

## REGIONAL GEOLOGICAL SETTING

### TECTONIC SETTING

The Mudgee-Gulgong district is located in the exposed northeastern margin of the Lachlan Fold Belt in central New South Wales and occurs mostly within the Capertee Structural Zone of Scheibner (1993). The western part of the area falls within the Hill End Structural Zone and has outliers of Permian sediment from the Sydney Basin Zone (Fig. 2).

Within the Capertee Zone, the Burranah Formation now forms the northernmost occurrence of the Late Ordovician Sofala-Rockley Volcanic Belt and is preserved along with elements of Late Silurian and Early Devonian shelf sequences. Carboniferous I-type granitoids intrude the Capertee Zone in the north and east of the area. Late Silurian turbidites comprise the basal unit of the Hill End Trough within the Hill End Zone.

The Late Ordovician volcanic units have been regarded as part of a single volcanic arc or series of arcs, possibly related to west-dipping subduction (Scheibner, 1974; Pemberton and Offler, 1985; Packham, 1987). However, Wyborn (1992) regarded these units as part of a mantle-derived igneous pile that were unrelated to Ordovician subduction.

From the Early Silurian until the Middle Devonian, the area probably occupied part of a backarc or intra-arc continental margin setting to the west of a west-dipping subduction zone located in the ancestral New England Orogen (Scheibner, 1989; Fergusson and Coney, 1992; Collins and Vernon, 1992). Extension in the eastern Lachlan Fold Belt created a series of meridionally-trending deep water basins or 'troughs' flanked by shallow marine to terrestrial platforms or 'highs' (Packham, 1960, 1969; Cas, 1983; Powell, 1984). The facies and palaeogeography of the Hill End Trough and its flanking volcanic margins (the Capertee and Molong Highs) during this time compare favourably with modern ensialic interarc or backarc basins, such as the southern Havre Trough in the Taupo Volcanic Zone north of New Zealand (Cas and Jones, 1979).

