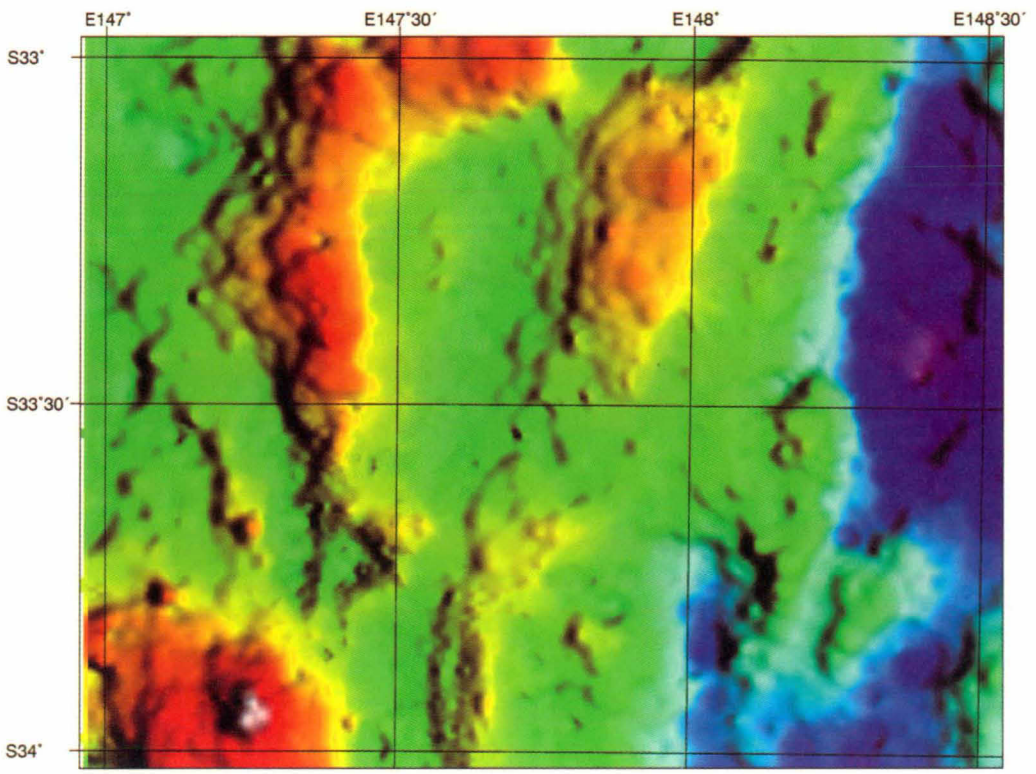



*Figure 17.3. Forbes 1:250 000 map sheet area Bouguer gravity anomaly image (using a density of 2.67 t/m$^3$). Scale 1:1 200 000.*

# 18. MINERALISATION

## Introduction

Brief outlines of the major metalliferous mineralisation styles, with summary descriptions of some representative examples of the mineral occurrences present in the Forbes 1:250 000 map sheet area, are presented here in the context of the new mapping and tectonic interpretation. Some styles of mineralisation, such as placer deposits, are only briefly discussed. Neither industrial minerals nor construction materials are discussed (although they are briefly noted), nor are historical data or descriptions of workings included. The discussion concentrates on primary mineralisation styles. Further details about individual mineral occurrences and districts can be found in Bowman (1977a,b), and the data are included in the Geological Survey's New South Wales Metallic Mineral Occurrence (METMIN) database (Downes, 1999). Descriptions of the individual host units and structural information are found elsewhere in this volume. Figure 18.1 shows the distribution of mineral occurrences within the Forbes 1:250 000 map sheet area. The Forbes 1:250 000 map sheet area has a history of mining extending back to the 1850s, when rich shallow alluvial gold placers were discovered. By the early 1860s, mining of the auriferous quartz veins was being attempted at a number of sites. However, interest quickly waned. It was the discovery of deep leads, mainly in the Parkes–Forbes and Grenfell areas that highlighted the potential of the area. Subsequently, a number of significant hardrock gold deposits were identified and mined, mainly during the period 1880 to 1914. The Forbes 1:250 000 map sheet area has produced significant gold and copper with minor manganese, lead, zinc, iron, clay, and other commodities. In total, the area has identified metalliferous resources and past production with a value of over $2 billion (1999 dollars).

A wide range of mineral deposit styles are present in the Forbes 1:250 000 map sheet area. These styles include: structurally controlled gold (and base metal) mineralisation; Ordovician intrusion-related copper–gold

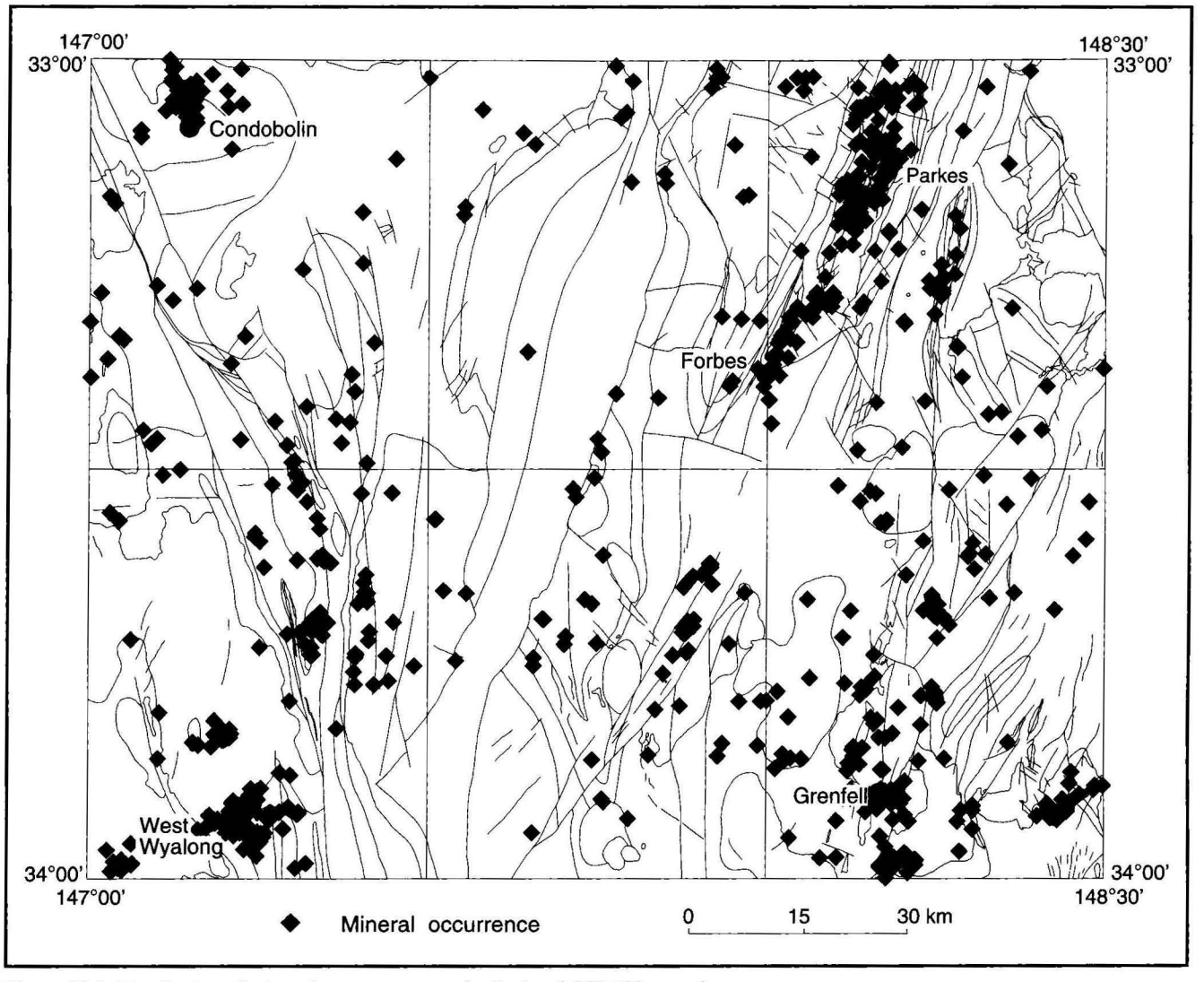



*Figure 18.1. Distribution of mineral occurrences on the Forbes 1:250 000 map sheet area.*

mineralisation; and copper–gold and iron mineralisation associated with the Silurian Young Granodiorite. Epithermal-style mineralisation is present at Bumbaldry and Condobolin, and a number of auriferous placer deposits, ranging in age from ?Tertiary to Recent.

As part of the 1:100 000 scale geological mapping of the Forbes 1:250 000 map sheet area, the mineral occurrence dataset was upgraded from that compiled by Bowman (1977b). The present study was essentially office-based, although some field verification was carried out. This process resulted in subdivision of descriptions of some occurrences, and the addition of new occurrences to the original dataset. Furthermore, the information about each occurrence was reviewed, and in many cases substantially revised. As of June 1999, the METMIN database contained records for over 650 metallic mineral occurrences for the Forbes 1:250 000 map sheet area. The database also contains details on approximately 130 industrial mineral and construction material sites. The METMIN database holds information on the location, mineralogy, host rocks, past production, published resources and references for individual mineral occurrences, and provides a link to the compilation by Bowman (1977b) and the special publication on the Parkes area by Clarke (1990b).

Many of the sites identified in the Forbes 1:250 000 map sheet area are simply mineral occurrences with no known historical production or identified resource. However, at least 100 sites have yielded significant production or contain known resources. The area contains many deposits that are either very large in terms of historic production (e.g., London-Victoria and Mallee Bull), or contain large delineated mineral resources (e.g., Endeavour 42 — Cowal project).

## Mineralisation in the Forbes 1:250 000 map sheet area

Mineral occurrences in the Forbes 1:250 000 map sheet area have been grouped on the basis of deposit style, geological association, and age. The groupings include Ordovician intrusion-related copper–gold mineralisation (including skarns and porphyries), orogenic mesothermal gold occurrences, deposits associated with post-Ordovician intrusive events, e.g., with Siluro–Devonian granites (including skarns), and deposits associated with potassic, Devonian granites. There are also minor or miscellaneous ungrouped styles, as well as various placer occurrences.

Mineralisation in the Forbes 1:250 000 map sheet area is dominated by a number of major associations related to major geological events. Some events directly related to mineralisation include:

- a major magmatic event in the Late Ordovician giving rise to porphyry copper–gold and related mineralisation;
- a significant deformation in the Late Ordovician–Early Silurian that may have remobilised gold and base metals into structurally controlled sites;
- felsic volcanism in the Middle Silurian;
- the emplacement of magmas and lavas in the Late Silurian or earliest Devonian;
- felsic volcanism in the Early Devonian;
- development of magmas and lavas in the Early Devonian, which gave rise to a variety of intrusion-related mineralisation, some being related to the Boggy Plain Supersuite;
- the Tabberabberan Orogeny in the Middle Devonian that remobilised some gold and base metals into structurally controlled deposits;
- the Kanimblan Orogeny in the Late Devonian–Early Carboniferous that may have remobilised gold and base metals into structurally controlled sites; and
- uplift and erosion at various times, resulting in gold placer deposits.

Major deposits within the Forbes 1:250 000 map sheet area include the Endeavour 42 gold deposit at Lake Cowal (Cowal project) and the London-Victoria gold mine. Historic mining areas include Parkes–Forbes, Grenfell, Condobolin, West Wyalong, Ironbarks, and Bumbaldry. The distribution of mineral occurrences is shown in Figure 18.1. The main feature of Figure 18.1 is that the bulk of mineral occurrences in the Forbes 1:250 000 map sheet area are associated with the Junee–Narromine Volcanic Belt, a meridional belt of Ordovician age.

## Structurally controlled mineralisation

Structurally controlled gold and base metal mineralisation occurs throughout the Forbes 1:250 000 map sheet area, with over 400 occurrences being identified (Figure 18.2). The geological setting and style of these occurrences is largely controlled by the structural competency of the host rocks, the depth of burial at the time of emplacement of mineralisation, and the host rock chemistry. The deposit styles include mineralised zones located in dilatant sites within faults and shears, such as the London–Victoria mine, and mineralisation located in sites where a ductility contrast has been important.

Significant gold and base metal production has come from the Parkes–Forbes, West Wyalong, and Grenfell areas. Other significant occurrences include the Endeavour 42 structurally controlled deposit at Lake Cowal. Details of these and other occurrences are given in the METMIN Database (Downes, 1999).

### *Parkes–Forbes*

Mineralisation in the Parkes–Forbes area has been described by a number of authors, including Andrews (1910), Bowman (1977a,b), Rollan (1984), Lindsay-Park (1985), and Clarke (1990b). In that area structurally controlled gold mineralisation is typically hosted in auriferous sulphide–quartz–calcite veins within Late Ordovician sedimentary and volcanic rocks (Figure 18.3).

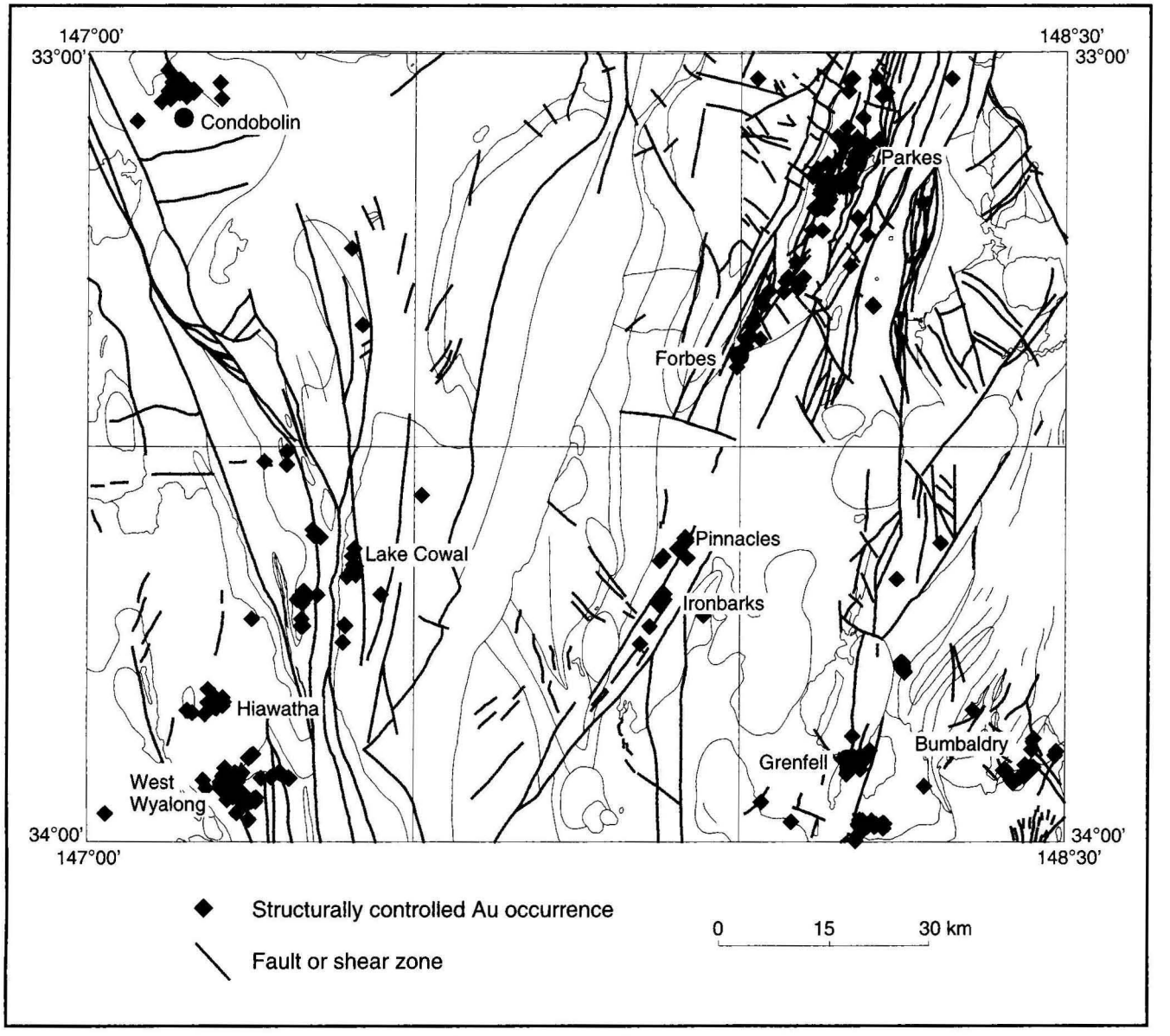



*Figure 18.2. Distribution of structurally controlled gold mineralisation and major faults in the Forbes 1:250 000 map sheet area.*

The occurrences are confined to a narrow belt with a north-northeast trend characterised by intense faulting and shearing. The mineralisation is commonly associated with brecciated veins and stockworks. The major ore minerals are gold, pyrite, and arsenopyrite, with minor tetrahedrite, pyrrhotite, and galena. Clarke (1990b) noted that pervasive wall rock alteration of carbonate, chlorite, sericite, quartz and pyrite was a common feature of the more significant occurrences. The occurrences are generally hosted by volcanic or fine-grained volcaniclastic rocks.

Andrews (1910) distinguished two groups of lode gold occurrences in the Parkes–Forbes area based on the host rock lithology. These were occurrences associated with "intrusive andesites" (Lachlan, Koh-i-noor, Phoenix, Bushmans, etc.) and those in zones of "crushing" (London-Victoria, Mount Morgan, New Haven, Band of Hope, etc.). This second group of occurrences lies to the west of the "andesite" related occurrences. Clarke (1990b) observed that the competency contrast between various rock units was a major control to mineralisation style and noted that finer-grained clastic units behave in a less competent manner. He grouped the occurrences into four classes:

- occurrences associated with near-vertical, longitudinal, shears and fractures parallel to the regional structural grain;
- occurrences associated with moderately to steeply dipping shears and fractures crosscutting the regional structural grain;
- mineralisation associated with saddle reefs; and
- disseminated occurrences.

In addition, Clarke (1990b) observed that, in places, the Mugincoble Chert is anomalous in gold and he suggested that some of the gold was derived from exhalative fluids discharged down the slope of a volcanic arc and deposited on the deep seafloor.

The largest gold producer has been the Parkes gold mine, located approximately six kilometres southwest of Parkes. The mine, which covers the historic London-Victoria line of lode, has been described by Rollan (1984) and Clarke (1990b). The Victoria deposit was discovered in 1873 and worked from 1876, while the London mine was worked from around 1877 to 1909. The workings extended to a depth of 80 m and it has been reported that 155 kg of gold was produced prior to 1988 (Clarke, 1990b). Opencut mining operations commenced in 1988 and ceased in 1991. Treatment operations ceased in 1996 with a total of approximately 3 million tonnes of ore having been milled at an average grade of 1.5 g/t Au (approximately 4.5 tonnes of gold). A resource totalling 670 000 tonnes at 2.4 g/t Au remains (Michelago Resources NL Quarterly report, 31/12/1998).

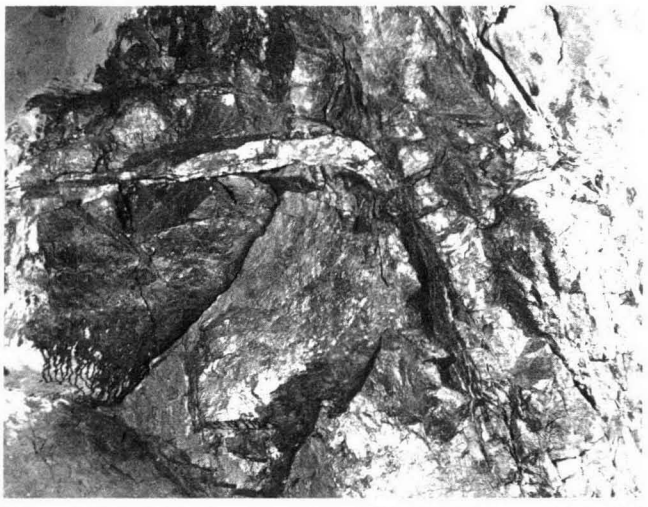


*Figure 18.3. Faulted quartz vein (reef) in the Bushmans Hill gold mine, Parkes. The vein has been dragged downwards into the fault on the right hand side, indicating normal displacement. (Photo taken in July 1897, DMR collection, Forbes 0012).*

Mineralisation in the London-Victoria deposit is hosted by an anastomosing shear zone within metamorphosed intercalated pyroclastic and volcanic-derived sedimentary units, with rare porphyritic volcanic rocks. The pyroclastic rocks include andesitic and trachyandesitic to trachytic tuffs forming part of the Late Ordovician Parkes Volcanics. To the west of the shear are mudstones and lithic sandstones of the Silurian Mumbidgle Formation and conglomerates of the Bocobidgle Conglomerate. The mineralised zone is up to 35 m wide in the vicinity of the London mine. Individual mineralised lenses overlap, extend for up to 100 m along strike and down dip, and are up to 10 m wide. The lenses are contained within a sericite–carbonate (including ankerite)–pyrite–quartz alteration zone up to 100 m wide and 3 km long, east of, and adjacent to the London-Victoria Fault. The London-Victoria Fault is a north–south striking, 70° east dipping, reverse fault that is probably a splay of the Parkes Thrust. The Parkes Thrust intersects the surface about three kilometres west of the mine.

