THE GEOLOGICAL EVOLUTION AND MINERALISED ENVIRONMENTS OF THE TASMAN GEOSYNCLINE

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C O N T E N T S

INTRODUCTION

The Tasman Geosyncline covers the eastern part of the continent of Australia, an area of over 2 million km^2. The area has been a major source of Australian gold and tin production, and though it contains important base metal sulphide deposits, these are overshadowed in scale by the very large stratabound Proterozoic deposits (for example, Mt Isa, Broken Hill and McArthur River). This dissertation deals with the metallic mineral deposits of the Tasman Geosyncline, and as such does not include the extensive post Palaeozoic continental successions, with their important coal reserves, that overlie the deformed geosynclinal sequences.

In this dissertation the geological evolution of the Tasman Geosyncline has been described, most of which occurred between the Cambrian and Triassic periods. Particular emphasis has been placed on the regional setting of mineralised environments within the evolving Geosyncline. In the reconstruction of the environments of magmatism and sedimentation within the Geosyncline, considerable emphasis has been given to palaeogeography, while palaeoclimatic and fossil evidence has also been provided.

In the section entitled "Tasman Metallogeny", some important ore deposits of the Tasman Geosyncline are examined in greater detail in order to determine the smaller scale (sub-regional) controls of ore deposition. Due to space considerations the deposits described have included only one example from each of the major categories of Tasman ore deposits. These categories include Cyprus-type cupreous pyrite deposits, Captains Flat-type stratabound volcanic base metal sulphide deposits, Cobar-type sedimentary copper deposits, granite-derived vein-, disseminated- and replacement-type gold and base metal deposits, and gold-quartz veins apparently not associated with granitic intrusives.

Enclosed in the back cover is a locality map of some Tasman Geosyncline deposits within their constituent fold belts, with the deposits listed in the Appendix. It must be emphasised that this is not intended as an exhaustive list of mineral occurrences within the Geosyncline, but is rather a location map for the more significant ore deposits which have been specifically discussed in the text. These deposits have been subdivided according to the categories mentioned above, except that "volcanic-associated" deposits here includes subaerial environment vein and disseminated deposits as well as submarine environment massive sulphides.

Until the 1970's both the Tasman Geosyncline and its constituent fold belts were known by the formalised title "Geosyncline". However, during the 1970's the word "geosyncline" generally lost favour and was replaced by a proliferation of tectonic terms, including "Orogen", "Orogene", "Orogenic Province", "Orogenic System", "Fold Belt", "Fold Belt System", "Mobile Belt", "Marginal Mobile Zone", etc. In this dissertation the formal title "Geosyncline" has been retained only for the Tasman Geosyncline, while the constituent fold belts (for example, the Lachlan, Thomson, etc.) are given the informal names "orogen", "fold belt" or "geosyncline".

In describing the geological history of a complex area of well over 2 million km^2, a major emphasis has been on the synthesising of information down to a specific level of detail. This has been hampered by the widely varying degree of detail of published information available for the constituent fold belts of the Geosyncline. On the one hand, the Lachlan fold belt is generally well known and its geological environments and mineral occurrences are well documented, while on the other hand, the Thomson orogen, which is largely obscured by later cover and occurs mostly in more remote parts of the country, is much less well known with correspondingly less published information available. The other fold belts are, in this respect, intermediate between the Lachlan and Thomson orogens.

Although the natural evolution of the Tasman Geosyncline's constituent fold belts (from crustal attenuation to subsidence, flysch type sedimentation, orogeny and post-kinematic magmatism) followed cycles considerably longer than the individual geological periods, this evolution has been described period by period (i.e. Cambrian, Ordovician, etc.). This has been done in order to achieve a more objective synthesis of contemporaneous events occurring in different parts of the Geosyncline.

Space has not permitted an account of the role of plate tectonics in the interpretation of the evolution of the Tasman Geosyncline. However, several such accounts are referenced, and include those by Oversby (1971), Solomon and Griffiths (1972), and Scheibner (1973), with a synthesis of these theories by Packham and Leitch (1974).

Location and Tectonic Setting

The Tasman Geosyncline (also called the Tasman Fold Belt System or Orogenic System) is a composite tectogenic or structural feature constituting the eastern part of the continent of Australia. It is composed of a series of Palaeozoic fold belts or orogens, trending roughly north-south, stretching for over 3 000 km from northern Queensland to Tasmania and occupying approximately one-third of the Australian continent.