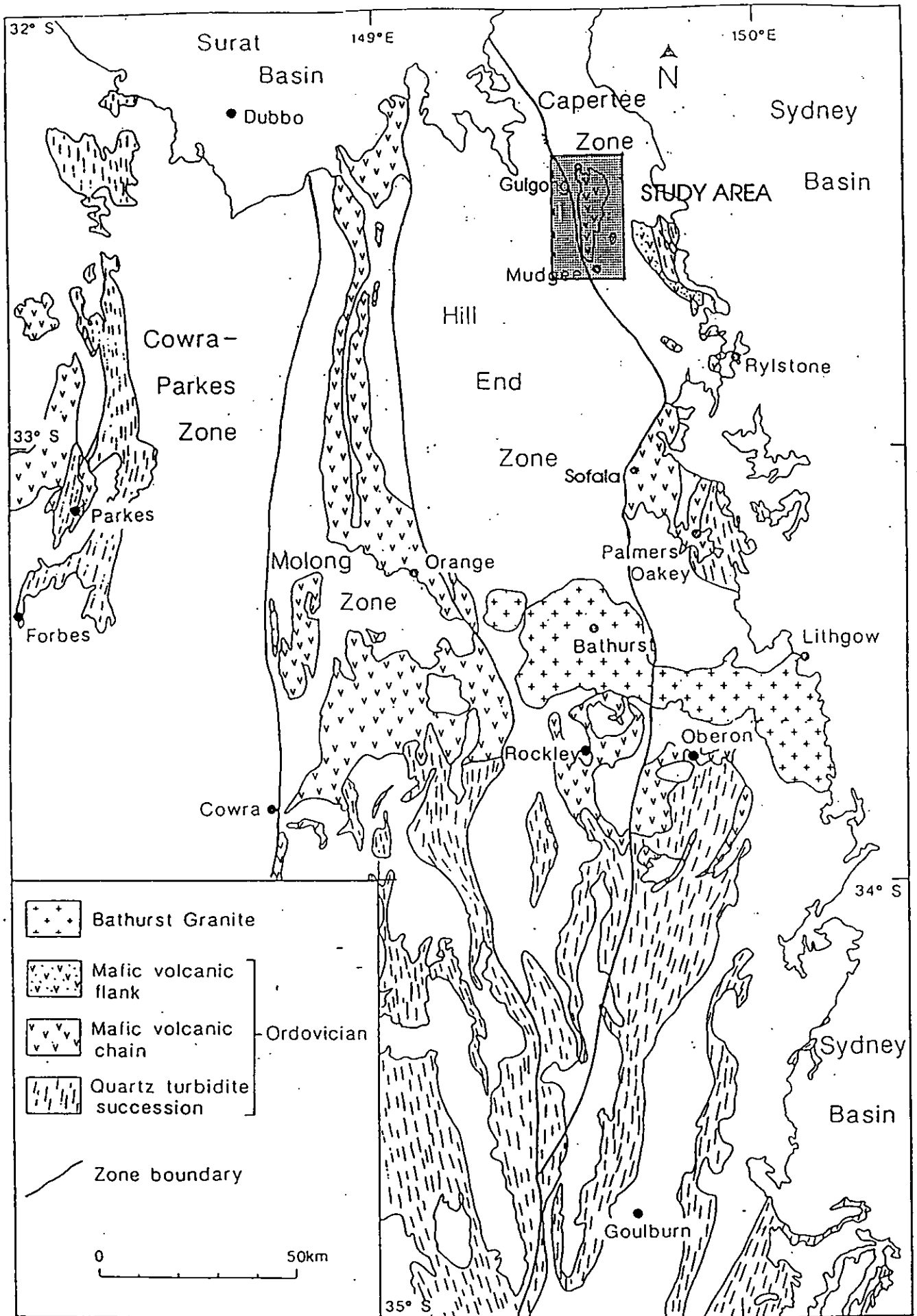


Fig.2. Location of main structural zones (adapted from Scheibner, 1993).

## REGIONAL STRATIGRAPHY

### Introduction

The first published account of the geology of the district was that by Jones (1940), with a map at 1:31,680 scale of the Gulgong Gold Field. Offenberget al., (1971) compiled the regional geology of the area as part of the Dubbo 1:250,000 geological sheet and established a stratigraphy for the area which has remained with little modification to the present day. Metallogenic data for the district was compiled by Matson (1973) from published and unpublished material. This data was published on a separate metallogenic map using a modified geological base after Offenberget al., (1973).

The accompanying 1:50,000 scale geological fact map (Fig. 3, in pocket) was compiled by the author from fieldwork undertaken during the period from July, 1995 to April, 1996. The 1:50,000 scale interpretative geological map (Fig. 4, in pocket) represents a synthesis of geological data and interpreted geophysical data, particularly magnetic data.

Considerable revision to the Palaeozoic stratigraphy of the area was required. This is shown in Fig. 5 which is a time-space diagram showing the previous and revised nomenclature for the area.

The newly revised stratigraphy of the area encompasses elements of an Ordovician volcanic belt and a Late Silurian shelf sequence located to the west of the Late Silurian to Early Devonian Hill End Trough sequence (Fig. 6). Together, these units form a westward-younging sequence that is similar to that found at Sofala about 70 km to the south.