Two alteration assemblages were recognised by previous authors at the London-Victoria mine (Rollan, 1984; Degeling *et al.*, 1986; Clarke, 1990b). A fine-grained outer zone, up to hundreds of metres wide, consists of abundant secondary chlorite with biotite, quartz, microcrystalline carbonate (including ankerite), epidote, calcite, clinopyroxene and actinolite. An inner zone of more intense alteration, extends only a few metres from the veins, and consists of a pervasive silicification with sericite, pyrite, carbonate (including dolomite and ankerite), albite, fuchsite, and minor chlorite.

At least two generations of veining have been identified at London-Victoria: early auriferous veins; and late stage, barren metamorphic quartz veins (Degeling *et al.*, 1986). The auriferous veins exhibit crack-seal textures and consist of quartz, carbonate (ankerite and calcite), albite, K-feldspar, sericite and rare chlorite, with gold, pyrite, and minor sphalerite, chalcopyrite and galena (Rollan, 1984) (Figure 18.4) Gold occurs as inclusions and fracture fillings in pyrite, and as fine-grained native gold in veins and in altered wallrock. Pyrite may account for up to 10% of the rock, with a high pyrite content in zones of higher gold grade. The altered rock between the mineralised lenses also contains minor gold mineralisation.

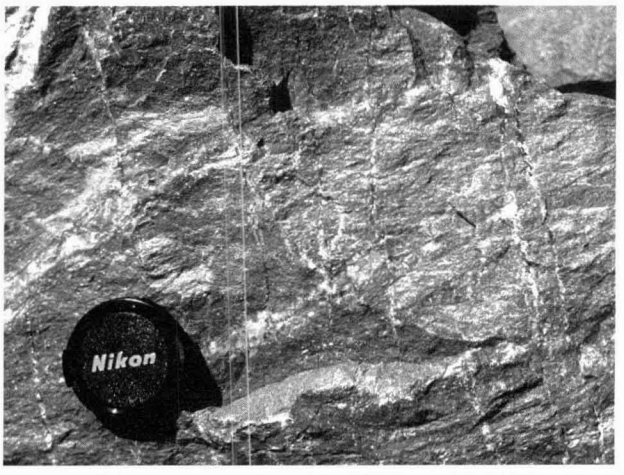



*Figure 18.4. Quartz–sericite rock with fine-grained, disseminated pyrite and quartz–K-feldspar veining. London-Victoria mine, Parkes (G. Burton, photograph)*

Minor base metal mineralisation, consisting of sphalerite–galena–pyrite–chalcopyrite with some arsenopyrite, is present in the vicinity of the Victoria open cut east of the gold mineralisation (Clarke, 1990b). Rollan (1984) speculated that this mineralisation may be related to an earlier, possibly VHMS, mineralising event. However, Govett *et al.* (1984) suggested that this style of mineralisation could also be formed by epigenetic processes.

The Nibblers Hill occurrence, seven kilometres southwest of Parkes, has been described by Rollan (1984), Lindsay-Park (1985), and Clarke (1990b). The occurrence is hosted by andesitic to trachytic volcanic rocks and ferruginous cherts of the Late Ordovician Parkes Volcanics, and metamorphosed fine- to medium-grained shales and sandstones of the Late Ordovician Cotton Formation. The auriferous veins are brecciated and Lindsay-Park (1985)

noted that the veins consist of quartz, calcite, albite, K-feldspar, and rare chlorite, with gold, pyrite, and chalcopyrite. Lindsay-Park (1985) recognised the close association of gold with faulting at Nibblers Hill and identified three alteration assemblages in addition to a greenschist metamorphic assemblage. The three alteration assemblages are: low-intensity carbonate alteration of quartz–albite–chlorite–calcite–epidote; intense carbonate alteration of quartz–ankerite–sericite with minor chlorite and calcite; and pervasive quartz–albite–ankerite–sericite–pyrite alteration directly related to gold mineralisation. Rare fuchsite was also recognised by Lindsay-Park (1985). In polished section, Rollan (1984) observed that gold occurs as minute grains in the altered wallrock adjacent to quartz veins, as inclusions within pyrite grains, and as very thin stringers within quartz–carbonate–chlorite veins.

The Calarie deposit, 3 km north of Forbes, was described by Bowman (1977b) and Clarke (1990b). The deposit contains an "in-pit resource" totalling 531 000 tonnes grading 3 g/t Au (*Register of Australian Mining*, 1998/99, p.130). The mineralisation occurs in lenses located at the sheared contact between the Late Ordovician to Early Silurian Cotton Formation and the Ordovician Northparkes Volcanic Group. In drill core, the Cotton Formation exhibits mud breccia textures consisting of black claystone clasts (several centimetres long) within a grey, fine- to very fine-grained sandstone–siltstone matrix. The mineralisation consists of gold, pyrite, arsenopyrite, and magnetite associated with quartz and carbonate in veins, stockworks, and breccia fill (Clarke, 1990b) (Figure 18.5). The alteration assemblage includes pyrite, chlorite, sericite, and carbonate. Within the Cotton Formation, pyrite content, intensity of chlorite and silica alteration, degree of schistosity, and abundance of fracturing all increase toward the sheared contact. In the main mineralised zone the rock is heavily brecciated, silicified, and contains abundant pyrite, which, as at London-Victoria, is more common in the host rock than in quartz–carbonate veins. In the main sheared zone the rock has a striped texture with alternating chlorite-rich rock and quartz with some pyrite in parallel layers. Within the Northparkes Volcanic Group, adjacent to the shear, the andesite is altered and contains a carbonate–sericite–silica–chlorite assemblage with minor disseminated pyrite. The mineralised zones range from less than one centimetre to greater than 10 metres wide and extend for several tens of metres down-plunge (Clarke, 1990b). The mineralisation is overprinted by later, barren, veins. In contrast to the London-Victoria mine the mineralisation at Calarie is mainly within the metasedimentary rocks rather than the andesite.

Clarke (1990b) proposed a meta-hydrothermal origin for the gold mineralisation in the Parkes–Forbes area and suggested that there is no relationship between the gold mineralisation and the "intrusive andesites" as previously envisaged by Bowman (1977a). Most vein deposits lie along, or near, contacts between volcanic and non-volcanic rocks, suggesting that competency contrast played a major role in producing structures. This, in turn, has focused fluid flow into dilatant sites with gold mineralisation being introduced late in the deformation history — with the timing of mineralisation at the London-Victoria mine probably being post-Silurian (Clarke, 1990b). Clarke (1990b) also proposed that gold was sourced from mantle-derived Late Ordovician shoshonitic volcanic rocks. Although the London-Victoria mineralisation is hosted by rocks of Late Ordovician age, the lead isotope signature of the deposit clearly shows that the lead contained within the deposit came from both the Ordovician mantle derived volcanic rocks and younger crustal sedimentary rocks. Based on the lead isotope signature, Carr *et al.* (1995) suggested that the mineralising event occurred around 400 Ma (Early Devonian). This is supported by field evidence from the Calarie mine area where the mineralised structure truncates the Siluro-Devonian Calarie Sandstone (L. Sherwin, pers. comm., 1999). However, post-mineralisation reactivation of the structure cannot be ruled out. Newcrest Mining Ltd (1993) interpreted the mineralisation at London-Victoria as post-dating the major reverse movement on the London-Victoria Fault and it may have formed during a later sinistral strike-slip movement.

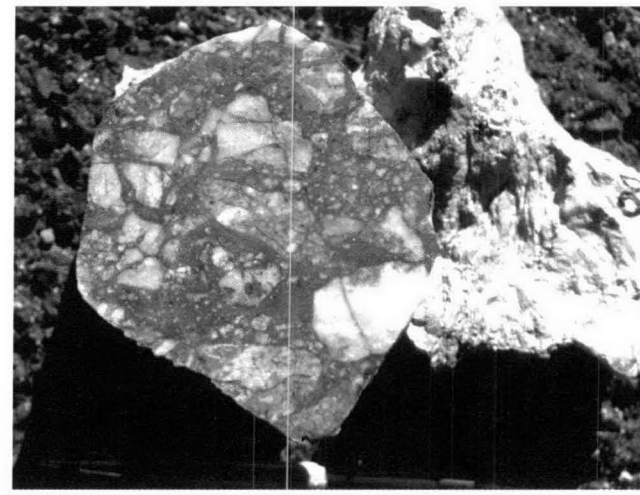


*Figure 18.5. Brecciated quartz vein with disseminated, fine to coarse-grained pyrite. Calarie mine, Forbes (G. Burton, photograph)*

*Lake Cowal (gold)*

The Ordovician Lake Cowal Volcanic Complex hosts four structurally controlled gold occurrences. The largest of these is the Endeavour 42 deposit (also known as the Cowal gold project), with a total resource of 66.4 Mt grading 1.5 g/t Au (North Limited 1999 Concise Annual Report, 1999, p.42). The regional and local geology of Endeavour 42 has been described by Miles (1993), McInnes *et al.* (1998) and Miles & Brooker (1998). The complex consists of calc-alkaline to shoshonitic volcanic rocks and related sedimentary rocks deposited in a deep water environment (Miles & Brooker, 1998) and is unconformably overlain, in parts, by the Siluro-Devonian Manna Conglomerate (Ootha Group). The Lake Cowal Volcanic Complex is oval in plan, approximately 40 km long and 15 km wide, and has been defined by its distinct regional magnetic signature (McInnes *et al.*, 1998). The complex was intruded by diorites and granodiorites of

Middle to early Late Ordovician age. Low-grade porphyry copper mineralisation occurs in a number of places within granodiorite intrusions and this mineralisation is described separately. The four structurally controlled gold occurrences (Endeavour 40, Endeavour 41, Endeavour 42, and Endeavour 46) are situated in embayments within an elongate dioritic to gabbroic body, located in a strongly deformed belt, on the western margin of the Lake Cowal Volcanic Complex (Miles & Brooker, 1998). The area is covered by a thick sequence of lake sediments of Tertiary to Recent age.

The Endeavour 42 deposit is hosted by three significant volcanic units and an intrusive diorite. The volcanic units are the 'Great Flood unit', a vitric volcaniclastic debris unit, interpreted by McInnes *et al.* (1998) as a mass-flow deposit; the 'Golden Lava unit', a porphyritic trachyandesite, interbedded with a hyaloclastite containing fragments ranging from sand size to larger than 1 m, interpreted to be a submarine lava flow with associated quench fragmentation (Brooker, Miles & Thornett, unpublished data, 1995 — quoted in McInnes *et al.*, 1998, Miles & Brooker, 1998); and the 'Cowal conglomerate unit', a massive to graded, clast-supported, polymict volcanic debris unit interbedded with laminated siltstone and mudstone. This last unit is interpreted to be a mass-flow debris unit (Miles & Brooker, 1998). The 'Muddy Lake diorite' intruded the lower part of the volcanic sequence and has been dated by Perkins (unpublished data, 1993 — quoted in McInnes *et al.*, 1998) at 456 ± 5 Ma (early Late Ordovician) using the K–Ar method. This date is interpreted to be the minimum age of the intrusion. Later intrusions include a series of mafic to intermediate dykes, which Miles (1993) suggested were emplaced into active fault zones, as the dyke margins show signs of movement and are often strongly altered.

Within the primary zone at Endeavour 42, gold mineralisation occurs in narrow dilatant veins and within fault zones consisting of quartz–carbonate–sulphide and carbonate–sulphide ± quartz (Miles & Brooker, 1998). Less commonly, gold occurs with pyrite stringers and disseminations, shear-hosted chlorite–carbonate veins and shear-hosted quartz–carbonate–sulphide veins. The sulphides consist of pyrite, sphalerite, chalcopyrite, galena, and pyrrhotite, with small amounts of visible gold. McInnes *et al.* (1998) noted that the highest gold grades occur with sphalerite and to a lesser extent with adularia.

The auriferous quartz–carbonate–sulphide and carbonate–quartz–sulphide veins occur throughout the deposit and have a consistent strike of 305° and dip of 35° to the southwest (Miles & Brooker, 1998). The veins are typically parallel-sided, with some of the larger veins containing comb textures, indicative of open-space fills. Additionally, some veins within the diorite display a crude banding. Miles & Brooker (1998) also noted that the density of veining is generally highest in the 'Golden Lava unit', although the mineralised veins within the 'Muddy Lake diorite' tend to be thicker.

Four alteration styles have been identified at the deposit by Miles & Brooker (1998) and McInnes *et al.* (1998): a pervasive chlorite–carbonate–haematite ± epidote assemblage developed throughout the Lake Cowal Volcanic Complex; a silica–sericite ± carbonate assemblage up to several metres thick, associated with faults; a patchy adularia–silica assemblage almost entirely restricted to the 'Golden Lava unit'; and a chlorite–carbonate–pyrite assemblage that cross-cuts the first two assemblages and is spatially associated with the adularia–silica alteration or with adularisation of albite phenocrysts. This last assemblage is best-developed within the 'Golden Lava unit', especially along its base, and within the 'Cowal conglomerate'. Miles & Brooker (1998) noted that all the alteration assemblages, with the exception of the chlorite–carbonate–pyrite assemblage, appear to pre-date the mineralised veins. Some of the chlorite–carbonate–pyrite alteration is associated with, and cross-cuts, auriferous quartz–sulphide dilatant veins, although the alteration is more commonly cut by those veins (Miles & Brooker, 1998).

McInnes *et al.* (1998) described the gold-bearing veins at Endeavour 42 as generally being associated with one of two alteration styles: ankerite–quartz–pyrite–sphalerite–chalcopyrite–galena veins, which are associated with ankerite–quartz–sericite–carbonate alteration; and quartz, potassium feldspar, pyrite, sphalerite, and chalcopyrite veins associated with the chlorite–carbonate–pyrite alteration.

McInnes *et al.* (1998) and Miles & Brooker (1998) proposed that the Endeavour 42 deposit is structurally controlled, with the mineralised dilational vein arrays being, predominantly, adjacent to north-trending faults. They suggested that local fault geometry and rheological contrast have been the major controls to mineralisation, with the 'Golden Lava unit' being the preferred host. Archibald (unpublished data, 1991 — quoted in McInnes *et al.*, 1998) suggested that these mineralised structures may be modelled by a Riedel shear array, which Brooker, Miles & Thornett (unpublished data, 1995 — quoted in McInnes *et al.*, 1998) suggested formed as an oblique sinistral shear array, generated in response to a northwest–southeast compressive event.

C. Perkins (unpublished data, 1993 — quoted in McInnes *et al.*, 1998) dated the intrusions at Endeavour 42 at 456 ± 5 Ma (K–Ar method) and at Endeavour 39 at 465.7 ± 1 Ma (Ar–Ar method). In addition, Perkins *et al.* (1995) dated sericite from the sericite–silica ± carbonate alteration at Endeavour 42 mineralisation at 439.0 ± 4.5 Ma (Ar–Ar method). Based on this dating, McInnes *et al.* (1998) and Miles & Brooker (1998) suggested that there is a significant 15 Ma gap between the timing of the granodiorite–diorite intrusive event and the gold mineralising event. However, the alteration assemblage that was dated has been recognised by those authors as pre-dating the gold mineralisation. This leaves open the possibility that the gold mineralisation at Endeavour 42 may be significantly younger than previously indicated.

McInnes *et al.* (1998) and Miles & Brooker (1998) noted that the Endeavour 42 mineralisation has geometrical relationships and mineralisation styles typical of shear-hosted gold deposits, with the distribution of gold controlled by dilatational zones formed during the evolution of a fault system. Those workers also noted that the Endeavour 42 mineralisation has features that are typical of low sulphidation or adularia–sericite epithermal systems and cited the vein styles, mineralogy, gangue associations, structural relationships, and alteration assemblages in support for that model. The greater than 15 Ma gap between the granodiorite–diorite intrusive event and the age of the mineralisation makes it unlikely that the mineralisation is related to a porphyry copper–gold/epithermal event, rather, it supports the concept that the deposit is typical of shear-hosted mineralisation. The alteration assemblages and preliminary studies of the fluid chemistry suggest that the mineralising fluids were of low salinity and low temperature (<150°C) (Miles & Brooker, 1998). These features are more typical of metamorphic fluids, which again supports the shear-hosted model. The lead isotope data for the Endeavour 42 mineralisation (Carr *et al.,* 1995), which indicates an Ordovician mantle signature, is consistent with the interpretation that the metallic elements were derived from the Ordovician host rocks.

*West Wyalong*

Structurally controlled gold mineralisation was discovered at West Wyalong (Figure 18.6) in 1893. Mining ceased in 1920 with a reported total production of 13.86 tonnes of gold from 340 000 tonnes of ore at an average grade of 41 g/t Au (Timms, 1993). The mineralisation has been described by a number of workers including Watt (1899), Degeling (1975), and Bowman (1977b). It is contained within about 25 mineralised zones, each consisting of narrow (generally <0.5 m), auriferous quartz veins within chloritised faults or shears (Figure 18.7). The mineralised structures strike north-northeast, and dip steeply to the east, with the mineralisation in shoots that typically dip steeply east and pitch south. An exception to this is the Pioneer zone, which strikes approximately east–west. Watt (1899) described the veins as lenticular and noted that "spur" veins are common, while Timms (1993) reported that the veins exhibit pinch and swell structures. The majority of the mineralised veins are hosted by the Early Silurian, S-type, locally foliated, Ungarie Granite. Suppel *et al.* (1986) noted that some of the mineralisation is hosted by Early Silurian Bland Diorite, which they interpreted to be I- type (now confirmed — see these Notes). Some veins, such as at Pine Hill, occur within the Ordovician Narragudgil Volcanics. The True Blue workings are the deepest in the field, being over 400 m deep, and many other mines were worked to over 200 m depth (Aliano & Schwebel, 1981).

The veins in the West Wyalong field consist of quartz with colloidal silica, minor calcite, and gypsum (Watt, 1899). G. McLean (pers. comm., 1999) has described the veins as typically massive or vuggy, with rare breccia textures. The textures within the veins include comb textures and chlorite laminations, while the breccias are described as matrix-poor crackle (breccias) to matrix-rich with angular or rounded milled clasts. Slickenlines, defined by chlorite, are rare. G. McLean (pers. comm., 1999) suggested that these textures reflect silica deposition within a dilational setting under relatively static or steady state kinematic conditions.

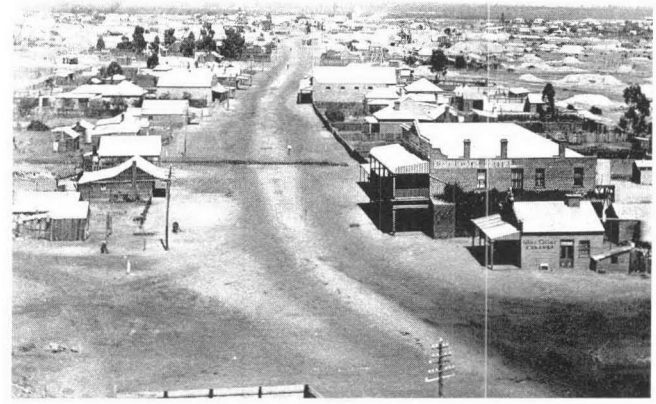


*Figure 18.6. Main street of West Wyalong, looking west from the top of the chimney stack of the True Blue mine,* ca *1906. The view is indicative of the numerous mine workings developed within the area. (DMR collection, Forbes 0173).*

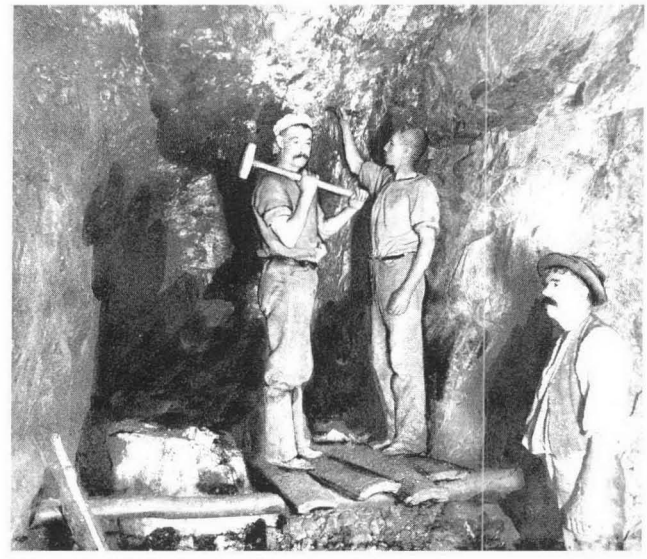


*Figure 18.7. True Blue mine, West Wyalong. An exposure of the mineralised quartz vein is visible in the roof of the drive. (DMR collection, Forbes 0026).*

In addition to gold, the veins at West Wyalong contain pyrite, arsenopyrite, galena, sphalerite, and chalcopyrite, while the secondary minerals include cerussite, pyrolusite, copper carbonates, and native copper. Benjamin & Garman (1984) observed that antimony, tellurium and palladium were also associated with the mineralisation. The silver mineral, iodyrite, has also been identified from the Lucknow mine, which is part of the Pine Hill reef (G. McLean, pers. comm., 1999). G. McLean (pers. comm., 1999) suggested that the mineralisation consists of a Au–Ag–Pb–As–Bi–Te metal assemblage. Gold occurs as grains both within the wallrock and the veins, and as inclusions

and as filling in micro-fractures within pyrite (SEM data, G. McLean, pers. comm., 1999). Microprobe analyses of individual gold grains indicate that gold fineness values average 860 GFN (35 analyses, range 760 to 950, G. McLean, pers. comm., 1999). Schwebel (1982) reported that white quartz containing very little visible mineralisation was found to contain significant gold. However, Timms (1993) noted that old reports indicate a correlation between the amount of pyrite present and the gold grade.