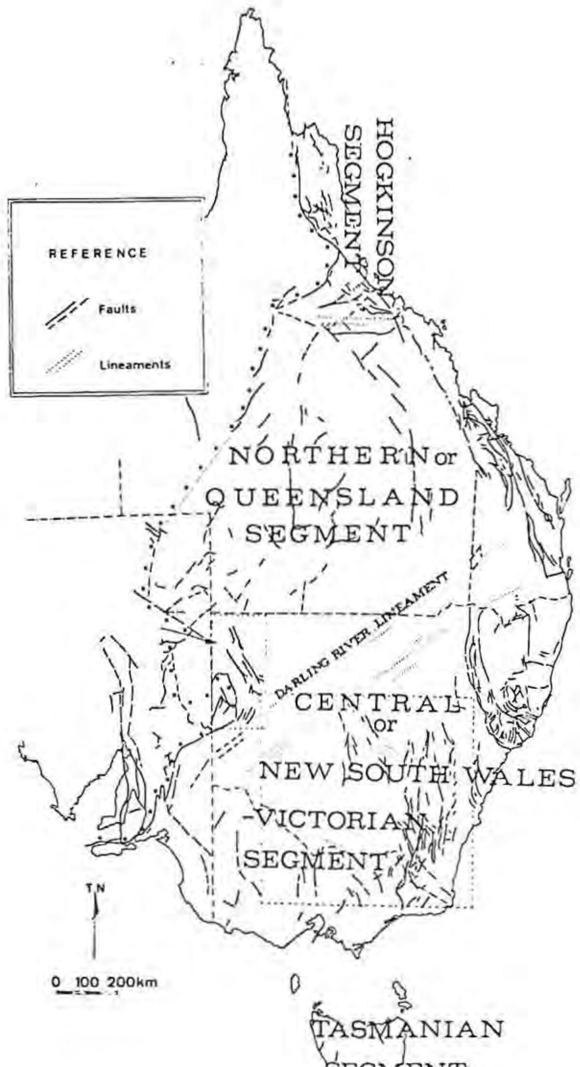

Fig. 1.1 Schematic map showing the segments of the Tasman Geosyncline (Modified from Scheibner 1978)

Scheibner (1978) shows the Tasman Geosyncline subdivided into several segments, separated by extensive "fossil fracture zones" (see fig 1.1). These plates may represent individual lithospheric blocks or subplates, active during the Palaeozoic, which are today welded into the Australian plate.

Four major segments are recognised: the Hodgkinson Segment occurs north of the Clark River and Burdekin River Lineaments, and is bordered to the South by the Northern or Queensland Segment. This segment is found between the above lineaments to the north and the Darling River and Cobar-Inglewood Lineaments to the South. Large areas of this segment are obscured beneath Mesozoic and Cainozoic cover. Between the Darling River and Cobar- Inglewood Lineaments, and the coast of Victoria to the south occurs the Central or New South Wales - Victorian Segment, while the Tasmanian Segment occupies the southern end of the Geosyncline. Differences in tectonic history (as well as sedimentary and igneous activity and structural deformation) may be seen between these segments.

Superimposed on these now-welded segments or subplates are the major, approximately north-south trending fold belts which comprise the Tasman Geosyncline. These are, from south west to north east (older to younger), the Kanmantoo, Lachlan, Thomson, New England and Hodgkinson - Broken River fold belts.