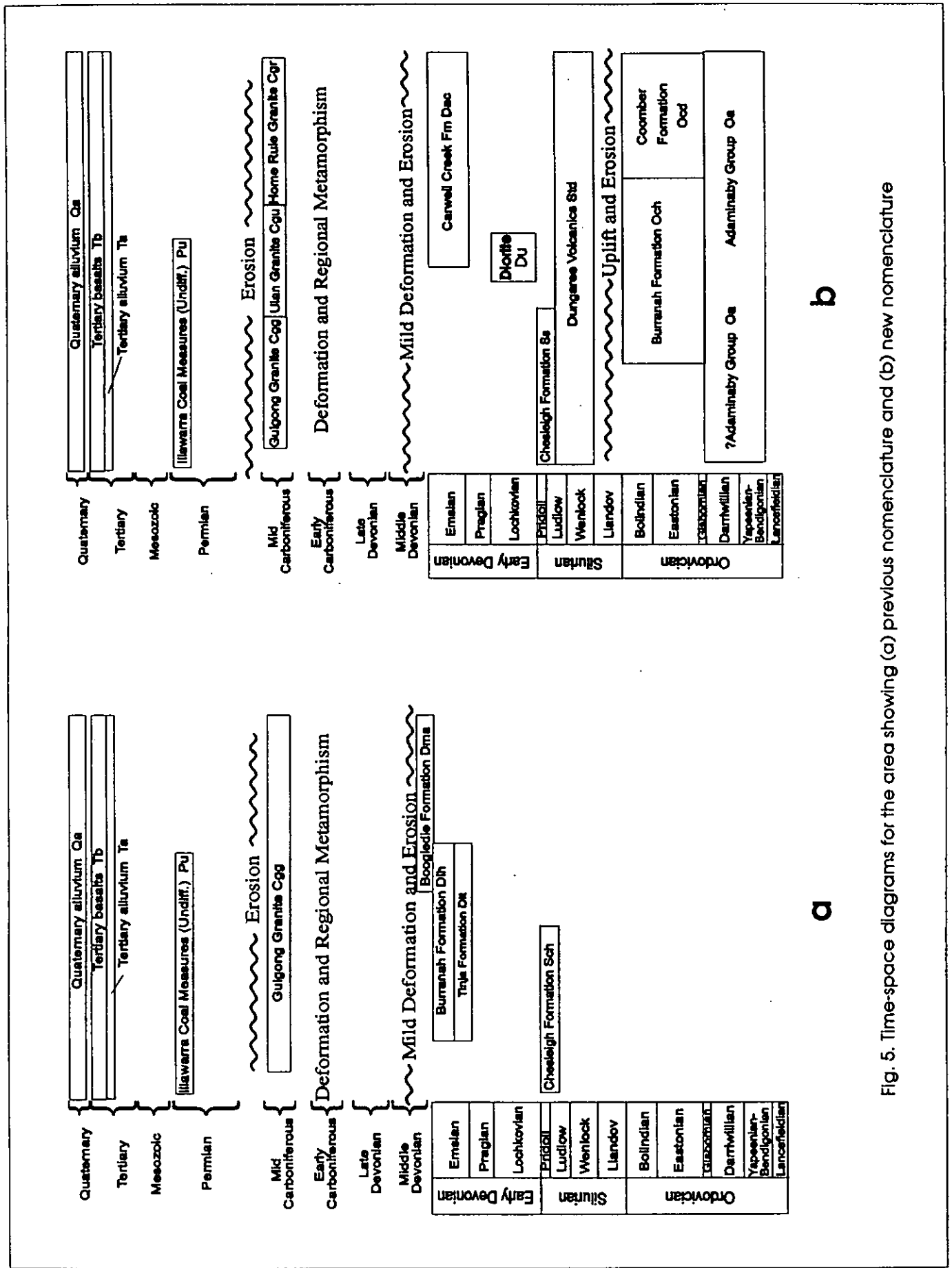
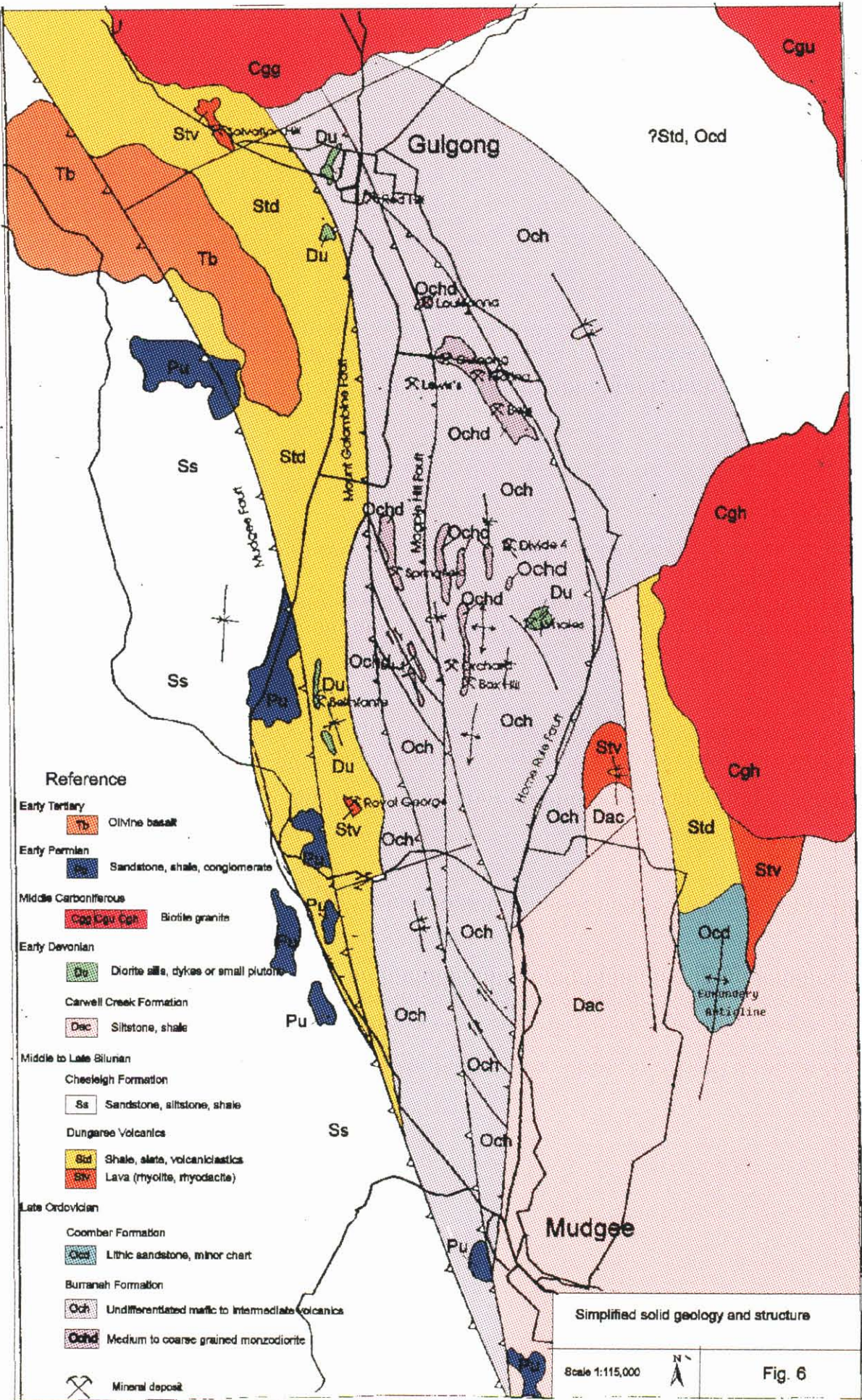


Fig. 5. Time-space diagrams for the area showing (a) previous nomenclature and (b) new nomenclature