G. McLean (pers. comm., 1999) proposed that the West Wyalong mineralisation belongs to the plutonic class of gold deposits (Morrison, 1988). However, the present authors consider the mineralisation to be more typical of shear-hosted occurrences. Degeling (1975) noted that the highest gold grades generally occur at the intersection between the main mineralised structure and subsidiary structures. G. McLean (pers. comm., 1999) observed that alteration is restricted to major shears and is of very limited extent. Within the Ungarie Granite, the alteration consists of a sericite–chlorite–pyrite assemblage and, within the Bland Diorite, the alteration consists of a sericite–chlorite–pyrite–epidote–actinolite assemblage. Benjamin & Garman (1984) also recognised silicification and minor carbonate flooding in the Ungarie Granite. According to G. McLean (pers. comm., 1999) the alteration mineralogy indicates that the mineralisation formed at the epithermal–mesothermal temperature boundary, and that the fluids were neutral to slightly acidic.

The mineralisation at West Wyalong represents a shear-hosted style that has preferentially developed within the competent Ungarie Granite. Timms (1993) suggested that the mineralised structures were closely related to faults associated with the Gilmore Fault Zone. The Gilmore Fault Zone, which separates the Early Silurian Ungarie Granite from the Ordovician Narragudgil Volcanics, has had a long history of movement that commenced in the Late Ordovician to Early Silurian (Benambran Orogeny) and has undergone significant later reactivation. R. Glen (pers. comm., 1999) suggested that the mineralised structures are possibly Late Devonian or Early Carboniferous in age (Kanimblan Orogeny). This is supported by Carr *et al.* (1995) who proposed a Late Devonian (LFB model 365 Ma) age for the mineralisation and by Benjamin & Garman (1984), who observed that the mineralised structures postdate the main period of deformation that produced the strong foliation in the Ungarie Granite.

The lead isotope data for the West Wyalong mineralisation indicate a mixing of lead derived from both mantle and crustal sources and are similar to those obtained from the Yeoval copper–molybdenum–gold–silver district further east (Carr *et al.*, 1995). Based on this, and similar host rock associations, Carr *et al.* (1995) suggested that the host rocks to the West Wyalong mineralisation may be related to the Early Devonian, Boggy Plain Supersuite, a distinctive group of I-type igneous rocks (Wyborn *et al.*, 1987). This is unlikely, as recent work (these Notes) has established the age of the Ungarie Granite and the Bland Diorite as Early Silurian.

*Grenfell*

The Grenfell goldfield was discovered in 1866 and has a recorded production of around 10 tonnes of gold, with approximately half coming from vein-hosted occurrences (Bowman, 1977a, Diemar, 1985) (Figure 18.8). The major mine in the area was the Young O'Briens reef. The majority of the mineralised veins are located within a quartz–feldspar porphyry, which is part of the Early Silurian Glenisla Volcanics, to the east of the town, though some vein-type mineralisation also occurs in the slates and phyllites of the Ordovician Kirribilli Formation. The porphyry rests upon the Kirribilli Formation and has a faulted contact with the Middle Devonian Schneiders Granite on its western side. The auriferous veins consist of quartz and minor calcite with minor arsenopyrite, pyrite, chalcopyrite, galena, and gold (Bowman, 1977a,b).

*Figure 18.8. Workings of the Grenfell goldfield, adjacent to the Grenfell township (no date). (DMR collection, Forbes 0001).*

Within the porphyry (Glenisla Volcanics), the veins strike northeast to east and dip between 45° and 80° to the northwest. Most veins are less than 1 m wide, though some are up to 3 m, and are generally lenticular in plan (Bowman, 1977a,b). Post-mineralisation, northwest trending faults cut the mineralised lodes. Bowman (1977a) and Diemar (1985) noted that the most productive veins are within the most intensely faulted porphyry. Bowman (1977a) observed that the veins replace host rock along zones of fracturing, noting that veins commonly grade into altered and silicified porphyry at depth. Often only one wall of the vein is well-defined while the other grades into the host rock. The alteration is poorly documented. However, it seems to consist of silicification with variable amounts of calcite, pyrite, and possibly chlorite (Diemar, 1985).

Most of the veins in the Grenfell area within the Kirribilli Formation are narrow, short, lenticular, and carry only minor gold. They strike northeast–southwest and are located near small porphyry bodies (Bowman, 1977a; Diemar, 1985).

The origin of the mineralisation at Grenfell is not clear. Bowman (1977a) considered that the porphyry was

intrusive and that the mineralisation was associated with its emplacement. However, O.L. Raymond (pers. comm., 1999) suggested that the porphyry is not intrusive — rather, it is a partially reworked volcanic unit. Alternatively, the mineralisation may have formed within dilational zones formed within, and adjacent to, porphyry bodies (due to a competency contrast) as part of a later deformation. The observation by Bowman (1977a) that the most productive veins are associated with the most intense zones of faulting within the porphyry supports the latter view. Vein development may be related to the fault (north-northeast trend) separating the Middle Devonian Schneiders Granite from the Early Silurian Glenisla Volcanics (porphyry) and the Middle Devonian Grenfell Granite. This would suggest that the veins are Middle Devonian or younger. No mineralisation has been identified within the Schneiders Granite, and only one occurrence (Star Gully) is within the Grenfell Granite. Carr *et al.* (1995) noted that the lead isotope signature for the Grenfell mineralisation falls within the field of Devonian granite-related deposits.

The Warraderry area, 14 km northeast of Grenfell, also contains mineralised quartz veins associated with quartz–feldspar porphyry dykes (Mulholland, 1935), which intruded the Kirribilli Formation. The dykes and the veins strike north-northwest, parallel to the regional cleavage. High arsenic levels are present in the veins (G. McLean, pers. comm., 1999). The workings are within both the Kirribilli Formation and the porphyry bodies. G. McLean (pers. comm., 1999) considered that the mineralisation was concentrated along the contact between porphyry and country rock.

*Pinnacles–Ironbarks area*

About 30 km south of Forbes is the Pinnacles–Ironbarks area. The area extends for about 15 km in a north-northeast direction, and may represent the southerly extension of the Parkes–Forbes gold belt. The gold mineralisation occurs within crenulated and kinked phyllite of the Ordovician Kirribilli Formation. Also present in the area are small felsic intrusions. The mineralisation consists mainly of pyrite and native gold in quartz veins, with minor carbonates (including siderite). Wallrock alteration is minor, if present, and consists of silicification, sericitisation and chloritisation. Rampe (1992b) also noted the presence of a sericite–pyrite–silica (–quartz) assemblage.

The Pinnacles–Ironbarks mineralised zones strike north-northeast and dip vertically to subvertically (Bowman, 1977a). The zone consists of quartz veining and stockwork zones between 2 m and 45 m wide and between 20 m and 450 m long (G. Hemming, pers. comm., 1999), with individual quartz veins up to 1m wide. The veins are both parallel and discordant (cross-cutting) to the dominant foliation, which trends 020° and has a steep easterly dip.

The origin of the mineralisation in the Pinnacles–Ironbarks area is not clear. Bowman (1977a) considered three possibilities: an association with "intrusive" andesites (as proposed for the Parkes–Forbes area); the mineralisation was epigenetic and formed from metamorphic fluids; or, as his preferred model, that the veins are associated with the late kinematic Caragabal Granite, which is located 3 km to the south. G. Hemming (pers. comm., 1999) favoured the epigenetic model. O.L. Raymond (pers. comm., 1999) suggested that the cleavage and shearing in the host rocks are most probably Kanimblan (Carboniferous) in age. He based this on the observation that the Parkes Fault Zone and its associated cleavage-affected rocks are at least as young as the Siluro-Devonian Derriwong Group at Forbes and in the Marsden 1:100 000 map sheet area. The auriferous quartz veins cross-cut the cleavage associated with the fault zone, suggesting that the mineralisation is at most Carboniferous in age and is substantially younger than the Early Devonian Caragabal Granite.

## Ordovician porphyry copper–gold and related mineralisation

Significant porphyry copper–gold mineralisation is associated with Ordovician magmatism in central New South Wales. Major deposits include the Cadia and Northparkes mines, which lie outside of the Forbes 1:250 000 map sheet area. The Ordovician volcanic rocks are prospective because they were formed from mantle-derived magmas, which remained undersaturated with respect to sulphur until late in the magmatic cycle. This resulted in a concentration of copper and gold in late-stage magmatic fluids (Wallace & Wyborn, 1997). Figure 18.9 shows the distribution of Ordovician units and intrusive-related copper–gold mineralisation within the Forbes 1:250 000 map sheet area. The volcanic belt hosting the Northparkes mine, north of the Forbes 1:250 000 map sheet area, also contains significant occurrences in the Forbes 1:250 000 map sheet area. Two major volcanic centres have been identified: the Northparkes Volcanic Group, which hosts the Northparkes mineralisation and the Lake Cowal Volcanic Complex, which hosts the Endeavour 39, Endeavour 35, and Marsden porphyry copper–gold occurrences near Lake Cowal and the structurally controlled Lake Cowal gold deposit (Endeavour 42, described above).

*Goonumbla*

The Goonumbla porphyry copper mineralisation and its geological setting have been described by a number of workers, including Jones (1985), Heithersay (1986), Heithersay *et al.* (1990), Muller *et al.* (1994), Heithersay & Walshe (1995), and Hooper *et al.* (1996). The Late Ordovician Northparkes Volcanic Group, which hosts porphyry copper–gold and skarn-type mineralisation, is located within a circular aeromagnetic and gravity feature some 22 km in diameter, which Jones (1985) had interpreted as a collapsed caldera structure.

The Northparkes Volcanic Group is bisected by the northern boundary of the Forbes 1:250 000 map sheet area, with the Northparkes copper–gold mine (Endeavour 22, Endeavour 26 North, Endeavour 27, and Endeavour 48 deposits) located in the area of the Narromine 1:250 000 sheet and the Endeavour 44, Endeavour 6 (Gunningbland

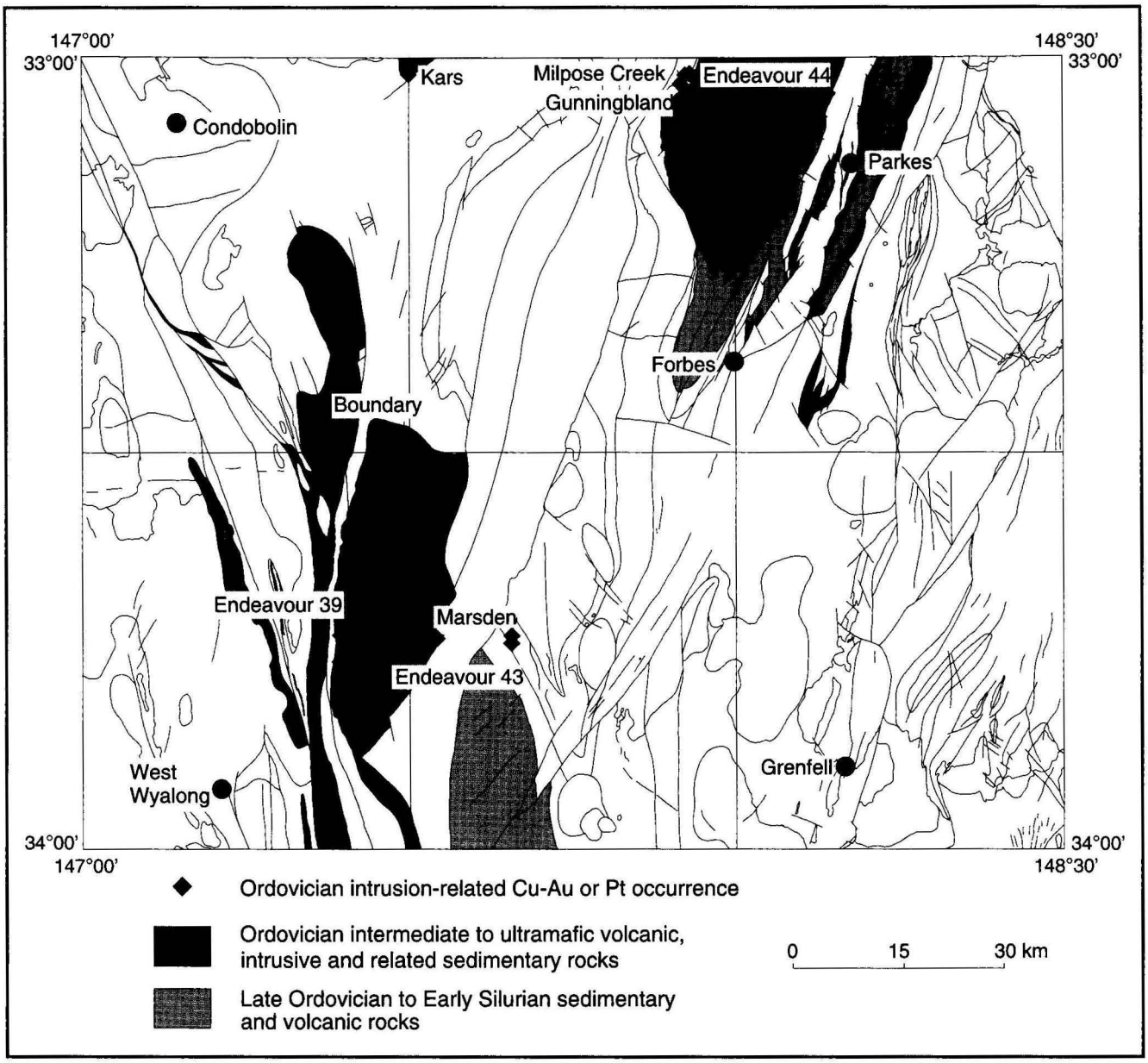



*Figure 18.9. Distribution of Ordovician units and intrusion related copper–gold mineralisation in the Forbes 1:250 000 map sheet area.*

copper mine), and Endeavour 7 (Milpose Creek prospect) occurrences located in the Forbes 1:250 000 map sheet area.

The porphyry-type mineralisation in the Northparkes Volcanic Group consists of sub-vertical pipe-like intrusions of quartz monzonite porphyry. In general, the mineralisation occurs as disseminations and within fractures and veins within both the intrusion and the surrounding volcanic rocks. The strongest mineralisation is associated with quartz stockwork veining within a central, potassic alteration zone (Heithersay *et al.*, 1990). Pervasive sericitic alteration and widespread propylitic alteration have been identified. A mineral zonation has been identified with a poorly defined outer pyritic zone surrounding a chalcopyrite-dominant zone that, in turn, surrounds an inner, higher grade, central bornite and chalcocite-dominated zone (Heithersay *et al.*, 1990).

The Endeavour 26 North deposit has been described by Heithersay and co-workers (Heithersay, 1986; Heithersay *et al.*, 1990; Heithersay & Walshe, 1995) as consisting of a bornite-dominated quartz-stockwork pipe, with a vertical extent of over 900 m, centred on two adjacent porphyry intrusions. The sulphide minerals include pyrite, bornite, chalcopyrite, and digenite. Heithersay & Walshe (1995) have identified eleven separate stages of alteration, paragenesis and zonation.

In the Forbes 1:250 000 map sheet area, skarn-related copper and gold–lead–zinc mineralisation has been identified adjacent to, but outside of, the southern margin of the Northparkes Volcanic Group at Endeavour 44, Gunningbland copper mine (Endeavour 6) and the Milpose Creek prospect (Endeavour 7). The Endeavour 44 gold–lead–zinc mineralisation is 13 km north of Gunningbland and could contain 2 Mt of mineralisation (as has been reported in the Register of Australian Mining, 1993/1994).

The high-grade mineralisation consists of semi-massive pyrite and marcasite with interstitial galena and sphalerite. Gold is associated with hessite, which has formed in association with galena. The mineralisation is hosted by Late Ordovician limestones and reworked volcanic sedimentary units of the Northparkes Volcanic Group, which are overlain by Late Devonian sedimentary rocks of the Hervey Group.

The mineralisation at Endeavour 44 has been described by Jones (1991) who identified a single prograde–retrograde skarn assemblage associated with the intrusion of oxidised, highly fractionated microsyenite dykes and sills. This was followed by faulting and late-stage epithermal gold and telluride deposition. The initial stage identified by Jones (1991) was the development of contact metamorphism that resulted in recrystallisation of the limestone to marble and development of a calc-silicate hornfels. Subsequently, a massive garnet (grossular and andradite)–wollastonite ± vesuvianite prograde assemblage formed with minor apatite, sphene, and hematite. The texture of the prograde skarn varies from layered to massive and mottled. The initial retrograde assemblage consists of epidote, chlorite, calcite, quartz, rutile, sphene, prehnite, magnetite, and hematite. Pyrite, sphalerite, chalcopyrite, bornite, chalcocite, and galena were deposited later, while gold, hessite, altaite, petzite, tennantite, and sericite formed late in the retrograde stage. Gold-bearing vein and breccia mineralisation is also present, with associated sericitic alteration and silicification. Veins of quartz, calcite, and K-feldspar commonly cross-cut earlier assemblages, and are often mineralised. The hanging wall volcanic rocks are frequently altered to epidote and, in places, overprinted by garnet skarn.

Jones (1991) found that the sulphur isotope values for the Endeavour 44 mineralisation are consistent with a magmatic source (approximately -4.5 $\delta^{34}S$) although there was some evidence of mixing with a country rock source that had lighter $\delta^{34}S$ values. Preliminary fluid inclusion studies by Jones (1991) suggested that the retrograde assemblage formed at temperatures between 250°C and 300°C. Jones (1991) concluded that the Endeavour 44 mineralisation was formed in a proximal, oxidised system dominated by magmatic fluids, with the gold and base metals being transported by chloride complexes.

At the Gunningbland copper mine (Endeavour 6) and the Milpose Creek prospect (Endeavour 7) the mineralisation is hosted by a limestone unit within a sequence of lithic and crystal tuffs, agglomerate, and fine- to medium-grained sedimentary rocks. Most of the mineralisation is stratabound and confined to the calc-silicate skarn unit, which is up to 30 m thick. This skarn unit consists of variable amounts of grossular garnet, chlorite, hematite, epidote, vesuvianite, calcite, wollastonite, quartz, and magnetite. This is surrounded by a magnetite-rich volcanic sandstone that forms the foot wall and hanging wall to the calc-silicate unit. Mineralisation occurs in discontinuous lenses of variable size (data provided by North Limited, 1999) and comprises pyrite, chalcopyrite, bornite, sphalerite, galena, molybdenite, and arsenopyrite (Bowman, 1977a). Narrow, transgressive, calcite stringers carrying minor pyrite, chalcopyrite, sphalerite, and hematite, as well as disseminated pyrite, occur within the adjacent wallrocks (data provided by North Limited, 1999). Some skarn development (garnet, epidote, vesuvianite, and chlorite) occurs in the rocks forming the hanging wall to the limestone (data provided by North Limited, 1999).

Alteration at the three prospects (Endeavour 44, Gunningbland copper mine, and Milpose Creek prospect) consists of incipient to massively pervasive epidote. The incipient epidote alteration is associated with intense magnetite development that may have formed earlier in the paragenetic sequence. Massive epidote coexists with pyrite with or without hematite, which is a more oxidised assemblage than the epidote–magnetite assemblage. A sericitic (sericite and quartz) assemblage is also present at Endeavour 44. Mineralisation in the vein-breccia zones is always associated with magnetite-destructive quartz–sericite–sulphide alteration (data provided by North Limited, 1999).

At Endeavour 6 and Endeavour 7, the skarns are considered to have formed through contact metamorphism of limestone by a monzonite–microsyenite porphyry intrusion (data provided by North Limited, 1999) thought to have been emplaced at about the Late Ordovician to Early Silurian.

Perkins *et al.* (1995) dated alteration sericite from the retrograde skarn assemblage at Endeavour 44 as 440.0 ±1.1 Ma. This is similar to the age of the Goonumbla porphyry copper–gold system (439.2 ± 1.2 Ma; Perkins *et al.*, 1990). Work by Carr *et al.* (1995) on the Endeavour 7 mineralisation has confirmed that the metals were sourced from the mantle-derived Ordovician shoshonitic volcanic rocks, and that data also support a pre-440 Ma age for the mineralising system. Percival & Dargan (1999) identified Darriwilian conodonts in limestone from the easternmost pit at Endeavour 6, confirming the age of the limestone as Middle Ordovician. Approximately 10 m from that location, limestone containing Late Silurian corals crops out. L. Sherwin (pers. comm., 1999) interpreted this latter unit to be part of the Siluro-Devonian Byong Volcanics and in thin section the rock contains no evidence of contact metamorphism or skarn-related minerals (L. Barron, pers. comm., 1999). It seems most probable that the latter limestone body is a younger unit juxtaposed by faulting against the older, mineralised limestone.

*Lake Cowal (porphyry bodies)*

In addition to the structurally controlled gold mineralisation at Lake Cowal, low-grade porphyry copper–gold mineralisation has been identified at the Endeavour 39 and Endeavour 35 prospects, which are located to the south and southwest of the lake. The mineralisation is hosted by the Ordovician Lake Cowal Volcanic Complex. The complex has been intruded by diorites and granodiorites of early to middle Late Ordovician age, and much is now covered by a thick sequence of Cainozoic lake sediments.

The complex consists of calc-alkaline to shoshonitic volcanic rocks and related sedimentary rocks that were deposited in a deepwater environment (Miles & Brooker, 1998). The complex is oval in plan and has a distinct magnetic high signature (McInnes *et al.*, 1998). The following description of the Lake Cowal porphyry bodies is from information provided by North Limited, except where otherwise noted.