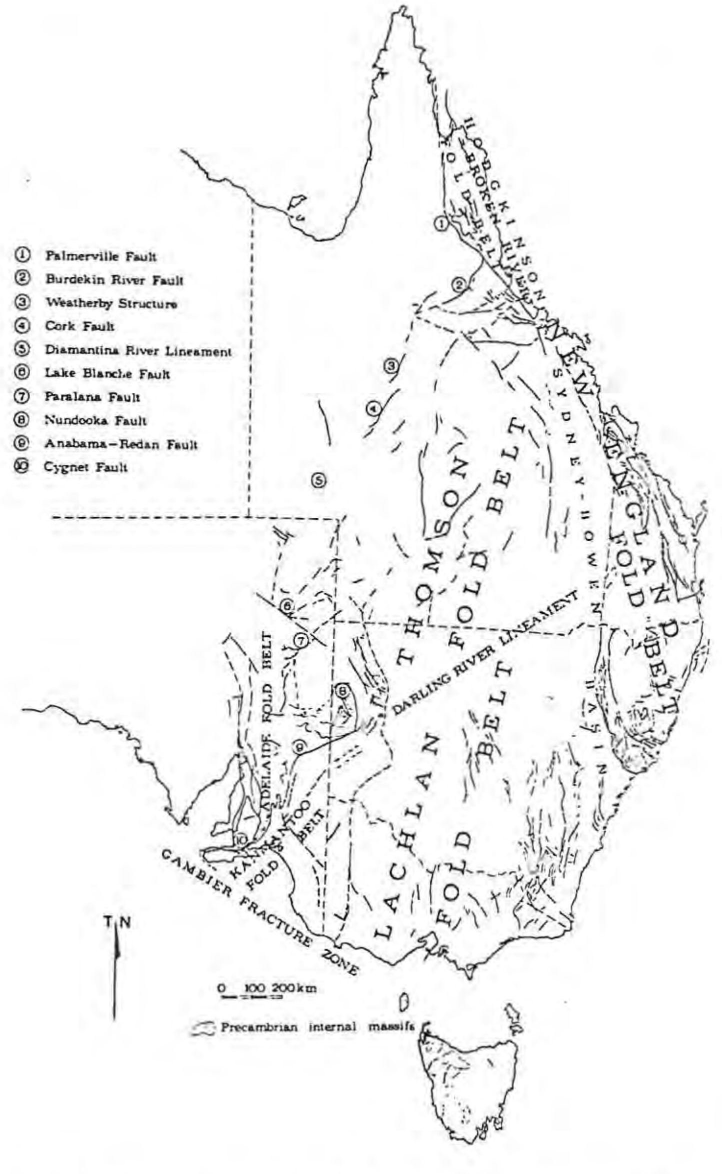

Fig. 1.2 Schematic map of Tasman Geosyncline, showing boundaries and a distribution of constituent fold belts. (from Scheibner 1978)

The Tasman Geosyncline may be defined as a composite orogenic belt which has developed from several partly-overlapping pre-cratonic tectonic provinces (also referred to as geosynclines or fold belts) during the Palaeozoic of eastern Australia. These pre-cratonic provinces were probably mobile zones marginal to the Australian plate, perhaps in a similar tectonic setting to that of the present south west

Pacific. Tectogenic activity in eastern Australia generally terminated at the end of the Palaeozoic, though some activity in the north east part of the Geosyncline continued into the Mesozoic.

The eastern boundary of the Tasman Geosyncline has in the past been taken as the present eastern continental margin of Australia. Strictly speaking, however, it should be taken as far east as the western edge of the late Palaeozoic and Mesozoic New Zealand and New Caledonian geosynclines, and should include various micro continent elements in the south west Pacific Ocean.

Much of the western boundary of the Tasman Geosyncline is obscured and disputed. Generally the south western boundary may be taken along the Cygnet and Anabama - Redan Faults which separate the orogenic Kanmantoo fold belt from the intracratonic Adelaide Fold Belt. Fig. 1.2 shows a possible western boundary of the Geosyncline extending north eastwards from the Anabama - Redan Fault Zone, through the Nundooka, Paralana and Lake Blanche Faults, the Diamantina River Lineament, Cork Fault, Weatherby Structure and Burdekin River and Palmerville Faults.

Physiography

Introduction

Australia is a largely arid continent whose 7,7 million km^2 lies astride the Tropic of Capricorn. It is unusual among continents in that it contains no active volcanoes or permanent snowfields or glaciers, while its highest peak attains only 7308 ft (2227 m). Areas of highland do occur but are largely uplifted and dissected peneplains. Fig 1.3 shows the major topographic regions of Australia.