## Late Ordovician Units

### *Burrannah Formation*

The Burrannah Formation comprises a north-trending belt of volcanics about 20 km long and 5 km wide between Mudgee and Gulgong (Fig. 6). The name Burrannah Formation was first used for this belt by Offenbergh et al. (1971) and assigned an Early Devonian age based on palaeontological work by Exon, (1962). This study continues this usage of the name but assigns a Late Ordovician age based on new fossil evidence. Results of geochemical and isotope studies of the Burrannah Formation compare favourably with other known Ordovician units in the Lachlan Fold Belt. The Burrannah Formation also has a distinctive red (potassic) radiometric signature that is characteristic of many of the Late Ordovician volcanics (particularly shoshonites) of the Lachlan Fold Belt.

The Late Ordovician Burrannah Formation and its distal equivalent, the Coomber Formation, are the oldest stratigraphic units exposed in the area. Evidence from new mapping to the south, on the Bathurst 1:100 000 sheet (Watkins, in prep.) and the Mudgee 1:100 000 sheet (Colquhoun et al., 1996), suggests that both of these units are underlain, or in part interfinger with, the Early Ordovician Adaminaby Group. The Adaminaby Group is a quartz turbidite fan deposit that has now been recognised throughout much of the Lachlan Fold Belt in eastern New South Wales (Ferguson et al., in press).

The Burrannah Formation dominantly comprises a syn-eruptive and post-eruptive sequence of intermediate to mafic volcanoclastic sandstone and breccia accompanied by minor coherent lava, intrusions, and non-volcanic sedimentary rocks. The unit is poorly exposed and shows rapid lateral facies changes which together make it difficult to distinguish an internal stratigraphy.

### *Syn-eruptive volcanoclastic deposits*

Resedimented syn-eruptive deposits occur throughout the Burranah Formation. Coarse grained volcanic breccias form units with outcrop widths up to 100m and strike lengths of up to 1 km. Individual units are very thickly bedded and are generally unsorted. They are matrix supported and contain angular lithic blocks up to 20 cm in a sandy matrix (Fig. 7). The deposits are essentially monolithologic with clasts of latite composition and often show a crude reverse grading and bedforms that indicate rapid deposition. Resedimented hyaloclastite breccia is also present and forms medium bedded units with little lateral extent. Fig. 8 shows a matrix supported hyaloclastite breccia with a chlorite altered fine grained volcanoclastic sediment matrix. The clasts are aphanitic latite and are also chlorite altered.

### *Volcanic sandstone and siltstone*

Juvenile, clast-rich volcanoclastic sandstones and siltstones form the principal volcanic facies of the Burranah Formation. The sandstones are the dominant facies and generally consist of fine to medium grained, well sorted, angular, volcanic lithic fragments (usually latite) and minor crystal fragments. Beds vary from thinly bedded to very thickly bedded and they can form both massive ungraded units and graded turbidite units interbedded with siltstones. There is little evidence for any traction current reworking.

### *Intermediate and mafic lavas*

Lavas are relatively uncommon and generally form massive units up to 5m thick which can be traced for up to 10 m to 15 m along strike. The lavas are compositionally dominated by potassium-rich latites (extrusive equivalent of monzonite) but also include absarokites and shoshonites. They are generally chlorite altered and porphyritic, carrying feldspar and/or euhedral phenocrysts of clinopyroxene. Rare pillow basalts are also present.



Fig. 7. Coarse grained volcanic breccia unit with matrix supported angular lithic blocks in a sandy matrix.



Fig. 8. Resedimented hyaloclastite breccia. Clasts of chlorite altered quenched latite in a matrix of altered volcaniclastic sediment.



### *Syn-volcanic intrusions*

Medium to coarse grained intrusions of monzodiorite are relatively common within the Burranah Formation. The intrusive bodies range up to 3 km in length by 600 m to 700 m wide and are elongate parallel to the strike of the country rock. They are compositionally similar to the volcanics and are interpreted to be co-magmatic.

The volcanic facies described above are interbedded with a sedimentary facies that comprises massive black (often pyritic) mudstone, graded sandstone turbidites, conglomerates and breccias of mixed provenance. The breccias often contain clasts of limestone and have rare red (oxidised) volcanic clasts. Poor outcrop and rapid facies changes make it difficult to distinguish an internal stratigraphy, however an interpretation of the airborne magnetic data and measured structural data suggests the Burranah Formation can be sub-divided into two main magnetic packages. The lower package (V1, Fig. 4, Fig. 9, Fig. 11) has a moderate to high magnetic signature and a high proportion of coherent volcanics, and breccias. The upper package (V2, Fig. 4, Fig. 9, Fig. 11) is less magnetic and consists dominantly of volcanoclastic sandstone, comagmatic intrusions and sediment. Although these magnetic packages cannot be mapped, they have been incorporated into the interpretative cross-section (Fig. 9) as a guide to the internal structure of the Burranah Formation.