Initial exploration by Geopeko, in the Lake Cowal area, intersected low-grade copper mineralisation (0.2% to 0.35% Cu) at the Endeavour 39 prospect, 5 km south of the Endeavour 42 deposit (Cowal project). This mineralisation is hosted by granodiorite with a marginal diorite phase (Perkins *et al.*, 1995). The mineralisation has been described as consisting of chalcopyrite and/or magnetite-bearing quartz veins, sulphide–albite ± magnetite stringers, and minor disseminated chalcopyrite and pyrite in altered granodiorite. In addition, structurally controlled zones of sericite–pyrite–chalcopyrite ± epidote are present. A number of differing alteration styles has been described, including: an early sericite–pyrite (sericitic) assemblage, which correlates with the porphyritic phase of the granodiorite; a potassic alteration consisting of pink K-feldspar that surrounds the chalcopyrite-bearing quartz veins; and a moderate to intense, structurally controlled, late sericitic alteration that surrounds shears filled with quartz–carbonate–chlorite–sulphide ± epidote and fault-related veins. This last alteration assemblage is controlled by structures with northerly and northwest trends and overprints and destroys earlier assemblages.

C. Perkins (unpublished data, 1993 — quoted in Miles & Brooker, 1998) dated the granodiorite at Endeavour 39, by the Ar–Ar method, at 465.7 ± 1 Ma (Middle Ordovician). In addition, sericite from that occurrence has been dated at 439.6 ± 4.5 Ma (Ar–Ar method — Perkins *et al.*, 1995).

Miles & Brooker (1998) interpreted the Endeavour 39 mineralisation as forming part of a large low-grade porphyry-type Cu–Au system. The mineralisation was formed from high salinity fluids (E. Bastrakov, pers. comm., 1995 — quoted in Miles & Brooker, 1998) during the Middle Ordovician.

The Endeavour 35 copper–gold mineralisation is located immediately to the south of Lake Cowal. The host rocks consist of an interbedded sequence of andesitic, dacitic, and trachytic volcanic units that form part of the Ordovician Lake Cowal Volcanic Complex. The host rocks have undergone varying degrees of pervasive argillic alteration, with some silicification and subsequent shearing. The mineralisation consists of disseminated pyrite and chalcocite, the latter being interpreted as secondary. Alteration minerals comprise montmorillonite, cryptocrystalline and microcrystalline silica, sericite, kaolinite, and alunite, with minor pyrophyllite and illite, and up to 10% disseminated pyrite. The mineralisation at Endeavour 35 has been interpreted to form part of an advanced argillic alteration zone peripheral to the intrusive complex (Miles & Brooker, 1998).

*Marsden*

The Marsden copper–gold prospect is located 15 km southeast of the Endeavour 42 deposit and 36 km northeast of West Wyalong. The mineralised zone is covered by 100 m to 120 m of Quaternary cover. The following description is based on information supplied by F. MacCorquodale (pers. comm., 1998), Newcrest Mining, Limited (pers. comm., 1999), and observations made on drill core.

The host rocks at Marsden consist of quartz diorite, diorite, and monzodiorite, with lesser andesite porphyry, granodiorite porphyry, and monzonite dykes and volcanic rocks, that form part of the Ordovician Lake Cowal Volcanic Complex. These units, and the mineralisation, are faulted along their eastern edge, and at depth, by a shallow, west-dipping thrust. Movement on the thrust has resulted in the Ordovician units being thrust over rocks of the Late Devonian Hervey Group. To the west, the intrusive complex is bounded by mafic volcanic rocks.

Mineralisation at Marsden is hosted by quartz diorites and consists of a sheeted vein and stockwork system of quartz–calcite–chalcopyrite veins and disseminated chalcopyrite in the wall rock. Rare bornite is also present. A pervasive biotite (potassic) alteration affects all rock units within the intrusive complex. Alteration consists of a biotite, albite, actinolite, quartz, magnetite, hematite, chalcopyrite, and bornite assemblage. Veins associated with the potassic alteration are dominated by quartz, calcite, and chalcopyrite, with accessory orthoclase, biotite, actinolite, magnetite, apatite, bornite, pyrite, molybdenite, hematite, epidote, and rare fluorite. These veins vary in thickness from less than 1 mm to 10 mm. A weak to moderately developed propylitic alteration occurs within the potassic zone, while an overprinting low-intensity retrograde propylitic alteration is also present. The propylitic assemblage consists of chlorite, calcite, leucoxene, prehnite, and epidote. The intensity of the propylitic alteration increases towards the western edges of the diorite intrusive complex and into the adjacent wallrock. The potassic and propylitic assemblages are overprinted by a structurally controlled sericitic and argillic alteration with late stage quartz–pyrite–chalcopyrite–chlorite veins and quartz–calcite–pyrite–sphalerite–sericite–chalcopyrite veins. All the alteration assemblages are cut by calcite–laumontite–fluorite veins.

## Post-Ordovician skarns and intrusion-related mineralisation

There are a number of skarns and intrusion-related occurrences related to post-Ordovician magmatism in or near the Forbes 1:250 000 map sheet area (Figure 18.10). These include the Bumberry skarn occurrences, 18 km west-southwest of Cowra that contains several minor skarn sulphide, copper–gold, and iron occurrences associated with the Silurian Young Granodiorite. The majority of these occurrences are located in the Forbes map sheet area, however those in the Bathurst 1:250 000 map sheet area include the Broula iron mine and the Robinson

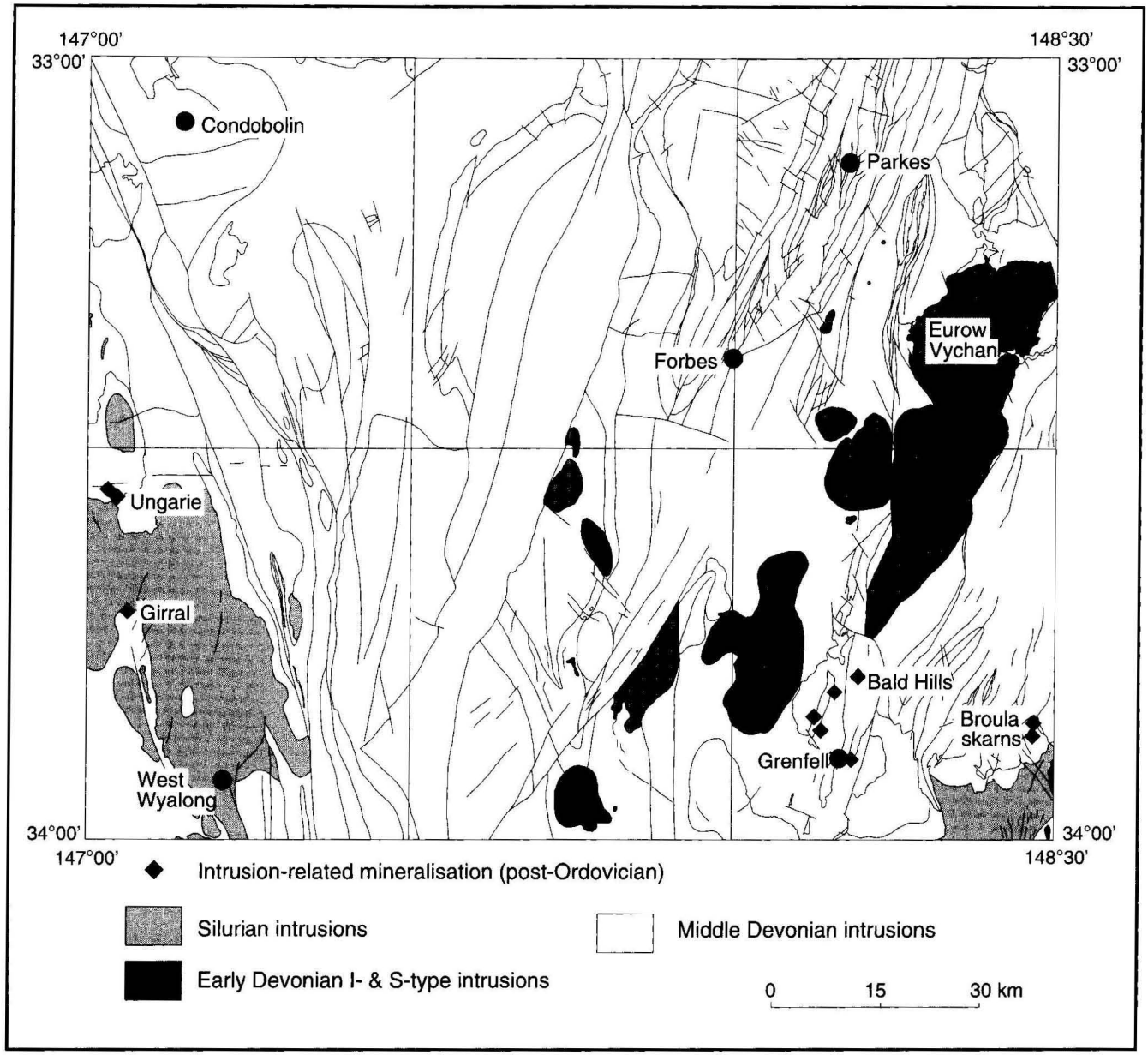



*Figure 18.10. Distribution of post Ordovician intrusive units and related mineralisation.*

deposit. The skarns in the Bumberry area are poorly described with the exception of the Broula iron mine, which produced approximately 125 000 t of high-grade iron ore (Bowman, 1975). Dickson (1971) described the mineralisation at the Broula iron mine as consisting of magnetite (80% to 90%) with abundant pyrite (5%), traces of chalcopyrite, and garnet, epidote, quartz, and calcite present as gangue minerals. Rangott & Kennedy (1989) described the skarns at the Broula iron mine as including calc-silicate skarns, magnetite-rich skarns, garnet–diopside-rich carbonate rocks, and a clinopyroxene-bearing marble and noted that a range of prograde and retrograde minerals including garnet, diopside, amphibole, epidote, chlorite, magnetite, pyrite, quartz, and carbonates (including calcite) were present. The mineralisation is hosted by hornfels and metamorphosed limestones within the Early Silurian Illunie Volcanics, which has been intruded by hornblende–biotite granodiorite, hornblende–pyroxene-rich granodiorite, and microgranites of the Young Granodiorite.

## Epithermal mineralisation

Epithermal style mineralisation has been identified in the Bumbaldry area and at Condobolin. In addition, a number of poorly mineralised epithermal related alteration systems of probable Devonian age are present within the Forbes 1:250 000 map sheet area. Figure 18.11 shows the distribution of Late Silurian to Middle Devonian volcanic and sedimentary units and epithermal style mineralisation in the Forbes 1:250 000 map sheet area.

### *Bumbaldry*

The Bumbaldry area is 26 km east of Grenfell. The area contains a number of gold, copper and silver occurrences,

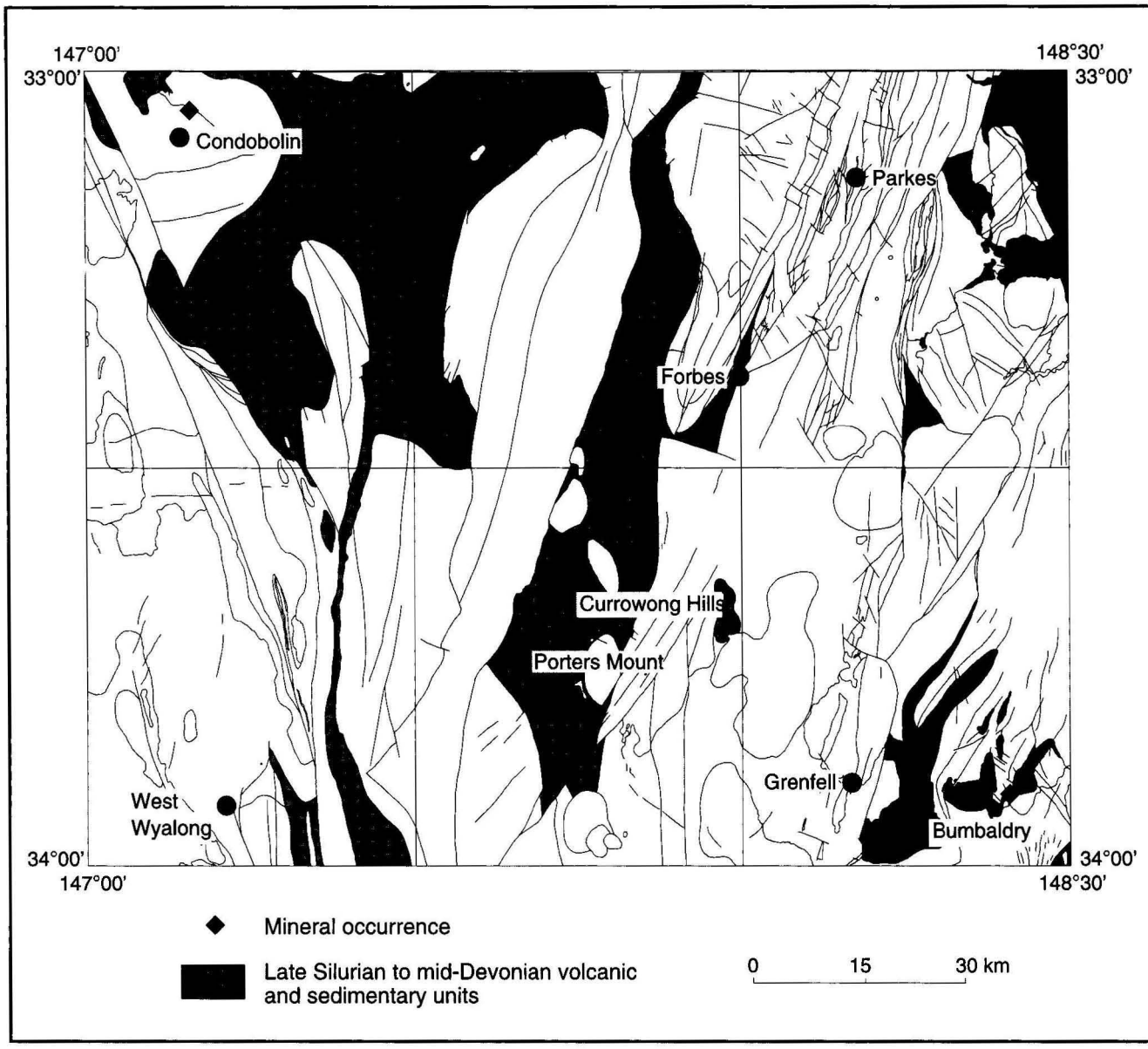



*Figure 18.11. Distribution of the Late Silurian to Middle Devonian volcanic and sedimentary units and epithermal mineralisation in the Forbes 1:250 000 map sheet area.*

including the Broula King gold mine, the Cowfell mine and the Claypit alteration zone. These have been described by Bowman (1977a), Smith (1985), Cluff Resources Pacific Ltd and Lachlan Resources N.L. (1989), and Rangott & Kennedy (1989). The mineralisation is hosted by units of the Early Silurian Illunie Volcanics, which have been intruded by the Silurian Young Granodiorite to the south of the Broula King area.

The Broula King gold mine consists of at least five north-northwest trending zones, which dip moderately to the west, and two east trending zones, which dip vertically. The deposit has been reported to contain "In situ reserves totalling 210 000 tonnes at 2.6 g/t Au" (Cluff Resources Pacific Ltd and Lachlan Resources N.L., 1989, p. 7). The mineralisation is hosted by altered and brecciated felsic to intermediate volcanic rocks, volcaniclastic sedimentary rocks, and carbonate units of the Illunie Volcanics.

Two styles of mineralisation at the Broula King deposit have been described in Cluff Resources Pacific Ltd and Lachlan Resources N.L., (1989, p. 9). These are: "interstitial fine-grained gold within highly silicified wallrock ...; and vein ore where coarse gold is found in the outer edges of thin quartz veins". The veins are up to 1.5 metres thick. Some of the veins contain colloform textures and in places the quartz is chalcedonic. The sulphides associated with the mineralised veins include pyrite, galena, and sphalerite, with lesser chalcopyrite. Patchy disseminated pyrite is associated with the altered volcanic units and a sericitic alteration overprints the area. In places, a strong argillic alteration has been identified and a patchy chloritic alteration is present. The reefs consist of quartz veins and stockworks. Crack-seal type textures have not been described from the dilational veins, although Smith (1985) noted that some veins were shear-related.

Smith (1985) proposed that the fluids that formed the Broula King deposit were metamorphic in origin, and that brittle deformation had occurred both prior to the mineralising event and as a result of high fluid pressures. This contrasts with later workers who described the mineralisation as epithermal. England (1995) suggested that the mineralisation formed as part of a moderately high sulphur system, at low to moderate temperatures, which probably overprinted an earlier porphyry stage. This is supported by the presence of quartz phenocrysts with veils of secondary (aqueous) inclusions containing small vapour bubbles and ?halite daughter crystals (England, 1995).

The Claypit alteration zone, 2 km west of Bumbaldry, occurs at the contact of the Early Silurian Illunie Volcanics and the Middle Devonian Warrumba Volcanics, and has been described by Rangott & Kennedy (1989). The zone is hosted by altered porphyritic rhyolite flows and crystal tuffs with minor volcaniclastic units, ignimbrites and limestone lenses. The prospect consists of an extensive advanced argillic alteration zone with zones of chalcedonic silica that are extensively and variably fractured and brecciated. These zones are surrounded by a weak argillic alteration halo and an outermost propylitic alteration halo. In places the alteration zone is anomalous in gold with minor lead, zinc, copper, silver, antimony and arsenic. Glaser (1988) identified fine-grained chalcopyrite, galena, sphalerite, pyrite, hematite, titanomagnetite, barite and possibly discrete silver minerals within the Claypit alteration zone. Glaser (1988) suggested that boiling had taken place within the alteration zone, although the evidence was somewhat tentative. In addition, preliminary observations on fluid inclusions by Glaser (1988) suggested that the alteration system formed from relatively low-temperature fluids with a salinity of less than 23% NaCl.

Alteration of the Middle Devonian Warrumba Volcanics in the Claypit area indicates that the Claypit alteration zone is Middle Devonian rather than Early Silurian. It could also be possible that the alteration at Broula King, which is wholly within the Early Silurian Illunie Volcanics, is of Middle Devonian age.

*Condobolin*

North of Condobolin gold–silver–lead–zinc–copper mineralisation occurs within quartz veins. The veins are hosted by the biotite facies-metamorphosed, kinked and crenulated, sandy to silty phyllites of the Middle to Late Ordovician Girilambone Group. Some veins are auriferous only (e.g., Surprise mine and Gold Paint mine), while others are predominantly lead–zinc–silver–rich (e.g., Potters mine). The mineralisation is contained within silicified zones, up to 2 m wide, consisting of cross-cutting, massive to (more commonly), crystalline quartz veins up to several centimetres wide. Some veins have a layered/banded texture, which is crustiform or colloform to botryoidal in places, and some veins contain angular fragments of earlier vein quartz and silicified wallrock within a quartz ± sulphide matrix. The majority of zones strike northeast and dip to the southeast, (45° to vertical), mainly parallel to the $S_2$ foliation. However, even where $S_2$ is flat-lying, the zones still trend northeast and, in places, the veins are parallel to $S_3$ (kink axis).

Mineralisation in the Condobolin area consists of disseminated, stringy to semi-massive, generally fine-grained pyrite, with lesser galena, sphalerite, chalcopyrite, bornite, arsenopyrite, and native gold. The mineralisation is in discontinuous zones and shoots within quartz veins and also within adjacent wallrock. Secondary minerals include cerussite and copper carbonates (azurite, malachite). Gangue minerals include quartz, minor colloidal silica, and chlorite. The chlorite occurs as fine-grained clots up to several centimetres long. The wallrock is variably silicified and chloritised and contains disseminated, fine- to medium-grained pyrite and possibly arsenopyrite, and in places weathers to a porous, sinter-like rock.

The Mascotte mineralisation (gold–silver–lead–zinc) has been described by G. Hemming (pers. comm., 1999) as being contained in an 80 m wide by 1000 m long zone, with 1 m to 2 m wide outcropping quartz lodes (strike northeast, dip 50° southeast). The veins consist of saccharoidal, brecciated, comb-textured quartz with silica replacement of carbonate and boxworks after sulphide. The sulphides include disseminated to stringy, fine- to medium-grained pyrite, with lesser galena and sphalerite. These occur both within the altered wallrock and the quartz veins. The wallrock is silicified and chloritised and cut by quartz veinlets several millimetres wide. Breccias are present and consist of quartz and chlorite fragments, up to about 50 mm long, in a fine-grained matrix rich in pyrite, with sphalerite and galena (Figure 18.12).

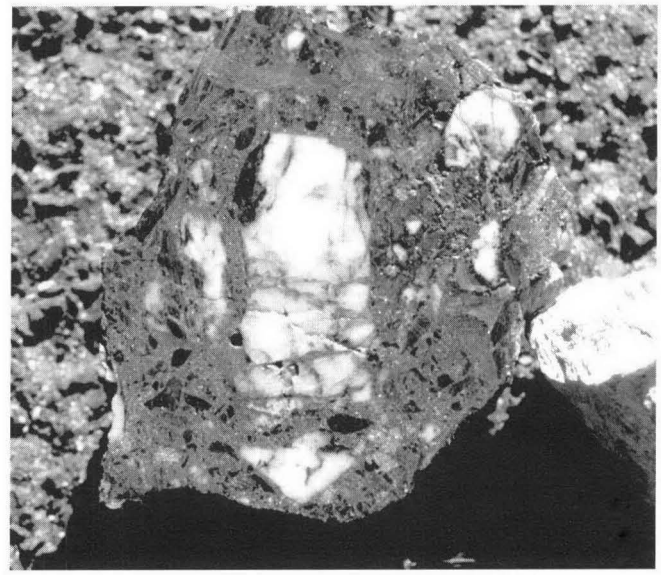


*Figure 18.12. Breccia comprising clasts of quartz and chloritised wallrock fragments in a matrix of fine-grained galena, sphalerite and pyrite. Mascotte mine, Condobolin (G. Burton, photograph)*

A number of workers have suggested that the metal distribution at Condobolin is zoned. However conflicting patterns have been reported. Bowman (1977a) suggested that base metal mineralisation occurred in a central east–

west trending zone (e.g., Au, Pb, Zn, Ag, and Cu at the Phoenix mine) while gold-rich mineralisation occurred in a halo surrounding the central zone (e.g., Surprise mine). G. Hemming (pers. comm., 1999) noted that soil geochemical anomalies present at the Red Paint mine, Mascotte mine and Piebald mine consisted of an inner gold–lead and outer gold–zinc–lead zone. G. Hemming (pers. comm., 1999) also suggested that a horizontal and vertical zonation of metals was present with Au and Cu with or without As and Pb–Zn–Ag with or without As rich zones being present in some areas.