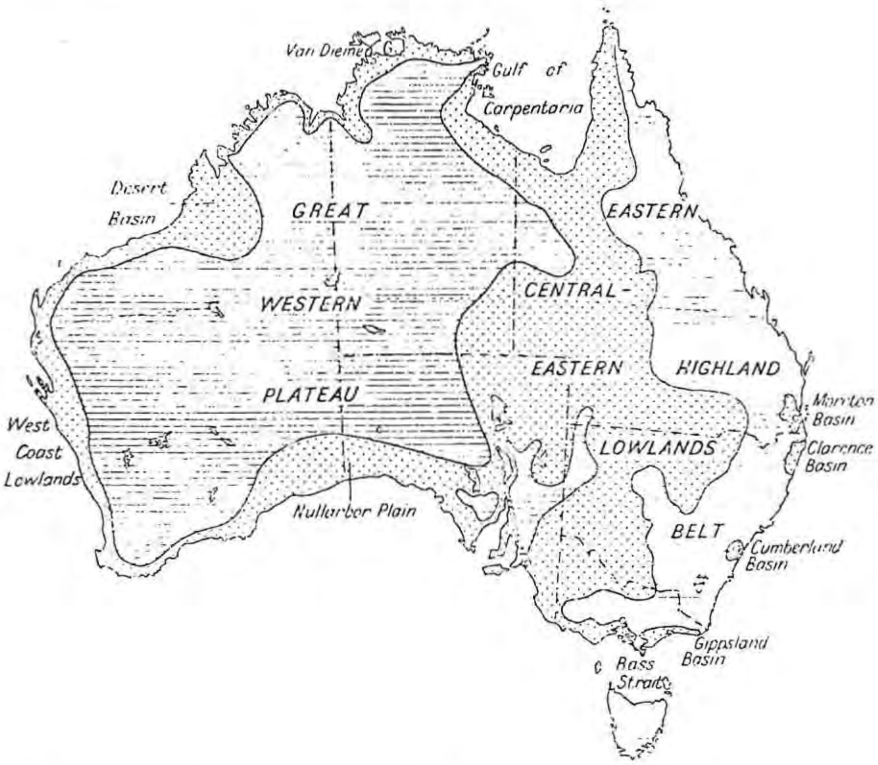

Fig. 1.3 Major Topographic Regions of Australia

(From David 1950)

The area underlain by the Tasman Geosyncline comprises the States of Queensland, New South Wales, Victoria and the island state of Tasmania. The three mainland states fall into three major physiographic sub-divisions; the

Eastern Highland Belt occurs along the coast and west of the Main Divide (the watershed of the highlands); it merges into the Central - Eastern Lowlands which itself merges into easterly remnants of the Great Western Plateau (the latter does not form part of the area under consideration and will not be discussed further here).

The Eastern Highland Belt follows the east coast of Australia, roughly north-south in orientation and convex towards the Pacific. In Victoria the highlands change to an east-west trend, and die out near the border of South Australia. Tasmania also falls physiographically within this belt.

This highland belt, composed mainly of folded and steeply dipping Palaeozoic rocks, is very narrow in the north, but widens to the south to a maximum width of over 650 km. In the southern part of the belt, two large embayments occur on its west side, which correspond to the drainage basins of the Darling and Murray Rivers. On the landward side the highlands merge very gradually into the Central - Eastern Lowlands, while towards the coast there may be a gradual slope or the highlands may terminate with cliffs against the sea. The axis of this highland belt undulates in altitude and bears no constant relation to the regional strike of the constituent rocks (in Victoria cutting right across the grain of the country). Transverse structural and erosional gaps appear at intervals along the belt.

In Queensland most of the belt is below 600 m in altitude, while relief generally increases towards the south in New South Wales, Eastern Victoria and Tasmania. The highest altitudes are reached in the Kosciusko Plateau of south east New South Wales.

Much of the continent of Australia has been peneplained by a duricrusted Miocene surface, and although large parts of this surface have been eroded away from the eastern highlands, areas of it survive, especially in the drier parts of Queensland and New South Wales, as well as sporadically in Victoria and Tasmania. Isolated hills, plateau remnants of various sizes, and residual mountain ranges rise above this Miocene surface. Monadnocks on the Miocene surface are often regarded as remnants of an earlier Cretaceous peneplain, although some monadnocks are capped with basalt more or less identical to known Tertiary basalts. The Miocene peneplain was uplifted in the late Miocene, with a further major uplift in the late Pliocene (named the Kosciusko epoch by E.C. Andrews).

In the eastern highlands the Miocene surface has been dissected by broad Pliocene valleys of various depths and altitudes, and where the highlands merge into the central-east lowlands the valleys coalesce to form extensive plains. Where the late Pliocene uplift was marked, rejuvenated streams have cut deep below the Pliocene valley floors. Many of the Pliocene valleys were excavated on the sites of older valleys which had been buried by Oligocene basalt (fig 1.4).