The presence of black pyritic mudstone, abundant mass flow deposits (including turbidites), hyaloclastite and pillow lava provide evidence for a dominantly below storm wavebase, submarine setting. However the presence of numerous limestone blocks also suggests the volcanics were partly emergent with fringing reefs.

The Burranah Formation is now regarded as Late Ordovician. This age is based on the identification by J. Pickett (pers. commun.) of the corals *Plasmoporella* sp., *Nyctopora* sp., and *Heliolites* sp., plus the ubiquitous Ordovician alga *Vermiporella* sp. in limestone clasts from a debris flow unit north of Mudgee. Pickett (1978) reported the same coral

and alga, together with a Gisbornian conodont fauna, from limestone clasts in a breccia from the Late Ordovician Sofala Volcanics, 80 km to the south. The total thickness of the Burranah Formation is estimated from the interpretative cross section (see Fig. 4) to be 2.5 km.

### *The Coomber Formation*

The Coomber Formation occurs in the core of the Eurundury Anticline in an area formerly mapped by Offenberg (1971) as part of the Early Devonian Boogledie Formation. In the Eurundury Anticline area, the Coomber Formation is unconformably overlain by the Late Silurian Dungaree Volcanics and the Early Devonian Carwell Creek Formation. The formation was named by Pemberton et al (1994) for a thick succession of lithic sandstone, mudstone, radiolarian chert with minor mafic lavas and conglomerate occurring along the Cudgegong River near Rylstone to the southeast of Mudgee.

In the Mudgee-Gulgong district, the Coomber Formation is dominated by massive lithic sandstones. It has a distinctive red (ie., potassic) radiometric signature that is similar to the Burranah Formation and many other Ordovician volcanic units in the Lachlan Fold Belt. The massive and thick-bedded nature of the lithic sandstones is consistent with deposition by high density turbidity currents in a deep marine environment. The Coomber Formation has not been dated directly, but on stratigraphic grounds it is thought to be a distal equivalent of the Burranah Formation.

## Silurian Units

### *Dungaree Volcanics*

The name Dungaree Volcanics was first used by Offenberg et al., (1971) for a belt of felsic volcanics west of Rylstone and Kandos. The unit was assigned to the local name Moonbucca Formation by Pemberton et al., (1994) but the original name has now been re-introduced.

The Dungaree Volcanics comprise a Middle to Late Silurian succession that unconformably overlies or is faulted against the Burranah Formation and Coomber Formation. In the western part of the area, the unit is overlain by the Chesleigh Formation with apparent conformity and its areal extent corresponds approximately to that previously mapped as the Early Devonian Tinja Formation

The Dungaree Volcanics consist of a 700 m thick volcanic sequence that becomes increasingly sediment dominated towards the top. The volcanic-rich base consists of felsic volcanoclastic arenite with thick beds of coherent rhyolite and rhyodacitic lava (rarely flow banded) and rare autochthonous limestone. The top of the unit is dominated by non-volcanic shale.

An age of  $416 \pm 5$  Ma was obtained by U/Pb SHRIMP techniques for zircon from dacite lavas of the Dungaree Volcanics to the south of the study area (Colquhoun et al., 1996). Within the study area, an autochthonous limestone pod was located towards the base of the unit about 1 km southeast of Mount Galambine. The limestone from this site contained the following Mid to Late Silurian (Wenlock-Ludlow) fauna:

Rugose corals: *Phaulactis shearsbyi*; *Tryplasma* sp.

Tabulate corals: *Favosites* sp.; ?*Favosites lichenaroides*; *Coenites* cf. *juniperinus*;  
*Coenites* cf. *pinaxoides*.

Stromatoporoids: *Ecclimadictyon* sp.; *Densastroma* sp.; ? *Parallelostroma* sp.

Algae: *Solenopora* sp.; *Ortonella* sp.

Brachiopods: *Kirkidium* sp.

The presence of coral and a shelly fauna toward the base of the unit with flow banded rhyolite suggests that the Dungaree Volcanics were deposited in a shallow marine to emergent shelf environment that preceded deeper-water sedimentation in the Hill End Trough.

The Dungaree Volcanics in the map area are lithologically similar to a number of other Middle to Late Silurian units that also overlie Ordovician rocks to the south of the study area. These include the Willow Glen Formation and Windamere Volcanics in the Cudgegong district (Pemberton, 1990); the Tanwarra Shale and Bells Creek Volcanics in the Sofala district (Packham, 1969); and the 'mudstone-limestone facies', west of Capertee (Bishoff and Fergusson, 1982). Correlatives of the Dungaree Volcanics also occur on the western side of the Hill End Trough and include the Mullions Range Volcanics. The Mullions Range Volcanics host the important Lewis Ponds polymetallic massive sulphide deposit and the Mount Bulga massive sulphide deposit. These units also have shallow marine settings and were probably contemporaneous with the Dungaree Volcanics.

In the Eurundury Anticline area the Dungaree Volcanics contain weakly disseminated pyritic sulphides and thin quartz veins. This weak dispersed mineralisation may have been a contributing source to the small alluvial gold deposits found in streams that drain this area to the west.