Bowman (1977a) proposed that the Condobolin mineralisation was formed by hydrothermal fluids emanating from a granite and suggested that the metal zonation, predominance of lead over copper and zinc, vein form, and deformed sedimentary rocks supported this. However, Bowman (1977a) also noted that the nearest exposed granite, the Early Silurian Ungarie Granite, crops out approximately 25 km to the southwest. Similarly, G. Hemming (pers. comm., 1999) originally suggested that the veins are related either to the Devonian felsic volcanism at Wolongong Hills, to the north of Condobolin, or to the emplacement of a granite at depth. He described the veins as epithermal to mesothermal, and cited the dominance of base metals over gold and the presence of boiling textures as supporting this. However, there is a lack of extensive chalcedonic quartz and bladed carbonate. Classic epithermal textures are rare in the Condobolin veins, with massive quartz and breccia textures being more common and minor crack-seal textures present in places. More recently, Hemming (pers. comm., 1999) has revised his ideas and proposed that the veins are more likely mesothermal in origin with the mineralisation having formed below the boiling zone.

Another possible model is that the Condobolin mineralisation was formed as the result of a tectonothermal, or uplift, event without the involvement of magmatic heat sources. In this model metamorphic and/or meteoric fluids leached metals from either the host rocks and/or from crustal sources, and emplaced them into dilatant sites within a structural corridor. This model is consistent with the biotite-grade regional metamorphism of the host rocks, which indicates a depth of burial between 3 km to 4 km (L. Barron, pers. comm., 1999). The model is similar to that described by Henley *et al.* (1976) and McKeag & Craw (1989) for gold-bearing and scheelite-bearing quartz veins in the Otago area of New Zealand. Those veins formed during rapid uplift and contain similar textures to those observed at Condobolin. Fluid inclusion studies indicate that some of the vein systems have formed within 3 km to 6 km of the surface, with the Nenthorn vein system being formed at less than one kilometre below the surface and possibly as shallow as 120 m (McKeag & Craw, 1989).

The mineralisation at Condobolin post-dates the crenulation cleavage ($S_3$) in the Girilambone Group, which is considered to have formed during the Benambran Orogeny. The Siluro-Devonian Manna Conglomerate, which overlies the Girilambone Group to the north of the Condobolin gold-base metal district, contains clasts of epithermal quartz vein material and Girilambone Group phyllite. If the epithermal quartz vein clasts were derived from the Condobolin vein system (and this is conjectural) it follows that the Condobolin mineralisation was emplaced no later than the Late Silurian or earliest Devonian. Lead isotope data from the Potters mine (D. Suppel, pers. comm., 1999) is very similar to that for the Mineral Hill area and other deposits associated with the Early Devonian Mineral Hill Zone. Hence, it is probable that the Condobolin mineralisation was emplaced during the Early Devonian. The timing of mineralisation at Condobolin has significant implications for the timing of similar mineralisation along the Gilmore Fault Zone further south.

*Alteration systems*

A number of alteration zones are present in the Forbes 1:250 000 map sheet area. They include the previously described Claypit alteration area as well as the Porters Mount alteration system and the Currowong Hills alteration system. The Porters Mount alteration system is located about 15 km southwest of Wirrinya. It contains elevated arsenic, silver, antimony and gold. However, as yet no significant mineralisation has been identified (Ferris & Harley, 1993; Burrell, 1996). It is hosted by altered hydrothermal breccias and silica–tourmaline-flooded quartz sandstones and siltstones. R. Hine (pers. comm., 1999) described the breccias as including crackle-brecciated sandstones and matrix- and clast-supported breccias with clasts of both lithic and crystal fragments. The lithic fragments include felsic volcanic rocks, diorite, quartz sandstone and argillite. The matrix is fine-grained and consists of quartz–tourmaline and sericite–carbonate–pyrite assemblages. Sulphide-rich, lithic fragments (mainly altered volcanic and intrusive rock types) are present and R. Hine (pers. comm., 1999) suggested that the sulphides have formed by selective replacement, rather than being of exotic origin, because of the similarity between the sulphide assemblages in the fragments and the enclosing matrix.

The sericitic alteration at Porters Mount has been described by R. Hine (pers. comm., 1999) as consisting of a sericite, ankeritic carbonate, pyrite and minor arsenopyrite assemblage with both carbonate and pyrite increasing in abundance with depth. He noted that both clastic and hydrothermal tourmaline is present and that the sub-radiating and very fine euhedral tourmaline found in the matrix is considered to have formed during the sericitic alteration event. A high proportion of the gold present in the breccia is located in cross-cutting, quartz–carbonate–sericite–sulphide veinlets. These veinlets also contain pyrite and arsenopyrite, with traces of galena, sphalerite, and tennantite. These were considered by R. Hine (pers. comm., 1999) to have formed during the sericitic alteration event.

R. Hine (pers. comm., 1999) reported that the isotopic model ages of sericite from the breccias and of zircons from an intrusion at Porters Mount are consistent with a

Late Silurian to Early Devonian age and that the sulphur isotope signature is magmatic in derivation. The breccia is interpreted to be related to a hidden porphyry system at depth (Holliday, 1989; Burrell, 1996).

The Currowong Hills prospect (also known as the West Currowong prospect or Wirrinya prospect), 6 km west of Wirrinya, consists of an advanced argillic epithermal alteration zone centred around a prominent outcrop of intensely silica–alunite-altered, flow banded and brecciated rhyolite and associated intrusions of probable Devonian age. The alteration zone forms a thin, sub-horizontal sheet around 2 $km^2$ in area that Edgar (1990) interpreted as having formed within a near surface, palaeo-watertable. Edgar (1990) identified five alteration assemblages, including: a quartz and alunite alteration assemblage with very minor kaolinite and hematite; a quartz–alunite–sericite assemblage; a quartz–haematite, with or without alunite assemblage; a quartz–kaolinite–pyrite assemblage; and a quartz assemblage with very minor alunite and kaolinite. A vertical zonation was identified by Edgar (1990) with the quartz–alunite assemblage, giving way to the quartz–haematite, with or without alunite alteration at shallower depths. He also noted that the quartz–kaolinite assemblage is located peripheral to the quartz–alunite zone. Hewitt (1982) also reported the presence of minor pyrophyllite, diaspore, zunyite and jarosite. However, Edgar (1990) stated that pyrophyllite and diaspore were absent and that minor pyrite and arsenopyrite were present. Minor molybdenite in quartz veins has also been identified.

The alteration styles at Currowong Hills vary from intensely and pervasively silicified breccias, with up to 60% alunite, to weakly silicified and sericitised rhyolites. Minor vugs and some late-stage quartz veining are present. However, the alteration is generally pervasive and is not vein-dominated. Campbell (1989) reported hydrothermal brecciation of rhyolite, and chalcedonic quartz veins are present in a basalt unit 3 km to the east of the Currowong Hills alteration system.

Although the Currowong Hills alteration zone has many features characteristic of high-sulphidation epithermal systems (Heald *et al.*, 1987; White & Hedenquist, 1990), Edgar (1990) concluded that given the presence of quartz, alunite, kaolinite, sericite, hematite, and the absence of high temperature alteration minerals such as pyrophyllite and diaspore the advanced argillic alteration was probably the result of boiling, at depth, of a near-neutral pH, low-sulphidation, chloride-rich epithermal fluid. The boiling generated $H_2S$ gas that reacted with near-surface meteoric waters to form a low-pH, sulphate-rich, oxygenated fluid. This fluid reacted with the volcanic rocks to form a sub-horizontal, low-temperature, alteration blanket. Despite the formation of an extensive alteration system no significant mineralisation has been identified.

## Placer deposits

Significant gold and minor tin has been recovered from placer deposits within the Forbes 1:250 000 map sheet area (Figure 18.13). Over 60 placer deposits have been recorded in the METMIN database, with the majority of the alluvial gold and tin being won from shallow, generally small, Tertiary to Recent gravels associated with present and former drainages. Unfortunately, few production records exist, as most of the work was undertaken prior to the establishment of the Department of Mines in 1875.

The most prominent area for the production of alluvial gold was the Forbes–Parkes area where gold was discovered in 1861, and within two years approximately 9.3 tonnes of gold was recovered, mostly from rich deep leads (Bowman, 1977a,b). A second prominent area was the Grenfell district where gold was recovered from the basal units of a number of the Tertiary deep leads. Bowman (1977a,b) reported that cassiterite was also present in the Grenfell deep leads and suggested that it was derived from the Bald Hills tin–bismuth district.

The Wyalong goldfield is unusual in that no alluvial gold deposits were discovered in the area despite extensive early prospecting. Recent work by AGSO (Lawrie *et al.*, 1999) has identified a buried palaeochannel system adjacent to the Wyalong goldfield and Hiawatha goldfield that may host significant gold placer deposits.

## Other occurrences

A number of significant but minor mineralisation styles present within the Forbes 1:250 000 map sheet area have not been discussed. These include a number of barite–copper occurrences such as the Cookeys Plains occurrence (Ward, 1985) and miscellaneous molybdenum, antimony and mercury occurrences. Details of these and other occurrences are included in METMIN. Some of these occurrences have also been described by Bowman (1977a,b).

### *Kars*

Platinum mineralisation at Kars is associated with an Alaskan-type ultramafic intrusion known as the Kars Ultramafic Intrusive Complex, located 12 km east of Ootha (Figure 18.9). The main complex is a small, incompletely symmetrically zoned intrusion with a central olivine clinopyroxenite body containing dunite/wehrlite cores and an outer zone of hornblende monzonite grading to syenite and hornblendite. The mineralisation occurs in a linear zone trending approximately east–west along the central axis of the Kars Ultramafic Intrusive Complex. Based on limited exploration, the zone could contain a resource totalling 2.8 tonnes of platinum at 0.42 g/t Pt (Lea, 1995). Beneath the base of oxidation, widespread low-grade platinum is associated with zones of mixed olivine pyroxenite, peridotite, and minor dunite and a coarse pegmatitic phase (Lea, 1995). Alluvial platinum occurs nearby but is not economic (Richardson, 1994).

The Kars intrusion is part of a belt of platiniferous ultramafic intrusions that extend further north into the area of the Narromine 1:250 000 map sheet. These intrusions are of probable Late Ordovician age (Sherwin, 1996).

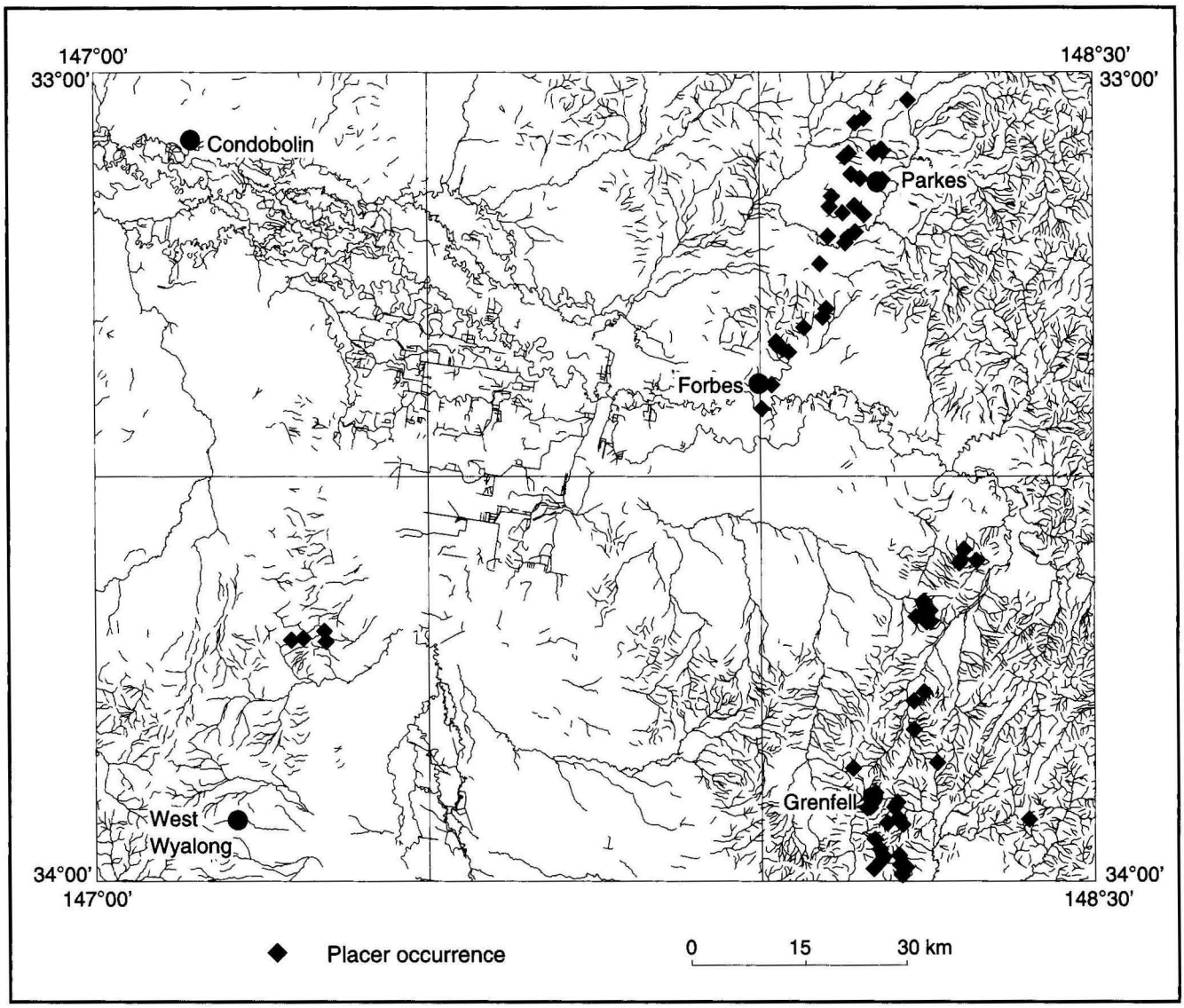



*Figure 18.13. Distribution of gold and other placer deposits in the Forbes 1:250 000 map sheet area.*

*Fairholme*

The Fairholme project, located to the north of Nerang Cowal, covers three mineralised zones: the Boundary prospect; Gateway prospect; and Dungarvan prospect. Those mineralised zones are hosted by Ordovician units of the 'Fairholme igneous complex', which is overlain by up to 120 m of Quaternary sediments. The following information has been supplied by Newcrest Mining Limited.

The Boundary copper–gold mineralisation is hosted by vesicular andesites to basalts and volcaniclastic and fine-grained argillaceous sedimentary rocks, which have been intruded by latite porphyries, andesite porphyries, and microdiorite (Figure 18.9). Andesitic rocks dominate, are variably porphyritic, and contain pyroxene, pyroxene–plagioclase and pyroxene–hornblende assemblages. Many are strongly vesicular. Some of the rocks are fragmental, having been formed by the reworking of debris from the andesitic rocks. The intrusions at the prospect consist of plagioclase–hornblende latite porphyries, which contain an oxidised ferromagnesian assemblage (hornblende–magnetite–sphene) and pyroxene–hornblende microdiorites. D. Wyborn (pers. comm., 1999) noted that the diorites are shoshonitic. Post-mineralisation dolerite dykes cut the Ordovician sequence.

The mineralisation at the Boundary prospect consists of disseminated pyrite–albite–chlorite–epidote in heavily altered volcanic rock together with fine-grained chalcopyrite and bornite intimately grown with disseminated (replacement) epidote. Most of the mineralisation occurs as vesicle fillings. However, some occurs in ragged patches and veins. The mineralisation is considered to have formed by the redistribution of locally derived copper during low-grade metamorphism.

At Boundary, a weak, selective to pervasive, propylitic (albite–chlorite–epidote±magnetite±actinolite) alteration is present. This alteration has filled amygdales with epidote, chlorite, actinolite, magnetite, K-feldspar, pyrite, chalcopyrite, calcite, and axinite. Abundant epidote veinlets are also present, as well as rare axinite veins.

Overprinting the initial propylitic alteration is a second intense propylitic alteration (epidote–calcite±sericite) assemblage and, less commonly, a potassic (epidote–K-feldspar) assemblage. The axinite veins appear to be associated with the more intense alteration zones. The alteration present at Boundary suggests that the area is part of the upper and outer zone of a porphyry copper–gold alteration system. It may be part of a system in which the latite porphyries represent the uppermost intrusive fingers.

Two kilometres east of the Boundary area is the Gateway prospect. There the mineralised zone trends in a northerly direction and covers a 2 km × 0.5 km area. The zone is just west of the Booberoi Shear Zone and consists of low-level copper and gold mineralisation within highly deformed and altered Ordovician rocks. The rocks include laminated, tuffaceous and schistose metasedimentary rocks dominated by meta-argillites, tuffaceous meta-argillites (quartz–sericite–pyrite schists), primary volcanic rocks, and minor porphyries and diorites. A sericitic alteration is the most intense alteration and consists of a sericite–silica–albite–chlorite–carbonate–pyrite assemblage over 1.5 km long. Associated with the sericitic alteration zone is disseminated pyrite, lesser pyrite veinlets, and rare chalcopyrite. The sericitic alteration grades into a pervasive chlorite–epidote–carbonate alteration. Later tension gash quartz veins are not mineralised. Deformation and shearing has been focussed in the sericite–chlorite–pyrite zones. This has lead to the formation of a well-developed cleavage and the remobilisation and recrystallisation of the pyrite and carbonate. Within these highly deformed zones only relict primary textures are present.

The Dungarvan prospect contains a weakly mineralised copper–gold system, which is located 3 km south of the Boundary prospect. The Dungarvan mineralisation is hosted by intermediate to mafic volcanic and volcaniclastic rocks that have been intruded by diorites and more mafic intrusions. These rocks have undergone a pervasive propylitic alteration, resulting in an epidote, actinolite, calcite, chlorite, leucoxene, and magnetite assemblage. Fracture-fill quartz–carbonate–epidote–chlorite veins are common.

*Eurow-Vychan*

The Eurow-Vychan copper–gold deposit is 12 km northwest of Eugowra (Figure 18.10) and contains an estimated resource of 375 000 tonnes with average grades of 1.0 g/t Au, 1.6% Cu and 71 g/t Ag (G. Bray, pers. comm., 1999, who also provided much of the following information). The mineralised zone is close to the contact between quartz–feldspar–biotite–cordierite porphyritic rhyodacite of the Early Silurian Glenisla Volcanics and the Early Devonian Eugowra Granite. The host sequence consists of conformable layers of coarse-grained quartz–biotite schist, quartz hornfels, fine- to coarse-grained biotite schist, and black hornfels. The mineralisation occurs at the contact between the hornfels and the schist units and consists of massive to disseminated pyrite, chalcopyrite (up to 10% Cu), and sphalerite (up to 9.2% Zn), with lesser galena and gold (up to 5ppm) in a quartz gangue. Magnetite is also found associated with the hornfels, but in bodies separate from the massive sulphides. The mineralised zone is tabular and grossly concordant with the enclosing rocks although discordant "spur" lodes are also present (Rampe, 1992a). The zone strikes 335°, dips 70° to the southwest, extends for at least 450 m along strike, and averages 3.4 m in width (range <1 m to 6 m). The zone of oxidation extends from the surface (gossan) to between 35 and 45m (Kennedy, 1969). The sulphide zone continues to at least 80m (established by drilling, R. Coenraads pers. comm., 1999 to G. Bray).

The style of the mineralisation present at Eurow is unknown. Two possible models are that it is exhalative in origin with the mineralisation having been remobilised into later shears, or that it is an epigenetic vein occurrence.

*Manganese mineralisation*

Stratiform and stratabound manganese mineralisation occurs in both the Grenfell and Cookamidgera areas. The occurrences consist mainly of pyrolusite and psilomelane, with rhodonite occurring at depth in some places. Cherts are commonly associated with the mineralisation. In the Grenfell area the manganese mineralisation is hosted by the Ordovician Brangan Volcanics (metamorphosed dolerite and basalt) and the Ordovician Kirribilli Formation (siltstone, shale, phyllite, and slate), while in the Cookamidgera area (Figure 18.14) it is hosted by the Kirribilli Formation.

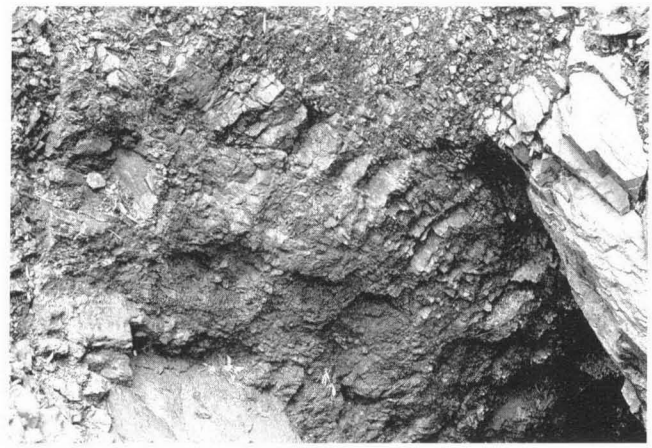


*Figure 18.14. Exposure of manganese ore at the Cookamidgera mine. The manganese-rich bed is about 0.3m wide (1 ft) and dips 45° to the west. (H. Bowman, November 1973, DMR collection, Forbes 0105).*

The manganese-rich bodies probably formed during the Ordovician as syn-sedimentary exhalative bodies in a deep marine environment, possibly somewhat similar to the model described by Fehn (1986) for manganese mounds formed near the Galapagos spreading centre.

*Tin, bismuth and tungsten mineralisation*

Minor occurrences of tin, tungsten and bismuth are present within the Forbes 1:250 000 map sheet area (Figure 18.10). The mineralised zones are small and occur within or adjacent to granites. Cassiterite is present in quartz veins in the Girral and Ungarie areas. These are associated with the

Early Silurian, S-type Ungarie Granite. In the Bald Hill area cassiterite with or without bismuthinite, in quartz veins, are associated with the Early Devonian, S-type Grenfell Granite while in the Hancocks Hill area, cassiterite with or without wolframite in quartz–tourmaline greisens are found with Early Devonian S-type granites.

*Industrial minerals*

There are approximately 130 industrial mineral and construction material occurrences present in the Forbes 1:250 000 map sheet area. Most of these are road base quarries developed within a variety of rock types. Other industrial commodities present in the area include kaolinite, dimension stone, limestone and sand. Figure 18.15 shows an exposure of granite dimension stone at the Carmina Granite Quarry. This material has been used in the construction of the new Parliament House in Canberra.

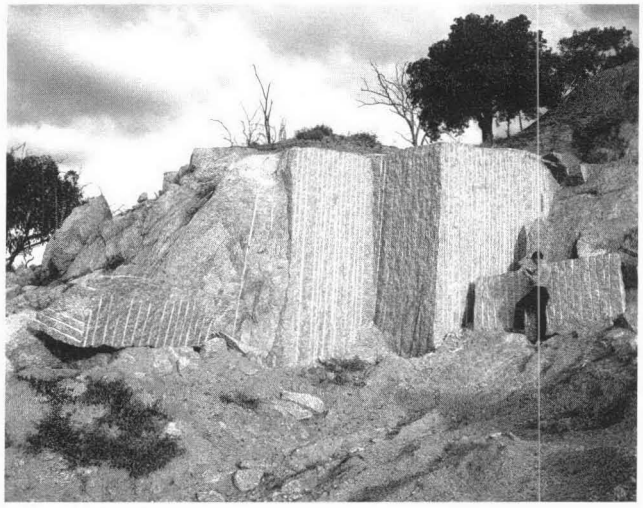


*Figure 18.15. Geologist with block of granite dimension stone at the Carmina Granite Quarry. This material was used in the construction of the new Parliament House in Canberra. (DMR collection, Forbes 0257).*

## Discussion

A widespread Ordovician magmatic event, which lasted from approximately 480 Ma to 440 Ma (Perkins *et al.*, 1995), is recognised in central New South Wales. The magmatism is interpreted to have been associated with the development of an island arc (the Molong Volcanic Arc, Scheibner & Basden, 1998). Work by Wyborn and others (e.g., Wyborn & Sun, 1993; Wallace & Wyborn, 1997), has shown that, during that time, strongly oxidised, potassium-rich, and sulphur-undersaturated magmas were generated in the mantle. Because of these characteristics the melts were able to retain significant concentrations of precious metals (gold, platinum and palladium) until the latter stages of crystallisation, leading to the development of significant intrusion-related copper and gold mineralisation. Carr *et al.* (1996) demonstrated that the mantle-derived lead isotope signatures are a characteristic of the mineralisation associated with the magmatic event. This includes the Goonumbla (Northparkes) porphyry copper–gold mineralisation, their associated skarn occurrences and the Lake Cowal porphyry occurrences. The platiniferous Alaskan-type ultramafic intrusions at Kars and in the Fifield area are probably related to the same Ordovician magmatic event and may represent deep-seated equivalents to the porphyry Cu–Au intrusions (Scheibner & Basden, 1998).

Stratiform manganese mineralisation is present in the Grenfell and Cookamidgera areas. This mineralisation probably formed as syn-depositional, manganese-rich exhalative deposits during the Ordovician, in a deep marine rift environment on the flanks of the island arc.

During the Early Silurian, the Ungarie Granite was emplaced with associated minor tin and bismuth mineralisation. Further tin and tungsten mineralisation is associated with the Early Devonian S-type granites. Also during the Early Devonian epithermal alteration systems were formed, such as at Porters Mount and the Currowong Hills area. The Claypit alteration system at Bumbaldry is no older than Middle Devonian and may have formed contemporaneously with nearby gold–copper–silver epithermal mineralisation. These Devonian alteration systems may be associated with porphyry copper–gold mineralisation but this has yet to be established.

Structurally controlled gold mineralisation occurs throughout the Forbes 1:250 000 map sheet area. The geological setting and style of these occurrences is largely controlled by the competency of the host rocks, the depth of burial at time of mineralisation, and the host rock chemistry. The occurrences can be divided on the basis of the rheology of the host rocks and the depth of burial at the time of deformation. The styles are: mineralised zones located in dilatant sites within faults and shears in competent host rocks, such as the West Wyalong occurrences; and mineralisation located in sites where a competency contrast has been important, such as in the Parkes area.

The age and nature of the fluids that formed the structurally controlled gold occurrences is not well-constrained. The Endeavour 42 (Lake Cowal) gold mineralisation is no older than Late Ordovician as it post-dates the nearby intrusions by at least 15 Ma. This deposit was formed by low-temperature, low-salinity fluids, possibly of metamorphic origin, with the lead isotopic signature being consistent with derivation of the metals from the Ordovician volcanic rocks. In the Parkes–Forbes area, Clarke (1990b) suggested that gold mineralisation occurred late in the deformation history, with the timing of mineralisation at the London-Victoria mine probably being post-Silurian. Carr *et al.* (1995) further concluded that the mineralising event occurred around 400 Ma (Early Devonian), based on lead isotope data. At the Calarie mine, the mineralised structure truncates the Siluro-Devonian Calarie Sandstone (L. Sherwin, pers. comm., 1999), further supporting an Early Devonian or younger age for the mineralisation (barring later reactivation of the structure). It is likely that the gold and minor base metals of the Parkes–Forbes veins were sourced from the Ordovician shoshonitic volcanic rocks, which, as noted above, are enriched in copper and gold.

The lead isotope signature of the London-Victoria mineralisation supports this, and suggests that the lead was sourced from both the mantle derived Ordovician volcanic rocks and younger (crustal) units. Most of the vein occurrences in the Parkes–Forbes area lie at, or near, contacts between volcanic and non-volcanic rocks where competency contrasts have played a major role in localising the mineralisation.

If the epithermal quartz vein clasts found in the Siluro-Devonian Manna Conglomerate, to the north of Condobolin, were derived from the Condobolin gold–base metal veins, this would limit the minimum age of the mineralisation to the Early Devonian. This is consistent with Pb isotope data from the Potters mine at Condobolin. The source of the fluids that formed the mineralisation at Condobolin has yet to be resolved. The authors favour a model whereby metamorphic and/or meteoric fluids mobilised gold and base metals from the surrounding country rocks during tectonism and deposited the metals at relatively shallow crustal levels in structurally formed sites.

The gold-bearing quartz veins at West Wyalong and the Pinnacles area post-date structures considered to have formed during the Kanimblan Orogeny, placing a maximum age of Early Carboniferous on those mineralised systems. The lead isotope data from the West Wyalong goldfield is consistent with this interpretation (Carr *et al.*, 1995). Similarly, the Grenfell gold veins may be related to structures of that age but they may be as old as Middle Devonian. These vein systems are all structurally controlled, with mineralisation having been emplaced into dilatant sites within faults and shears in competent host rocks. None of these districts have been studied in sufficient detail to give any clear insights into the origins of the mineralising fluids.

Uplift has resulted in the erosion of primary gold (and tin) occurrences resulting in the formation of numerous placer occurrences. Gibson & Chan (1999) noted that the process of uplift and subsequent erosion has been ongoing with the alluviation of the incised palaeo-Lachlan valley commencing in the Late Miocene (Martin, 1991). This resulted in the concentration of gold and other heavy minerals adjacent to their source areas, such as in the Parkes–Forbes and Grenfell areas. Further exploration may locate placer gold mineralisation associated with these buried palaeovalleys, such as in the recently discovered palaeovalleys to the north of Wyalong (Gibson & Chan, 1999).

## Conclusion

Over 650 metallic mineral occurrences are recorded in the Forbes 1:250 000 map sheet area. These occurrences encompass a variety of mineralising processes in a range of geological settings extending from the Early Ordovician to Recent. The district contains numerous structurally controlled gold deposits, as well as Ordovician intrusion-related copper–gold mineralisation, post-Ordovician intrusion-related skarns, veins and greisens, epithermal-style deposits, and various gold placer occurrences. The recognition of the Ordovician intrusion-related copper–gold mineralisation, such as at Lake Cowal and Marsden, has highlighted the prospectivity of the map area. A significant point arising from recent investigations is that Ordovician magmatism is probably the primary source of the gold and copper in the Forbes 1:250 000 map sheet area. Subsequent magmatism and deformation has mostly served to remobilise copper and gold into appropriate structural sites.

# 19. REGOLITH MATERIALS AND LANDSCAPE EVOLUTION

## Introduction

This section provides a general outline of the nature and development of the regolith in the Forbes 1:250 000 map sheet area. The Cainozoic units shown on the Forbes 1:250 000 geology map sheet have not been subdivided according to the principles of regolith geology, although there is some overlap. A separate regolith map sheet (not produced under the NGMA) is available from CRC LEME, c/- CSIRO Division of Exploration and Mining, Private Mail Bag, Post Office, Wembley, WA 6014.

The term regolith generally includes all earth materials between fresh rock and fresh air, which have been affected by processes operating at, or near, the Earth's surface. In addition, regolith mapping emphasises bedrock units that have a geomorphic context, e.g., Mesozoic/Cainozoic sedimentary and volcanic rocks. The regolith is, in effect, the zone of interaction between the lithosphere and the biosphere, hydrosphere, and atmosphere. There are two major types of regolith:

*In situ* regolith, which encompasses weathered bedrock retaining its original volume and structure (saprolite), and the collapsed remains of weathered bedrock, which are interpreted not to have moved laterally other than by local bioturbation (e.g., residual deposits and some lags); and transported regolith, which includes terrestrial sediments moved by water, wind, and gravity. Regolith also includes weathered rock and sediments cemented in the near-surface environment by silica, iron, carbonate, etc. — to form various hardpans and duricrusts.

Regolith is intrinsically related to the land surface and the processes that occur there. For example, the depth and degree of weathering of *in situ* regolith is dependent not only on the properties of the parent fresh bedrock, but also the depth to the water table and the chemistry of the groundwater, both present and past. Processes that depend on the interaction between landform and climate deposit transported regolith at the Earth's surface. Regolith is preserved when the rate of production by deposition or lowering of the weathering front at the fresh bedrock-saprolite interface is greater than the rate of erosion of the regolith mantle.

## Regolith Materials

### Alluvium

Alluvium is the dominant regolith type in the Forbes 1:250 000 map sheet area. This is a result of the alluviation of the formerly incised drainage system, as a response to rising base levels in the Murray Basin (Gibson & Chan, 1999a), which commenced in the Early Miocene in the Forbes 1:250 000 map sheet area. The alluvial fill has been subdivided into the Miocene to Pliocene Lachlan Formation, and the Pleistocene 'Cowra Formation' (both first published by Williamson (1964, 1969), although the latter stratigraphic name is technically invalid due to prior use of the term Cowra Granodiorite). There is an erosional hiatus between the two units. Details of the lithology of the units are known only from drillholes (mostly water bores). The Lachlan Formation consists of gravels, sands, clays, and silts. Finer-grained sediments are generally grey and reduced, and clasts in the gravels consist mostly of rounded quartz pebbles, with some chert (Williamson, 1969, 1986). The 'Cowra Formation' consists of brown clays, sands and gravels, and is more oxidised than the underlying sediments. Clasts in the gravels are representative of rock types in the modern Lachlan River catchment.

Deep, narrow, sediment-filled palaeovalleys, some mined for gold last century (deep leads), are known to be present in some erosional areas. The sediment in these is assumed here to be alluvium, although Wilson & McNally (1996) have interpreted much of the sediment fill of the Parkes deep leads to be deposited by debris flows. Gold-bearing deep leads are depicted on the Forbes 1:250 000 Metallogenic Map (Bowman, 1976) and on the Forbes Regolith Landforms map sheet (Gibson & Chan, 1999b), but downstream continuations of these palaeovalleys have not been mapped, due to low economic importance, difficulty in recognising their locations from surface observations, and lack of historical documentation.

Certain palaeodrainage deposits contain magnetic minerals (probably mostly maghemite), rendering them visible on magnetic imagery as high frequency, but generally low amplitude anomalies. Those discernible on publicly available magnetic data have been outlined on the regolith landform map. The largest area of magnetic sediments occurs in the Wyalong palaeovalley and its tributaries, north of Wyalong. On high resolution AGSO magnetic imagery, the main anomaly is traceable for over 22 km, with a width of up to 1 km (Lawrie *et al.*, 1999). The palaeovalley has been cut into granite probably weathered to around 50 m depth (old mining records from the Wyalong goldfield indicate that this is about the depth of weathering), and is present in a low relief erosional landscape. The sediments are exposed (1999) in trenches at the West Wyalong tip where they consist of about 75 cm of poorly cemented iron-stained conglomerate grading into 2 m or 3 m of sandstone and siltstone. Those sediments sharply overlie highly weathered mottled clay. It has not yet been firmly established whether this is transported or represents *in situ* very highly weathered bedrock. About 3.5 km downstream, five shallow AGSO RAB drillholes to 15 m encountered up to 9 m of gravelly and sandy sediment, overlying mottled, bleached and stained kaolinitic clay of unknown origin. Most of the detrital grains in the conglomerate are magnetic pisoliths, with minor ferruginous rock fragments, and rare small quartz pebbles. The magnetic susceptibility of the conglomerate ranges up to $30\,000 \times 10^{-5}$ SI.

Company data from the area of the expected downstream extension of the palaeovalley beneath the Bland Creek alluvial plain indicate that the depth of incision of the valley may reach 60 m at its downstream end. A CRC LEME high-resolution seismic survey has been carried out across the palaeovalley to help determine its profile, but results are not yet available. In many areas, modern drainage approximates the course of the palaeovalley. However, there are indications of topographic inversion in the headwater areas of the palaeovalley, and there has been major diversion of drainage by the accumulation of aeolian sand in an area north of Wyalong (discussed below in the section on aeolian sand).

The age of the valley-fill sediment is not known. The palaeovalley probably filled during the latter part of the time of the alluviation of the Lachlan River palaeovalley system, so a Pleistocene depositional age is expected.

Other magnetically defined palaeodrainage deposits are present mainly within alluvium of the Lachlan River and its tributaries. Confidential company data also show that magnetic palaeodrainage deposits are also present in the Grenfell area.

Alluvium is present as one of the minor regolith components of all erosional landforms, forming zones along creeks. It is expected that the alluvium interfingers with colluvium away from the creeks.

## Aeolian sediments

Aeolian sand is present mainly in local small dunes, mostly on the alluvial plains, and as climbing dunes or wedges deposited on the western sides of steep meridional ridges. Most of the sand is probably locally derived from deflation of dry swamps, lakes, and sandy levées associated with modern Lachlan floodplain drainage, although aeolian sand north of Wyalong is associated with the relatively narrow Wyalong palaeovalley. This sand is interpreted to have been locally derived from the palaeovalley sediments, and its deposition appears to have caused the evulsion of modern drainage from the palaeovalley in that area.

Most of the small dunes on the alluvial plain have a dark reddish signature on gamma ray spectrometric RGB images, indicating very low Th and U content, with low to moderate K. Areas with a similar signature east of Lake Cowal may correspond to the remains of a lunette adjoining a palaeo-lake larger than the present lake. Field investigation of these areas has so far proved inconclusive, with some areas corresponding to sand, but others to heavy clay. These areas have been shown on the Marsden 1:100 000 geological map sheet, but not the regolith landform map.

## Colluvium

Colluvium is present as a veneer over much of the lower relief erosional units in the Forbes 1:250 000 map sheet area. This is interpreted to be transported and deposited mainly by sheet flow that covers much of the lower-relief erosional areas during heavy rain. As there is a fine mosaic of colluvium- and saprolite-dominated areas within these units, they have been variously depicted as being saprolite- or colluvium-dominated rather than mapping out the detailed distribution. An exception to this is the colluvium that has been mapped on pediments surrounding areas of steeper relief. This has been delineated as two separate units, depending on whether the source of the colluvium is granite (*sensu lato*) or sedimentary and volcanic rocks.

Partly cemented, granite-derived, sandy and gravelly colluvium is also interpreted to make up a veneer over bedrock on eroding footslopes to granite hills north of Grenfell. Similar sediment has also been observed around granite hills north of Temora, south of the Forbes 1:250 000 map sheet area.

Colluvium in areas of steeper landforms has generally been moved by gravity, either as creep or debris flow deposits. Soils in these areas have formed mainly in colluvial deposits.

## Lacustrine and swamp deposits

Lacustrine and swamp sediments are generally fine-grained with heavy, grey clay soils. There is an area of possible sandier shoreline deposits immediately east of Lake Cowal.

## Saprolite

Saprolite includes all weathered bedrock. Saprock is an equivalent term to slightly weathered bedrock. The development of saprolite depends on local conditions such as bedrock lithology and its susceptibility to weathering, and topographic position. Only limited data are available on the degree of weathering in many areas, but rare deep exposures (e.g., the London and Victoria open cut mines near Parkes) indicate that the degree and depth of weathering across some erosional areas is highly variable. Therefore, many bedrock-dominated areas have been mapped as having undifferentiated saprolite, either through lack of knowledge or variability of weathering. However, the metamorphic rocks of the Wagga Group and Girilambone Group are generally only slightly to moderately weathered, as are some of the granites (e.g., at Tullabung Hill northwest of Wyalong, Billys Lookout northeast of Wyalong, and around Eugowra), sandstones of the Hervey Group, and volcanic units of the Dulladerry Volcanics and Brangan Volcanics. Known highly weathered rock types include small areas of Dulladery Volcanics in the northeast of the area, and granites around Wyalong, where old mining records indicate highly weathered rock to about 50 m. At least some of the granite saprolite in this area is mottled. Company exploration data and logs of water bores indicate that much of the bedrock beneath the thick alluvial sediments of the Lachlan palaeovalley and its tributaries is highly weathered, with thicknesses of saprolite up to about 50 m.

## Lag

Lag of resistant rock fragments is locally present across the Forbes 1:250 000 map sheet area. Areas underlain by the

generally slightly weathered Wagga Group and Girilambone Group metamorphic rocks generally have a lag of angular siliceous fragments derived from the underlying rocks. Areas of highly weathered granite in the Wyalong area are characterised by a lag of small ferruginous clasts. These are generally magnetic, and have maghemite as a mineral component. They appear to be formed by erosion of hardened ferruginous mottles from granite saprolite, and transformation of goethite to maghemite by either heating or microbial action while at the surface.

## Regional Context of Regolith Development

Recent studies allow preparation of a synopsis of the current understanding of landscape, and hence, regolith development in the Forbes 1:250 000 map sheet area. Further details can be found in Chan (1999), Gibson & Chan (1999a), and O'Sullivan *et al.* (2000).

The oldest recorded weathering in the region is at Northparkes mine (just north of the Forbes 1:250 000 map sheet area), where Pillans *et al.* (1998) recorded an interpreted Carboniferous palaeomagnetic pole in highly weathered Late Ordovician monzonite. These authors concluded that weathering of saprolite in the area has been an ongoing process since, at least, the late Palaeozoic. O'Sullivan *et al.* (1998; 2000) have combined these data with apatite fission track data from samples gathered from the mine and surrounding area. They conclude that the rocks in the mine area were near the surface and undergoing weathering in the Early to Middle Carboniferous, then buried under a Late Carboniferous to Late Permian sequence that was thick enough to raise temperatures to more than 110° C. Note that there is no preserved record of Permian sedimentation in the Forbes region to confirm the fission track data, although further south, at Illabo (between Junee and Cootamundra), remnants of *Glossopteris*-bearing sedimentary rock have been recorded (Warren *et al.*, 1995). Rapid cooling in the Late Permian to Early Triassic indicates possible vigorous erosion, possibly related to the Hunter–Bowen Orogeny. O'Sullivan *et al.* (2000) concluded that the rocks were reheated during the late Mesozoic, followed by rapid cooling in the Early Tertiary.

Chan (1999) and Gibson & Chan (1999a) have previously considered it most likely that the sediments of the Surat Basin originally extended over much of eastern New South Wales and that rapid uplift of what is now the eastern highlands at about 95 Ma gave rise to a northwesterly palaeoslope over the north Lachlan Fold Belt area, giving rise to initial erosion of the sedimentary cover. This conclusion was based on analysis of drainage evolution, and apatite fission track data provided by O'Sullivan *et al.* (1995) and Raza *et al.* (in press). The fission track data indicate an eroded section of 1 km to 2 km in the southeast portion of the Surat Basin near Coonabarabran, and rapid denudation (several kilometres over a few million years) over what is now the Great Dividing Range of southeastern Australia at about 95 Ma. The fast rates of denudation are thought to be attainable only if poorly consolidated sedimentary units, such as would be present in a southward extension of the Surat Basin, rather than the harder and more consolidated rocks of the Lachlan Fold Belt, were being eroded. Data from O'Sullivan *et al.* (2000) suggest that heating (and thus, most probably, deposition) continued in the Northparkes area after 95 Ma, indicating that some of the deposition may have been a result of erosion further east.