### *Chesleigh Formation*

The Middle to Late Silurian Chesleigh Formation conformably overlies the Dungaree Volcanics in the western part of the study area where it forms the basal unit of the Hill

End Trough. The name was first published by Dulhunty and Packham (1962), and later defined by Packham (1969). The Chesleigh Formation is a deepwater turbiditic unit with several horizons of felsic volcanics towards the top. The turbidites show considerable variation in the sand and shale ratio, with sandstones becoming thinner and less prevalent towards the top. Only the basal part of the Chesleigh Formation crops out within the study area and consists of interbedded quartz-lithic and feldspar-lithic sandstone with minor quartz siltstone and shale.

## **Early Devonian Units**

### *Carwell Creek Formation*

The Carwell Creek Formation occurs to the northeast of Mudgee around the Eurundery Anticline where it unconformably overlies the Dungaree Volcanics and is faulted against the Burranah Formation. In the Eurundery Anticline area, the unit was originally mapped as the Melrose Formation by Wright (1966), and subsequently renamed the Boogledie Formation by Offenberg et al. (1971). To the west of the Eurundery Anticline the unit was previously mapped as the Tinja Formation (Offenberg et al, 1971).

The Carwell Creek Formation is the uppermost unit of the Kandos Group (Pemberton et al, 1994) and crops out extensively in the Rylstone-Cudgegong district about 80 km to the south. In this area, the unit comprises over 1000m of siliclastics and carbonates deposited in barrier island and shoreline settings (Pemberton et al, 1994; Colquhoun, 1996).

In the Mudgee-Gulgong district, the Carwell Creek Formation consists dominantly of poorly outcropping siltstone and shale. A more resistive ridge-forming sandstone unit occurs at the base of the formation and forms a distinctive low ridge that outlines the Eurundery Anticline.

The lower sandstone unit is composed of iron stained, massive, fine to coarse-grained quartz, quartz lithic and quartzofeldspathic sandstone, with minor pebbly sandstone, siltstone and conglomerate. A fossil horizon occurs near the middle of this unit containing spirifers, crinoid ossicles and gastropods. The upper part of the unit consists of a poorly outcropping and monotonous sequence of siltstone and shale with minor pebbly and crinoidal tuffaceous sandstone. A thin limestone horizon occurs high in the unit,

Vertical (skolithos type) burrows, tabular cross beds and channels, common disarticulated crinoids and occasional ?reed fragments suggest a near shore shallow marine depositional setting. An Early Devonian age (Late Pragian to Early Emsian) was suggested for the unit by Colquhoun (1995) for the Rylstone-Cudgegong area based on conodonts, brachiopods and corals. A new fossil site located 10 km north of Mudgee produced a diverse shelly fauna with a probable Late Emsian age (T. Wright, pers commun.). Exon (1962), reported an Early Devonian age for corals, a trilobite, gastropods, molluscs, bryozoans, and fossil wood from the brick pit quarry north of Mudgee (previously mapped as Tinja Formation).

The Carwell Creek Formation represents the uppermost unit of an extensive shallow marine platform sequence located on the Capertee High during the Early Devonian. The presence of the Carwell Creek Formation in the map area now represents the northernmost occurrence of the unit and a similar palaeogeographic setting for this part of the Capertee High during the Early Devonian.

### *Diorites*

Small diorite intrusives were recorded west of Gulgong and at the abandoned Red Hill mine (now located within the Gulgong town boundary) by Jones (1940) and Offenbergl (1971). They were thought to be associated with the nearby Gulgong Granite and were assigned a similar Carboniferous age. However a number of additional occurrences have now been located to the south of Gulgong which also host gold mineralization. At the

Belinfante Deposit (deposit no. 13, Fig. 3), a diorite dyke intrudes the Dungaree Volcanics and at the Whales Deposit (deposit no. 10, Fig. 3) a small circular diorite body intrudes the Burranah Formation.

The diorites are composed of interlocking, euhedral, fine to coarse-grained plagioclase crystals (typically albite) with minor pyroxene. The feldspar is often weakly altered to carbonate and sericite and microveins of carbonate are also present.

An age of  $409 \pm 7$  Ma was obtained by U/Pb SHRIMP techniques for zircon from the diorite body at the Whales Deposit. The diorites near Gulgong, and the new additional occurrences, have similar whole rock geochemistry that is also distinct from the Carboniferous granites. They are all now regarded as part of the same Early Devonian magmatic event.

### **Middle Carboniferous**

Large areas of granite occur to the north, northeast and southeast of Gulgong (Fig. 6) that were previously regarded as a single batholith referred to as the Gulgong Granite (Offenberg et al, 1971). New airborne magnetic data however, show the large area can be subdivided into three plutons. These have been named the Gulgong Granite, the Ulan Granite and the Home Rule Granite.

The granite bodies have all been passively emplaced and intrusive relationships between the three plutons suggest that they young to the south. All three granites are discordant, unfoliated, post-deformation I-type, biotite granites intruded at high crustal levels. The Gulgong Granite is faulted on its southern and western sides and the Home Rule Granite is cut by numerous northeast and northwest-trending fractures and late stage dykes. A 318 Ma (Middle Carboniferous) age has been determined from K/Ar ratios of biotite separates for the Ulan Granite (Jones, 1986).

## **Early Permian**

Early Permian rocks (part of the Illawarra Coal Measures) are restricted to the western part of the map area and occur as thin, flat-lying veneers that overlie older rocks with angular unconformity. The sediments consist predominantly of fine and coarse-grained sandstone, conglomerate and shale, with occasional lenticular beds of carbonaceous shale that pass into thin coal seams. *Glossopteris* is abundantly distributed throughout. The basal unit consists of coarse conglomerate ranging from 6 m to 15 m in thickness. Gold has been mined from these basal conglomerates at Slashers Flat, about 7.5km northwest of Mudgee.

## **Early Tertiary and Quaternary**

The early history of Gulgong is associated with the mining of gold from the Early Tertiary alluvial deposits (deep leads). The Early Tertiary deep leads follow down palaeo-valleys which have their headwaters in the Burranah Formation. The more accessible shallow parts of the deep leads were only 1.5 cm to 4 cm in thickness and were quickly mined out. The sediments within the leads were mostly gravel, sand and mudstone (Jones, 1940).

Early Tertiary olivine basalt crops out extensively to the west of Gulgong where it follows a northwest-trending palaeo-valley. Basalt also occurs in many of the deep leads (Rayner, 1940), where flows up to 50 m thick cap the Early Tertiary alluvial deposits. Dulhunty (1972), reported K/Ar dates of 15.2 Ma and 14.2 Ma (Middle Miocene) for the basalts to the west of Gulgong.

Extensive deposits of Quaternary alluvium, colluvium, and residuum occur throughout the area and mask much of the bedrock geology. Alluvial deposits of unconsolidated sand, gravel and clay are associated with the Cudgegong River and its tributaries. The modern drainage system has also been worked in many areas for small amounts of alluvial gold.



## REGIONAL STRUCTURE

The Mudgee-Gulgong district lies mostly within the Capertee Structural Zone of Scheibner (1993). To the west are elements of the Hill End Structural Zone and outliers from the Sydney Basin Zone are preserved west of Gulgong

The Sydney Basin strata are for the most part, flat lying and undeformed. Strata of the Hill End Zone, in the west of the map area, are characterised by open, south-plunging, north to north northwest-trending folds and few faults. The Capertee Zone however contains north northwest-trending folds, several major thrusts, north trending oblique-slip faults and numerous northwest and northeast-trending faults. The Capertee Zone and the Hill End Zone are separated by the northern continuation of the Mudgee Thrust (Fig. 4).

Evidence for significant pre-cleavage deformation is meagre and re-fold patterns observed in Ordovician strata to the south (eg, Capertee area, Ferguson, 1979; Glen and Watkins, in prep.) are not found in the Mudgee-Gulgong district. A weak pre-Late Silurian D<sub>1</sub> has been reported for the Orange area of the Lachlan Fold Belt by Glen and Watkins (1994)

In the Eurundury Anticline there is an angular unconformity between Late Ordovician Coomber Formation and the Late Silurian Dungaree Volcanics. However a lack of structural data close to the contact makes it difficult to gauge the degree of angular discordance. Unconformities exist on both sides of the Hill End Trough at the base of the Late Silurian, and indicate that the trough opened during the Early Silurian (Glen and Watkins, 1994).

Although it is probable that the Late Ordovician rocks were deformed before deposition of the overlying Late Silurian units, it is not possible to identify any structures in these rocks that are not present in younger rocks.

An angular unconformity is also present between the Late Silurian Dungaree Volcanics and the Early Devonian Carwell Creek Formation. However the degree of angular discordance is low and this break may best be attributed to erosion due to sea-level fall or very gentle uplift and tilting. Unconformities are also widely developed to the south of the study area where Powell and Edgecombe (1978) found a low angle discordance between Early and Late Devonian sequences in a structural study of the Mount Frome syncline. They concluded that erosion, uplift and broad tilting had occurred during the Middle Devonian Tabberabberan Orogeny.

The major Early Carboniferous deformation ( $D_2$ ) (Powell and Edgecombe, 1978) was responsible for the majority of folding, thrusting and cleavage formation in the study area. The Hill End Zone is characterised by generally tight, upright  $F_2$  folds with long planar limbs and angular to rounded hinges, normally with axial plane cleavage well developed.  $F_2$  folds typically plunge at shallow angles to the south.  $D_2$  structures in the Capertee Zone are considerably more varied and complex. The major separating structure, the Mudgee Thrust, is a steeply west-dipping thrust fault with Hill End Zone sediments thrust eastwards over Capertee Zone rocks.