The total original thickness of Mesozoic sedimentary rocks that may have extended across the Forbes 1:250 000 map sheet area is not well-constrained. However, interpretation of apatite fission track data for the Northparkes area (discussed above) suggests that it may have been in the order of one kilometre. The present model of drainage evolution is based on superimposition of drainage from a veneer of Mesozoic rocks, requiring at least a minimal thickness. Apatite fission track data (P. O'Sullivan, pers. comm., 1999) show that the major circa 95 Ma cooling episode recorded further east, in the Bathurst area, becomes less marked to the west, and has not been recorded in the Forbes 1:250 000 map sheet area. However, the Early Tertiary cooling event referred to above (discussion of the Northparkes area) has been recorded across a wide area of western New South Wales. In areas where the Mesozoic rocks are preserved, such as at Gunningbland, west of Parkes, this cooling must represent erosion of these or younger sedimentary units. Elsewhere, the estimated Tertiary erosion gives an upper limit to the possible original thickness of Mesozoic cover.

Drainage was to the north in the pre-Mesozoic sedimentation landscape, as shown by palaeocurrent directions in the lower parts of the Surat Basin sequence preserved near Molong (about 50 km east of Parkes; Gibson & Chan, 1999a) and Gunningbland. Prior to sedimentation at Molong, local relief was up to 100 m. In the Forbes 1:250 000 map sheet area, there are also indications of prior relief, with basement strike ridges protruding through remnants of Mesozoic sedimentary rocks in the northeast of the Bogan Gate 1:100 000 map sheet area (Krynen *et al.*, 1990). This is backed up by data from company drilling in the area (North Ltd, pers. comm., 1999). At about 95 Ma, drainage was probably still to the north, with rivers flowing over a broad floodplain, possibly with some protruding strike ridges of Lachlan Fold Belt rocks. Rapid uplift to the east of the area induced a general northwesterly slope over central New South Wales (normal to the coastline), and initiated erosion in the uplifted areas. The formation of a new (palaeo)slope would have been accompanied by the migration of rivers across the floodplain until they were flowing generally to the northwest. These initially deposited sediment derived from the east, but then began to erode at some time in the Late Cretaceous or Early Tertiary. One of these rivers is interpreted to have been the palaeo-Lachlan, which eroded through the Surat Basin section, superimposing its course across the structural grain of the Lachlan Fold Belt rocks.

Some tributaries, such as the palaeo-Goobang Creek and palaeo-Mandagery Creek, also had the erosive power to superimpose their courses across the structure of the underlying rocks. Others, such as the palaeo-Bland Creek, established their courses in either newly eroded or exhumed strike-controlled valleys.

This establishment of a new drainage pattern occurred prior to the initiation of the Murray Basin as a thermal sag during the Palaeocene. Continued subsidence of the Murray Basin created new low base levels, and accelerated the incision of major rivers into Lachlan Fold Belt rocks. By the Late Eocene, the Lachlan and Murrumbidgee River were entering the topographically depressed Murray Basin via gorges, as shown by Late Eocene sediments in the base of thick (~140 m) valley fills near Narrandera and Hillston (Martin, 1991). Nickpoint migration would have extended gorge erosion upstream. There are two control points for the timing of this incision in the Forbes 1:250 000 map sheet area. Jemalong Gap (downstream from Forbes) was eroded to 140 m below the present floodplain level by the Late Miocene, at least, as shown by sediments with a *T. bellus* Zone palynoflora (late Early to mid-Late Miocene, about 17 Ma to 9 Ma — absolute age from AGSO STRATDATA database, 1999) near the base of the section at this location (Martin, 1991). Secondly, a basalt flow from the 12 Ma Canobolas volcano, near Orange, is enclosed near the base of the 60 m thick alluvial fill beneath Mandagery Creek at Eugowra (Williamson, 1986). Rapid incision of gorges in response to lowered base levels is a well-known phenomenon in landscape development, with headward advancement of nick points occurring far more rapidly than valley widening or erosion of drainage divides (e.g., Nott *et al.*, 1996). Williamson (1986) and Anderson *et al.* (1993) have described the morphology of the buried Lachlan palaeovalley in the region in detail.

As part of the gorge development phenomenon, many tributaries of the palaeo-Lachlan also incised their courses (e.g., Mandagery, Goobang, and Bland Creeks). However, the nature of the incised palaeovalleys varied. The palaeo-Mandagery and palaeo-Goobang Creeks eroded steep narrow valleys across the general north-trending bedrock structure of the areas, but the palaeo-Bland Creek eroded a broad, generally strike-aligned, valley. In general terms, this is probably because the rocks in the area of Bland Creek must have been exceptionally weathered and/or friable for the palaeo-Bland Creek to erode such a wide valley.

It is possible that the broad depositional area centred on Bland Creek is a Cainozoic graben or structurally down warped area. However, seismic and drillhole sections across the valley in the vicinity of Lake Cowal and Marsden (Anderson *et al.*, 1993) show that the sediment/bedrock interface has a distinct valley form, with the base of the alluvial sediments at about 120 m depth. This would be the expected level if the valley was formed by the palaeo-Bland Creek and its tributaries, with local erosion base level controlled by the depth of incision of the palaeo-Lachlan River.

Major alluviation of the incised palaeovalleys commenced in the Late Miocene (Martin, 1991) over a probable variably weathered bedrock terrain. Weathering of buried bedrock is likely to have been ongoing, and perhaps accelerated, during sedimentation, resulting in deeply weathered bedrock covered by thick sediment. The alluvial fill has been divided into the Late Miocene to Pliocene Lachlan Formation, separated from the Pleistocene 'Cowra Formation' by an erosional hiatus (Williamson, 1969; 1986). These formations have been recognised only in the immediate environs of the Lachlan palaeovalley, and may be considered as proximal equivalents of sediments of similar age in the Murray Basin. The Lachlan Formation is relatively reduced, and contains well-rounded quartz gravels, implying reworking of older sedimentary deposits. The 'Cowra Formation' is relatively oxidised, and contains gravels with varied clasts, implying a local bedrock source. It is probable that the palaeovalley was widened by erosion during the depositional hiatus, thus giving the buried 'valley-in-valley' form present in several sections.

Alluviation occurred at much the same time as the Murray Basin filled. However, it is probable that sedimentation in the palaeovalley was controlled not only by rising base levels in that Basin, but by climatic controls (hence vegetation, sediment balance and discharge) in the upper catchment as conditions became drier from the Late Miocene (e.g., Martin, 1991). Thus alluviation probably occurred as a result of two independent time-transgressive mechanisms operating at opposite ends of the river system. It has been suggested (K. Tomkins & G. Salas, pers. comm., 1999) that the Lachlan Formation was deposited in response to rising base levels, but the 'Cowra Formation' was deposited in response to climatic controls.

The balance between erosion and deposition along the Lachlan River has probably varied considerably over time. At present, the river is incising into the 'Cowra Formation' upstream of the Eugowra–Gooloogong area, leaving terraces up to 40 m above river level. Downstream, there has been little incision, but there are large areas of stagnant alluvial plains with well-formed red earth soils, as well as depositional areas with younger alluvial soils closer to watercourses. Incision is consistent with both gradient reduction and uplift. However, the terraces converge to near modern river level near the mouth of Mandagery Creek, indicating that the most likely explanation is uplift, with hinging rather than faulting in the Eugowra area, and increasing differential uplift to the east.

The modern distribution of depositional regolith components on the alluvial plain is the result of the complex interplay between incision, sediment supply from both the Lachlan River and its tributaries, aeolian action, recharge and discharge of water to and from aquifers, soil formation and partitioning, climate and vegetation. The retention of depositional regolith on erosional slopes results from the balance between vegetation and climate. However, as demonstrated at Northparkes, much of the *in situ* regolith may be the result of weathering in the distant past.

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# APPENDIX

## Palaeontological Data

### Yarrimbah Formation

**Age**: Early Ordovician, Lancefieldian (La3) -Bendigonian (Be1)

**Assemblage**: graptolites *Adelograptus* sp., *Didymograptus acriculus*, *Didymograptus* (*Cymatograptus*) sp., *Tetragraptus approximatus*, *Tetragraptus fruticosus*, *Tetragraptus quadribrachiatus*; indet. lingulid brachiopods

**References**: Sherwin (1973d, 1979, 1984)

### Mugincoble Chert

**Age:** late Middle Ordovician to early Late Ordovician, ?Darriwilian - ?Gisbornian

**Assemblage:** conodonts *Belodina* sp. or *Pseudobelodina* sp., *Panderodus* sp., ?*Periodon* sp., *Phragmodus* sp., indet. chirognathid, ?*Walliserodus* sp; indet. filamentous algae

**Reference:** Percival (1999a)

### Hoskins Chert

**Age:** late Middle Ordovician to early Late Ordovician, ?Darriwilian - ?Gisbornian

**Assemblage:** conodonts *Drepanodus* ?*arcuatus*, *Drepanodus* sp. or *Drepanoistodus* sp., ?*Scalpellodus* sp., ?*Walliserodus* sp; indet. filamentous algae

**Reference:** Percival (1999a)

### Clements Formation (Wagga Group)

**Age:** late Middle Ordovician, Darriwilian 2-4

**Assemblage:** conodonts ?*Amorphognathus* sp., "*Belodella*" cf. *nevadaensis*, *Belodella* sp., ?*Belodina* sp., *Drepanodus* sp., *Drepanoistodus* sp., *Eoplacognathus* sp., chirognathid cf. *Erraticodon* sp., *Oistodus* sp., ?*Panderodus* sp., *Periodon* cf. *aculeatus*, *Phragmodus* sp., ?*Plectodina* or ?*Prioniodus*, "*Plectodina*" sp., *Pygodus serra*

**Reference:** Percival (1999a)

### Murda Formation (Girilambone Group)

**Age:** Late Ordovician, ?Gisbornian - ?Bolindian

**Assemblage:** conodonts *Belodina* sp. or *Pseudobelodina* sp., *Panderodus* sp., *Periodon* sp., ?*Plectodina* sp., *Protopanderodus* cf. *liripipus*, ?*Walliserodus* sp; brachiopod ?*Nushbiella* sp. or *Multispinula* sp; ?radiolaria

**Reference:** Percival (1999a)

### Goonumbla Volcanics, limestone in lower part of formation

**Description:** Gunningbland Copper Mine, (Endeavour 6 prospect)

**Age:** late Middle Ordovician, late Darriwilian (Da3)

**Assemblage:** conodonts *Drepanodus* ?*arcuatus*, *Periodon aculeatus*, *Protopanderodus* cf. *varicostatus*, *Pygodus* ?*anitae*, indet coniform elements; brachiopod *Conotreta* sp; gastropods; sponge spicules

**References:** Percival & Dargan (1999); Percival (1999)

### Goonumbla Volcanics, unnamed conglomerate member in lower part of formation

**Age:** late Middle Ordovician (?Darriwilian) to early Late Ordovician (Gisbornian)

**Assemblage:** trilobites *Dividuagnostus* sp., indet. catillicephalids, indet. asaphids; brachiopods; indet. echinoderms; sponge spicules

**Reference:** Sherwin (1984)

### Goonumbla Volcanics, top of formation

**Description:** The Secrets prospect, north of Parkes

**Age:** Late Ordovician (late Eastonian - ?early Bolindian)

**Assemblage:** corals *Catenipora* sp., *Favistina* cf. *juncta*, *Heliolites* cf. *digitalis*, *Palaeophyllum rugosum*, *Plasmopora* cf. *cargoensis*, *Plasmoporella* cf. *inflata*, *Tryplasma* cf. *spinulatum*, *Tryplasma* sp; bryozoans; indet. brachiopods; pelmatozoan stems; algae *Vermiporella* sp

**Reference:** Pickett (1984a)

### Billabong Creek Limestone (lower part)

**Age:** late Middle Ordovician (late Darriwilian) to early Late Ordovician (Gisbornian)

**Assemblage:** conodont *Pygodus anserinus*; corals *Coccoseris* sp., *Foerstephyllum* sp., ?*Nyctopora* sp; stromatoporoids *Cystistroma* cf. *cliefdenense*, *Stromatocerium* sp; stictoporid bryozoans; indet. strophomenid brachiopods; large trochiform gastropods; algae *Hedstroemia* sp., *Girvanella* sp., *Solenopora* sp., *Vermiporella* sp

**References:** Percival (1991, 1995); Pickett (1984b, 1985b)

### Billabong Creek Limestone (middle part)

**Age:** middle Late Ordovician (early Eastonian, Ea1)

**Assemblage:** corals *Acidolites* sp., *Bajgolia furcata*, *Coccoseris speleana*, *Eofletcheria hadra*, *Hillophyllum priscum*, *Nyctopora stevensi*, ?*Pragnellia* sp., *Tetradium* ?*apertum*, *Tetradium cribriforme*, *Tetradium cruciforme*; stromatoporoids *Rosenella woyensis*, *Stratodictyon ozakii*, ?*Stromatocerium* sp; bryozoa *Homotrypa* sp., *Batostoma* sp., *Stictopora* sp; brachiopods *Dinorthis* sp., *Eodinobolus* ?*stevensi*, *Eridorthis australis*, *Plectorthis* sp; gastropods ?*Holopea* sp., cf. *Mourlonia* sp., ?*Ophileta* sp; indet. illaenid trilobite; algae *Cliefdenia fasciculata*

**References:** Percival (1991, 1995); Pickett (1984b, 1985b); Webby & Semeniuk (1971)

### Billabong Creek Limestone (upper part)

**Age:** middle Late Ordovician (early Eastonian, Ea2)

**Assemblage:** brachiopods *Anoptambonites excedra, Australispira disticha, Bowanorthis fragilis, Didymelasma inconspicua, Dinorthis hadra, Doleroides mixticius, Eridorthis australis, Paraonychoplecia inversa, Protozyga definitiva, Quondongia alitis, Rhynchotrema oepiki, Sowerbyella billabongensis, Sowerbyites isotes, Trigrammaria ampla, Wiradjuriella halis, Zygospira carinata;* gastropods *Bucanopsis* sp., *Helicotoma* aff. *H. blodgetti* Rohr 1988, *Lophospira* sp., *Loxoplocus* sp., ?*Michelia* sp., *Mourlonia* sp., murchisonid gen. nov., *Raphistoma* sp., *Subulites* sp., *Trochonema* sp; trilobites *Amphilichas nasutus*, ?*Encrinuraspis* sp. A Webby 1973, harpid gen. et sp. nov., *Pliomerina austrina*, ?*Pseudobasilicus* sp. A Webby 1973, *Remopleurides saenuros*, *Remopleurides* sp. A Webby 1973, *Sphaerocoryphe exerta*; ostracod *Webbylla cyma;*conodonts *Belodina confluens*, *Panderodus* sp., *Phragmodus* sp; corals indet. heliolitids, *Hillophyllum priscum*, *Hillophyllum* sp., *Tetradium cribriforme;* stromatoporoid *Ecclimadictyon nestori;* indet. bryozoan; algae *Goobangia pyriformis*

**References:** Packham (1967); Percival (1991,1995); Schallreuter & Siveter (1988); Webby (1971, 1972, 1973, 1974); Webby & Morris (1976); Webby & Trotter (1992)

### Gunningbland Formation

**Age:** middle Late Ordovician (late Eastonian, Ea3-Ea4)

**Assemblage:** corals *Aulopora* sp. A Webby 1977, *Favistina floweri*?, heliolitids, *Palaeophyllum jugatum*, *Plasmoporella inflata*, ?*Streptelasma* sp; sponge *Cliefdenella perdentata;* trilobites *Amphilichas* sp., aff. *Bevanopsis* sp., *Encrinuraspis* sp., *Eokosovopeltis* sp., *Illaenus* (?*Parillaenus*) sp., *Parkesolithus gradyi*, *Pseudobasilicus* sp., *Remopleurides* sp., indet. harpid, indet. odontopleurid; brachiopods *Anomaloglossa porca*, *Casquella bifida*, *Doleroides* sp., ?*Dulankarella partita*, *Durranella septata*, *Elliptoglossa adela*, *Gunningblandella resupinata*, *Hisingerella hetera*, *Infurca tessellata*, *Kassinella anisa*, ?*Oepikina* sp., *Paterula* sp., ?*Scaphorthis aulacis*, *Sericoidea sejuncta*, *Sowerbyella anticipata*, *Sowerbyella lepta*, *Sowerbyites vesciseptus*, *Wiradjuriella* sp; gastropod ?*Helicotoma* sp; nautiloids *Bactroceras latisiphonatum*, *Paradiscoceras dissitum*, tarphyceratid indet.; algae *Ischadites* cf. *iowensis*; graptolites *Cactograptus* sp., *Climacograptus missilis*, *Dicellograptus elegans*, *Dicellograptus* cf. *ornatus minor*, *Dicellograptus* sp., *Dicranograptus teali*, *Dictyonema* spp, *Normalograptus* sp., *Orthograptus* cf. *amplexicaulis*, *Orthograptus apiculatus*, *Orthograptus* cf. *calcaratus incisus*, *Orthograptus* ?*quadrimucronatus*, *Orthograptus* ?*pulcherimus*, *Orthograptus truncatus pauperatus*, *Orthograptus whitfieldi*

**References:** Campbell & Durham (1970); Percival (1978, 1979a, 1979b, 1995); Sherwin (1970a, 1970b, 1971, 1973b, 1984); Stait, Webby & Percival (1985); Webby (1969, 1977, 1988); Webby & Morris (1976); McLean & Webby (1976); Wyborn *et al.* (1991)

### Nash Hill Volcanics

**Age:** Late Ordovician (?Eastonian – Bolindian)

**Assemblage 1** (Sherrard)**:** *Leptograptus flaccidus*, *Dicellograptus complanatus ornatus*, *Dicellograptus* ?*anceps*, *Climacograptus tubuliferous*, *Climacograptus* ?*hughesi*, *Orthograptus* ?*quadrimucronatus*, *Orthograptus truncatus pauperatus*

**Assemblage 2** (Sherwin)**:** *Climacograptus tubuliferous*, *Orthograptus* cf. *truncatus*, *Orthograptus* cf. *calcaratus*, *Orthograptus* cf. *truncatus*, *Dicellograptus elegans*, *Leptograptus* sp

**References:** Sherrard (1962); Sherwin (1970b)

### Jingerangle Formation

**Age:** late Late Ordovician, Bolindian (Bo2?)

**Assemblage:** graptolites *Dicellograptus gravis* Keble & Harris, *Dicellograptus ornatus* (Elles & Wood), *Diplacanthograptus* cf. *spiniferus* (Reudemann), *Normalograptus angustus* (Perner), *Orthograptus* ex. gr. *amplexicaulis* (J. Hall), *Ptilograptus* sp., indet. small climacograptid; brachiopods ?dalmanelloid, large multicostate ?orthide; nautiloids ?*Discoceras* sp., indet. cyrtoconic brevicone, indet. orthocone; sponges *Hindia sphaeroidalis* Duncan, indet. conical sponge, long monaxons; crinoid ossicle

**Reference:** Percival, (1999b)

### Cotton Formation (lower part)

**Age:** late Late Ordovician (Bolindian)

**Assemblage 1** – (fauna A of Sherwin, 1970a)**:** graptolites *Climacograptus bicornis*, *Climacograptus hastatus*, *Climacograptus latus*, *Climacograptus supernus*, *Dicellograptus complanatus*, *Dicellograptus* cf. *elegans*, *Orthograptus amplexicaulis*, *Orthograptus truncatus pauperatus*, ?*Orthograptus* sp. (tridentate proximal end), *Retiograptus pulcherrimus*, *Retiograptus* sp; lingulid brachiopod.

**References:** Packham (1969); Sherwin (1970a, 1970b, 1970c, 1971, 1983c, 1984, 1985)

**Age:** latest Ordovician (?late Bolindian)

**Assemblage 2** – (fauna B of Sherwin, 1970a)**:** graptolite *Climacograptus scalaris normalis*; brachiopod *Paterula giganta*; orthoconic nautiloids; trilobite fragments; ostracodes

**References:** Packham (1967, 1969);Percival (1978); Sherwin (1970a, 1970b, 1971, 1973b)

### Cotton Formation (middle part)

**Description:** Quarry at Secrets prospect east of Nanardine.

**Age:** early Early Silurian (early Llandovery)

**Assemblage:** graptolites *Climacograptus* cf. *minutus*, *Climacograptus normalis*, *Climacograptus* sp., *Dimorphograptus* sp., *Glyptograptus ?tamariscus tamariscus*, *Glyptograptus* cf. *sinuatus*, *Glyptograptus* sp., *Monograptus* cf. *atavus*, *Monograptus* cf. *capillaris*, *Monograptus ?cyphus*, *Monograptus gregarius*, *Monograptus* cf. *inexpeditus*, *Monograptus revolutus*, *Monograptus strachani*, *Orthograptus* cf. *insectiformis*, *Pseudoclimacograptus* cf. *hughesi*, *Pseudoclimacograptus* sp., *?Rhaphidograptus* sp; brachiopods *?Ectenoglossa* sp., *Orbiculoidea* sp., indet. lingulid; indet. bivalves.