East of the Mudgee Thrust  $D_2$  was responsible for at least two generations of faults. Early faults are commonly steeply west-dipping faults parallel to strike such as the Mount Galambine Fault, the Magpie Hill Fault and the Home Rule Fault (Fig. 6). Shear sense indicators preserved on the Mount Galambine Fault indicate the hanging wall has moved to the east. A later series of faults is also present and cuts across the prevailing strike and fold axis at high angles. North to northwest-trending  $F_2$  folds are generally tight with shallow plunges to the south. Doubly plunging folds are present in the Burranah Formation between the Magpie Hill Fault and the Home Rule Fault. Cleavage ( $S_2$ ) within the Burranah Formation is poorly developed but generally axial planar to the major folds. Within the Burranah Formation footwall synclines are developed east of the Magpie Hill

Fault and east of the Home Rule Fault. The Magpie Hill Fault has shear sense indicators that suggest dextral oblique-slip movement and together with the Mount Galambine Fault define a 1 km wide zone that has undergone dextral, oblique-slip deformation. Several folds in the footwall of the Magpie Hill Fault have their western limbs truncated by this fault indicating a period of later movement that postdated the folding event. Considerable shortening has taken place between the Mudgee Fault and the Home Rule Fault within the Burranah Formation and Dungaree Volcanics (Fig. 9). Between these two faults is a zone of higher strain in which most of the known primary gold deposits are located.

During the Carboniferous, the northeastern Lachlan Fold Belt was located in a backarc setting to the west of the well developed east-facing margin of the New England Fold Belt (Murray et al., 1987). Regional deformation (D<sub>2</sub>) of the northeastern Lachlan Fold Belt, in the Early Carboniferous, coincides with development of a subduction complex in the eastern New England Fold Belt (eg. Fergusson et al., 1993).

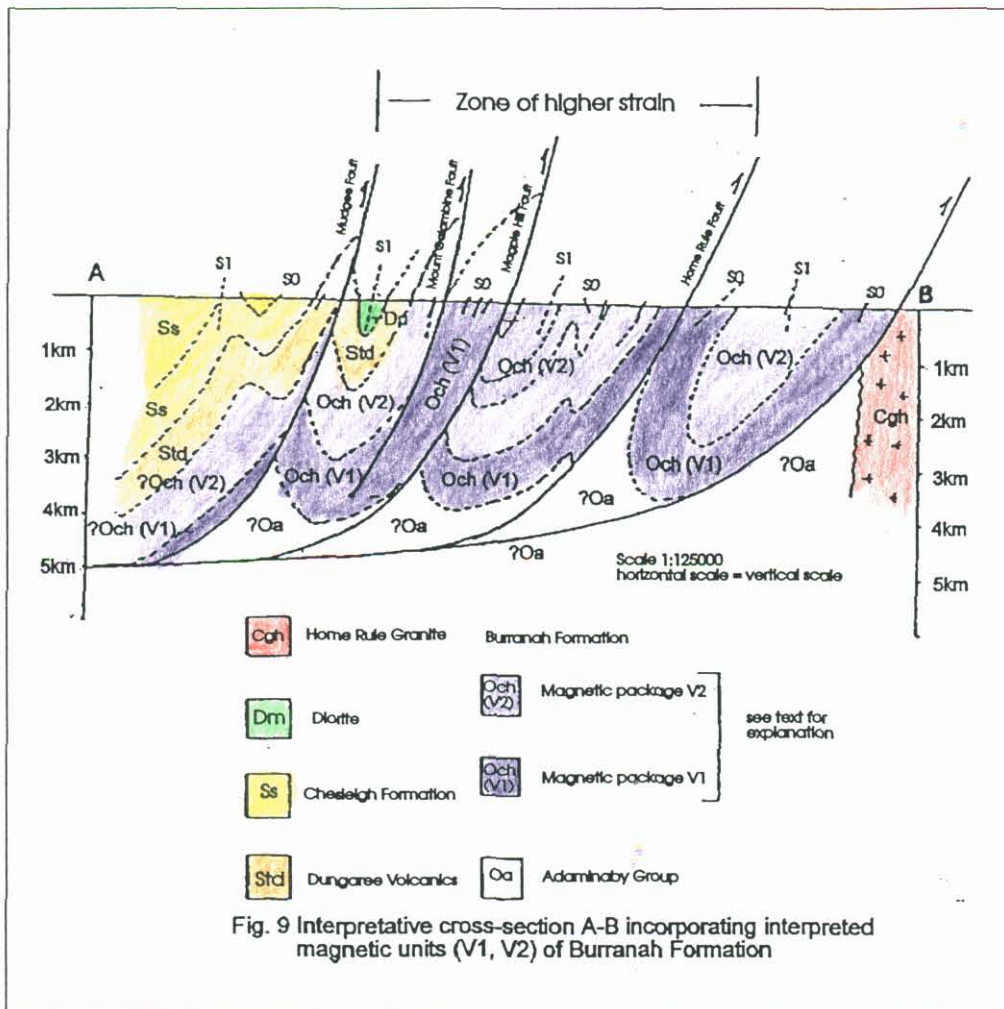


Fig. 9 Interpretative cross-section A-B incorporating interpreted magnetic units (V1, V2) of Burranah Formation