**References:** Sherwin (1974d, 1976a, 1984)

### Cotton Formation (upper part)

**Age:** middle Early Silurian (late Llandovery)

**Assemblage –** (fauna C of Sherwin, 1970a)**:** graptolites *?Dictyonema* sp., *Glyptograptus tamariscus*, *Monograptus andrewsi*, *Monograptus* cf. *becki*, *Monograptus jacobseni*, *Monograptus nudus*, *Monograptus planus*, *Monograptus* cf. *pseudobecki*, *Monograptus regularis*, *Monograptus* cf. *sedgwicki*, *Monograptus* cf. *spiralis*, *Orthograptus cyperoides*; trilobite *Odontopleura* sp

**Assemblage –** (fauna D of Sherwin, 1970a)**:** graptolites *Dictyonema* sp., *Monograptus* cf. *gemmatus*, *Monograptus halli*, *Monograptus* cf. *involutus*, *Monograptus* cf. *proteus*, *Monograptus turriculatus*, *Orthograptus cyperoides*, *Rastrites* sp; trilobites *Odontopleura* sp., *Paraaulacopleura* sp

**Assemblage** – (undifferentiated fauna C/D)**:** graptolites *Glyptograptus tamariscus*, *?Glyptograptus* sp., *Monograptus* cf. *acus*, *Monograptus andrewsi*, *Monograptus* cf. *barrandei*, *Monograptus* cf. *denticulatus*, *Monograptus* cf. *halli*, *Monograptus* cf. *hybridus*, *Monograptus pankhurstae*, *Monograptus regularis*, *Monograptus* cf. *sedgwicki*, *Monograptus* sp. A, *Petalograptus minor*, *Rastrites linnaei*; trilobites *Aulacopleura* sp., *Primaspis* sp.; orthoconic nautiloid

**References:** Packham (1967, 1969); Sherwin (1967b, 1968, 1970a, 1970b, 1971, 1973f, 1974a)

### Bocobidgle Conglomerate (Forbes Group)

**Age:** Early Silurian (late Llandovery-Wenlock)

**Assemblage:** corals *Aphyllum lonsdalei*, *Coenites juniperinus*, *Drymopora* sp., *Halysites lithostrotonoides*, *Pseudamplexus* sp., *Thecia* sp; stromatoporoid *?Labechia* sp; algae

*Rothpletzella* sp; ?foraminifera *Wetheredella* sp

**References:** Percival & Dargan (1999)

### Mumbidgle Formation (Forbes Group)

**Age:** middle Silurian (late Wenlock-early Ludlow)

**Assemblage:** *Monograptus dubius*, *Monograptus sherrardae*, *Monograptus* sp., retiolitid fragments, *Dictyonema* sp; *Streptelasma australe*, *Phaulactis* sp., *Tryplasma dendroidea* Etheridge, *Tryplasma* sp., *Tryplasma* cf. *vermiformis*, *Mucophyllum liliiformis*, *?Syringopora* sp., *Aulopora* sp., *Thamnopora* sp., *Acanthohalysites australis*, *Heliolites daintreei*, *Nipponophyllum* cf. *colligatum*, *Propora conferta*, *Cystiphyllum* sp., *?Pycnostylus* sp., *Favosites* sp; *?Gypidula* sp., *Leptaena* cf. *thomsonensis*, *?Brachyprion* sp., *?Plectatrypa* sp., *?Isorthis* sp., *?Barrandina* sp., *Strophochonetes* sp; stromatoporoids; large spired gastropods; *Fenestella* sp; *Praectenodonta* cf. *victoriae*; *?Lampterocrinus* sp., *Cheirocrinus* sp. sensu lato; *Dalmanites* cf. *loomesi*, *Encrinurus* sp., *Calymene* sp., *?Odontochile* sp., Proetidae gen. et sp. indet; indet. hyolithids; *Bathysiphon* sp., *Glomospirella* sp; indet. ostracodes; radiolaria; algae

**References:** Dun *in* Andrews (1910); Pickett (1966); Sherwin (1967a, 1971, 1972, 1973b, 1974, 1975f, 1983a)

### Illunie Volcanics (Douro Group) unnamed limestone member

**Age:** middle Silurian (?late Wenlock)

**Assemblage:** *Halysites chillagoensis* or *H. yarrangobillyensis*

**References:** Sherwin *in* Pickett (1982, p.47)

### Derriwong Group (basal?)

**Age:** Late Silurian (late Ludlow)

**Assemblage:** *?Dokophyllum* sp., *?Aphyllum* sp., *Tryplasma* sp., *?Tryplasma* sp., *Pseudamplexus* sp., *Squameofavosites* sp., *Alveolites* sp., *Favosites* sp., *Favosites* sp., *Heliolites daintreei* Nicholson & Etheridge group 1, *Parastriatopora* sp., *Cystiphyllum* sp; *Plexodictyon conophoroides* (Eth f.), *?Syringostromella* sp., *Amphipora sp.*, ?Labechiid, dense branching stromatoporoid

**Reference:** Pickett & Ingpen (1990)

### Calarie Sandstone (Derriwong Group)

**Age:** Late Silurian

**Assemblage:** Indet. rhynchonellid brachiopods, ramose bryozoans, proetid free cheek.

*?Linguopugnoides* sp., *Uncinulus* sp., *Meristella* sp., *?Actinopteria* sp., *?Kochia* sp., *?Goniophora* sp; ?helicotomid gastropods, *?Tentaculites* sp., beyrichiid ostracodes, crinoid ossicles

**References:** Sherwin (1971, 1973b, 1984)

### Edols Conglomerate (Derriwong Group)

**Age:** Late Silurian

**Assemblage:** brachiopods *Howellella* sp., *Molongia elegans capricorniae*; trilobite *Encrinurus mitchelli*; bivalve *Actinopteria* sp; indet. loxonematid gastropods

**Reference:** Nazer (1972)

### Byong Volcanics (Derriwong Group)

**Age**: latest Silurian (Pridolian)

**Assemblage**: *Skenidioides* sp., *Isorthis* (*Arcualla*) sp., *Ananaspis* sp., *Cheirurus* (*Crotalocephalus*) *regius*, indet. trochurid, *Didrepanon* sp., *Sthenarocalymene* sp., *Odontochile* cf. *loomesi*, *Leonaspis* cf. *rattei*, *Ceratonurus* cf. *impedita*

**Reference**: Sherwin (1990)

### Byong Volcanics (Derriwong Group)

**Age:** Early Devonian

**Assemblage:** *Clathrodictyon* sp. indet., *Stromatopora* sp. indet., *Heliolites daintreei*, *Favosites squamuliferus* forma *bryani*, *Mucophyllum* cf. *liliiformis*, *Plasmophyllum* (*Mesophyllum*) sp. nov., *Favosites richardsi*, *Camarotoechia pleurodon*, *Strophodonta* (*Strophondonta*) sp., *Favosites gothlandicus*, *Fardenia shearsbyi*, *Pholidostrophia bendeniensis*, *Howellella nucula*, *Howellella* sp., *Encrinurus mitchelli*, *Encrinurus bowningensis*, indet. scutellid, crinoids, *Tentaculites* sp., *Schuchertella* sp.

**References:** Foldvary (1969); Nazer (1972)

### Cookeys Plains Formation (Derriwong Group)

**Age:** latest Silurian (Pridolian) to earliest Devonian

**Assemblage:** *Batocara* cf. *mitchelli*, *Baturria* sp., *Encrinurus bowningensis*, *Encrinurus* cf. *civicae*; *Ancillotoechia dunii*, *Atrypa reticularis*, *Atrypa* sp., *Gypidula* sp., *Howellella nucula*, *Howellella* cf. *pyramidalis*, *Howellella* cf. *jaqueti*, *Isorthis* (*Isorthis*) *alpha*, *Iridistrophia* cf. *umbella*, *Pholidostrophia bendeniensis*, *Leptaena* sp., *Leptostrophia* (*Mitchella*) sp., ?*Retzia* sp., ?*Retziella* cf. *capricorniae*, *Shaleria* sp., *Strophodonta* sp; *Tryplasma* cf. *derrengullense*, *Cyathophyllum* sp., *Squameofavosites bryani*, *Heliolites daintreei*, ?*Aulopora* sp., *Favosites gothlandicus*, *Favosites tripora*, *Cladopora* sp., *Spongophyllum halysitoides*, *Lyrielasma* sp; conodonts (NB some are unrevised form species) *Acodus* sp., *Belodella resima*, *Belodella* sp., *Hindeodella equidentata*, *Hindeodella priscilla*, *Icriodus* sp., *Ozarkodina denckmanni*, *Panderodus simplex*, *Panderodus unicostatus*, *Spathognathus* sp., *Trichonodella inconstans*; *Plexodictyon conophoroides*, ?*Stromatopora* sp; *Loxonema* sp., *Murchisonia* sp; ?*Tellinopsis* sp.; ?*Ormoceras* sp; *Nicklesopora* cf. *geuriensis*

**References:** Nazer (1972); Pickett (1975); Sherwin (1990)

### Cookeys Plains Formation (Derriwong Group)

**Age:** earliest Devonian (early Lochkovian *hesperius-eurekaensis* zones)

**Assemblage:** conodonts *Latericriodus woschmidti hesperius*, *Ozarkodina eurekaensis*, *Ozarkodina excavata*, *Ozarkodina remscheidensis remscheidensis*, *Panderodus unicostatus*, *Pandorinellina optima*, *Pandorinellina* sp., *Polygnathus* sp; fish *Kadungalepis serrata*, indet. placoderm scales, *Trundlelepis cervicostulata*, indet. acanthodian scale; brachiopods ?*Boucotia* sp. (dorsal valve), *Opsiconidion robustum*, *Orbiculoidea* sp. (dorsal valve); indet. trilobite pygidium; hexactinellid sponge spicule

**References:** Brock, Engelbretson & Dean-Jones (1995); Percival & Dargan (1999)

### Yarrabandai Formation (Derriwong Group)

**Age:** Early Devonian (?early to late Lochkovian, *pesavis* Zone)

**Assemblage:** *Podolella* sp., *Iridostrophia* sp., *Eospirifer* sp., *Reeftonia* sp., *Howellella jaqueti*, *Cladopora* sp; *Actinopteria* sp., tentaculitids, dacryoconarids; crinoid ossicles, ?*Velibeyrichia* sp; conodonts (NB some are unrevised form species): *Icriodus* sp., *Hindeodella equidentata*, *Hindeodella priscilla*, *Trichonodella inconstans*, *Trichonodella symmetrica*, *Spathognathodus* sp., ?*Ozarkodina* sp., *Ozarkodina denckmanni*, *Belodella* sp., *Belodella resima*, *Panderodus simplex*, *Panderodus unicostatus*, *Acodus* sp., *Ozarkodina* ?*remscheidensis*, *Panderodus* sp., conodonts (multielement): *Amydrotaxis johnsoni*, *Ozarkodina remscheidensis*, *Pandorinellina exigua philipi*, *Pandorinellina paridens*, *Kimognathus alexei*, *Oulodus* sp

**References:** Pickett (1971, 1975, 1992); Percival & Dargan (1999); Sherwin (1975d, 1992)

### Derriwong Group Undifferentiated

**Age:** Late Silurian to earliest Devonian

**Assemblage:** *Encrinurus* sp., *Retziella capricornae*, ?*Leptostrophia* sp., *Actinopteria* sp., *Favosites* sp., *Heliolites* sp., *Lindstroemia* sp. or *Petraia* sp., *Spirifer jacqueti*, indet. bivalve, *Spirigerina* sp., *Howellella* sp., *Mucophyllum* sp., *Scutellum* sp., ?*Alveolites*, *Podolella* sp., *Cladochonus* sp., *Pleurodictyum* sp., crinoid stems, ?*Schizotreta* sp., ?*Moravostrophia* sp., *Reeftonia alpha*, reticularid gen. nov?, *Murchisonia* sp., ?*Ctenodonta* sp., *Aulacopleura* sp., indet. odontopleurid, indet ostracodes, sponge spicules, ?*Nanothyris* sp., ?*Craspedobolbina* sp., ?*Tentaculites* sp., ?*Cymostrophia* sp., ?*Iridostrophia* sp., indet odontopleurid fragments, *Fenestella* sp., indet branching bryozoans, *Cystiphyllum* sp., *Howellella* sp., ?*Atrypa* sp., ?*Atrypoidea* sp., *Striatopora* sp., *Ozarkodina excavata*, *Panderodus* sp., fish scales

**References:** Pickett (1983); Raggatt (1936); Sherwin (1973a, 1973e, 1975a, 1975b, 1975c, 1978)

### Yiddah Formation (Derriwong Group)

**Age:** Early Devonian

**Assemblage:** *Encrinurus* sp., *Heliolites* sp., *Retziella* cf. *capricorniae*, indet stropheodontid, *Actinopteria* sp.

**Reference:** Sherwin (1973a)

### Ootha Group (?Mulguthrie Formation) Undifferentiated

**Age:** ?latest Silurian (?Pridolian)

**Assemblage:** *Notanoplia* cf. *panifica*, ?*Actinopteria* sp., orthoconic nautiloids, poorly preserved ?monograptids,

plant fragments, ?*Coenites* sp., indet ?lyssakid sponge, crinoid stems, *Plectodonta* sp.,

**References:** Sherwin (1973d, 1974b, 1974c, 1981b, 1990)

### **Trundle Group** Undifferentiated

**Age:** Early Devonian (Lochkovian–Pragian)

**Assemblage:** *Favosites allani*, *Favosites gothlandicus*, *Favosites gothlandicus* var. *goldfussi*, *Favosites richardsi*, *Favosites squamuliferus* forma *bryani*, *Favosites* sp., *Alveolites* sp., dendroid *Favosites*, *Heliolites daintreei*, *Heliolites* sp., *Tryplasma lonsdalei*, *Cyathophyllum* sp. cf. *shearsbyi*, ?*Mucophyllum liliforme*, *Pseudamplexus princeps*; *Orthoceras* sp., ?*Coronuga*, ?*Loxonema* sp., aulacopiid sponge, *Scalaeotrochus* sp., ?*Desquamatia* sp., ?*Sieberella* sp., *Leptaena* sp., *Isorthis alpha*, *Atrypa reticularis*, ?*Buchanathyris* sp., *Spinatrypa* sp., *Atrypoidea* sp., *Howellella angustiplica*, *Iridistrophia* cf. *I. umbella*, *Pholidostrophia bendeniensis*, *Shaleria* cf. *armaghensis*, *Howellella jaqueti*, *Reeftonia* sp., *Howellella* sp., ?*Toquimella* sp., *Strophodonta* (*Strophodonta*) sp., *Schuchertella* sp., *Spinella pitmani*; *Cheirurus* (*Crotalocephalus*) *sculptus*, *Scutellum* cf. *bowingensis*, *Encrinurus mitchelli*, *Encrinurus bowningensis*, indet. proetid, odontopleurid and calymenid fragments, *Nicklesopora* sp. cf. *geuriensis*, *Aparchites* sp., indet. paraparchitaceans, indet. beyrichiid and ?craspedobolbinid ostracodes, bellerophontid gastropods, calyptomatids, *Kloedenia* sp., *Actinopteria* sp., *Nowakia* sp., crinoid ossicles; ?*Nuculana* sp., *Grammysioidea* sp., *Modiomorpha* sp. sensuo lato, ?*Septalaria* sp., *Fenestella* sp., ?*Tentaculites* sp., *Clathrodictyon* sp., conodonts (NB some are unrevised form species): *Icriodus* sp., *Hindeodella equidentata*, *Hindeodella priscilla*, *Trichonodella inconstans*, *Spathognathodus* sp., ?*Ozarkodina* sp., *Ozarkodina denckmanni*, *Belodella resima*, *Belodella* sp., *Panderodus unicostatus*, *Panderodus simplex*, *Acodus* sp., conodonts (multielement): *Amydrotaxis druceana*, *Kimognathus alexii*, *Pandorinellina exiguus philipi*, *Ozarkodina* cf. *remscheidensis*, *Delotaxis elegans*, *Delotaxis* sp., *Panderodus* sp.

**References:** Dun (1899; Booker *in* Raggatt (1936, 1937); Sherwin (1967a, 1971, 1973c, 1973d, 1975d, 1975e); Foldvary (1969) Nazer (1972); Pickett (1971, 1979)

### **Euchabel Gap Formation (Trundle Group)**

**Age:** Early Devonian (late Lochkovian-Pragian)

**Assemblage:** *Kimognathus alexeii*, *Amydrotaxis druceana*, *Ozarkodina ?buchanensis*, *Pandorinellina exigua*, *Pandorinellina optima*; ostracodes; *Favosites* sp; *Spinella* sp; fish scales

**References:** Pickett (1983); Percival (unpublished data)

### **Beugamel Sandstone (Trundle Group)**

**Age:** Early Devonian (late Lochkovian *delta* Zone)

**Assemblage:** *Oulodus* sp., *Ozarkodina remscheidensis remscheidensis*, *Pandorinellina optima*, *Spinella* sp., indet bivalve, gastropods, ostracodes

**Reference:** Percival & Dargan (1999)

### **Troffs Formation (Trundle Group)**

**Age:** Early Devonian (?Pragian)

**Assemblage:** *Spinella pittmani*, ?*Spinella* sp.

**References:** Sherwin (1992)

### **Cloghnan Shale**

**Age:** Late Devonian (?Frasnian-Famennian)

**Assemblage:** *Metaxygnathus denticulus*, *Bothriolepis* sp., *Remigolepis* sp., *Phyllolepis* sp., *Soederberghia* sp

**References:** Campbell & Bell (1977); Young (1993)

### **Weddin Sandstone**

**Age:** Late Devonian (Famennian)

**References:** Bell (1972)

**Assemblage:** *Bothriolepis* sp., *Holoptychius* sp., *Remigolepis* sp., *Phyllolepis* sp., *Ichthyostega* sp; Plantae: *Leptophloeum australe*, ?*Archaeocalamites* sp

**References:** Dun (1900, 1910); Andrews (1910); Hills (1932); Sherwin (1971, 1973f); Bell (1972); Young (1997)

### **Hervey Group** Undifferentiated

**Age:** Late Devonian (Frasnian-Famennian)

**Assemblage:** *Bothriolepis* sp., ?*Phyllolepis* sp., *Remigolepis* sp., very large antiarch plates;

lepidodendroid plant remains

**Reference:** Conolly (1965); Sherwin (1971)

### **Hunter Siltstone (Hervey Group)**

**Age:** Late Devonian (Frasnian-Famennian)

**Assemblage:** *Bothriolepis* sp., *Remigolepis* sp., *Groenlandaspis* sp., *Grenfellaspis* sp., phyllolepid indet., dipnoans, crossopterygians.

Osteichthyes: ?osteolepid (articulated gular plates), osteichthyan indet

**References:** Young (1993, 1997)

### **Peaks Formation (Hervey Group)**

**Age:** Late Devonian (Frasnian)

**Assemblage:** Placodermi: *Bothriolepis* sp., *Remigolepis* sp., *Groenlandaspis* sp.

**Reference:** Young (1997)

### **Mandagery Formation (Hervey Group)**

**Age:** Late Devonian (Frasnian)

**Assemblage:** *Kasibelinurus amicorum*, *Leptodesma* sp., *Sphenotus* sp., *Spathella* sp., *Polidevcia* sp., *Apsilingula parkesensis*, antiarch plates, crossopterygian plates, grazing trails, *Leptophloeum australe*

**References:** Pickett (1993); Williams (1977)

### 'Pipe Formation' (=?Mandagery Formation)

**Remarks:** Top of the 'Pipe Formation', about 15 m beneath the first massive sandstones representing the base of the Bumberry Formation type section.

Radiometrics indicate that this locality approximates to the 'Pipe Formation' along strike to the north, which is well exposed in 'The Dungeons' road cutting, the locality from which the horseshoe crab *Kasibelinurus* was recorded by Pickett (1993)

**Age:** Late Devonian (Frasnian)

**Assemblage:** Placodermi: antiarchs indet, *Bothriolepis* sp., *Remigolepis* sp., *Groenlandaspis* sp., phyllolepid indet

Osteichthyes: osteolepid scales, holoptychiid scales, crossopterygians indet

Brachiopoda: *Apsilingula parkesensis*

Mollusca: bivalves indet

Plantae: *Leptophloeum australe*

**Reference:** Young (1997)

### Bumberry Formation/Eurow Formation equivalents (Hervey Group)

**Age:** Late Devonian (Famennian)

**Assemblage:** Placodermii: large remigolepid antiarch, ?sinolepid indet, *Bothriolepis* sp., *Groenlandaspis* sp., *Remigolepis* sp., *Grenfellaspis branagani*

Osteichthyes:scales and bones (crossopterygian; ?actinopterygian), osteolepid (large cosmoid scales)

Acanthodii: '*Striacanthus*' sp

Mollusca: indet bivalves

?lingulid brachiopods

Plantae: plant remains (incl. *Leptophloeum australe* in a higher horizon)

**References:** Pickett (1993b); Young (1997)

### Hunter Formation

**Age:** Late Devonian

**Assemblage:** Acanthodii: ischnacanthid gen. nov

Placodermi: *Grenfellaspis branagani*, *Bothriolepis* sp., *Remigolepis* sp., *Groenlandaspis* spp Osteichthyes: ?*Eusthenodon* sp., ?*Ctenodus* sp., porolepiform gen. nov.

**References:** Young (1993, 1997)

### Formation: **ungrouped Mesozoic**

**Age:** ?Jurassic.

**Assemblage:** ?*Taeniopteris* sp., ?*Angiopteridium* sp.

**Reference:** Pickett (1985a)

### Formation: unknown

**Description :** "Mr. Hasemers brickpit at Forbes, in alluvium at a depth of 18 feet"

**Age:** Pleistocene

**Assemblage:** *Diprotodon* sp

**References:** Andrews (1910)

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