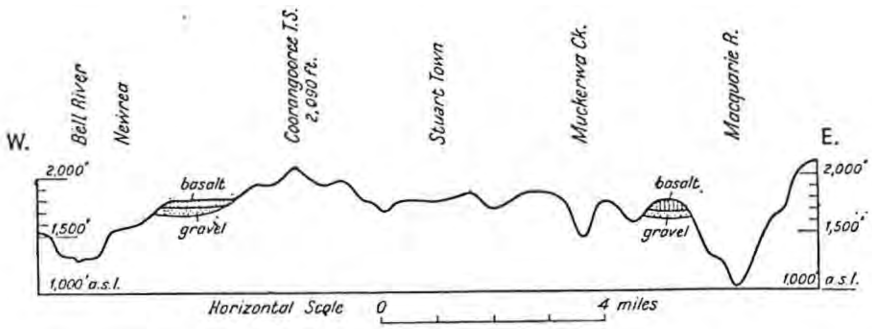

Fig. 1.4 Profile-Section across the Bell and Macquarie Rivers above Wellington, N.S.W., showing remnants of valley-filling Oligocene Basalts overlying river-gravels. (After M.J. Colditz) The benches just below the gravels mark the Pliocene valley-floors. (from David 1950)

Within the eastern highlands is the Main Divide, the watershed separating the rivers discharging to the east and south (into the Pacific Ocean and Bass Strait) from those discharging to the west (mainly into the Murray - Darling system). In Queensland the Main Divide forms a curve convex to the south west (more or less mirroring the offshore margin of the Continental Shelf, while in New South Wales it generally parallels the coast (with two noticeable westward embayments at the heads of the Goulburn and Umaralla Rivers). In Victoria the trend of the Main Divide changes to the south west, then the west, and finally terminates in western Victoria at the head of the Glenelg River.

The nature of the Main Divide is quite variable. In some areas it may be a well developed mountain range (as in the Bunya Mountains of Queensland or the Liverpool Range of New South Wales) while in others it may be picked out as a much less obvious watershed on broad plains. Often the Main Divide is not associated with the highest mountain ranges of the area, as in the Herberton Tableland of north Queensland where the Bellenden Ker Range to the east of the Main Divide rises 600 m higher. In northern New South Wales it traverses the prominent volcanic peaks of Bajimba, Capoompeta and Jondol. Although the Main Divide runs west of the Snowy mountains at Armidale and east of the highest mountains of the central highlands, it does cross Mt Kosciusko, the highest point on the continent.

For much of the length of the highland belt, the course of the Main Divide bears no close relationship to Palaeozoic structural trends, and in Victoria it truncates the regional strike. Its main controlling factor has been the location of the axes of the greatest Mesozoic and Tertiary uplift, and (according to David, 1950) its location is unlikely to have altered significantly since the uplift of the Miocene peneplain.

Off the coast of Queensland the Great Barrier Reefs are situated on a submerged shelf or platform which could have been submerged as a result of coastal faulting or regional downwarping. Further evidence of coastal submergence is shown by the fact that many western rivers rise very close to the coast, but flow to the west, suggesting that the coastline was formerly further east. Examples include the Nepean and Port Hacking Rivers which rise less than two kilometers from the coast. Other evidence of a drowned coast includes the submerged valleys like Pitt Water, a tributary of the Lower Hawkesbury in New South Wales (where drowning has occurred to a depth of over 100 m).

The varied topography of the coastal lands prior to submergence has resulted in a wide variation in the appearance of the present drowned coast. Thus youthful valleys have been drowned to form fjord-like inlets like Broken Bay and Port Jackson in New South Wales, while the submergence of a large marginal depression has given rise to the shallow Gulf of Carpentaria.

David (1950) also cites abundant evidence for Recent eustatic emergences, with features such as raised beaches, terraces, and rock platforms. Although these Recent uplifts average less than 10 metres over much of the continent, evidence may be found (e.g. in Tasmania) of coastal terraces more than 50 metres above present sea level.

THE EVOLUTION OF SEDIMENTATION AND MAGMATISM IN THE TASMAN GEOSYNCLINE

In this section the geological evolution of the Tasman Geosyncline has been outlined, with special reference made to the geological and tectonic setting of the mineralised environments within the developing Geosyncline.

Apart from the initial geosynclinal development of the Kanmantoo fold belt which commenced in the Late Proterozoic, the evolution of the Tasman Geosyncline was confined to the Phanerozoic, spanning the periods from the Cambrian to the Triassic. This evolution is dealt with for each geological period in turn, while the section entitled "The Precambrian" examines the western boundary of the Geosyncline and the Precambrian basement upon (and against) which it developed.

Brief mention has also been made of the prevailing climatic conditions during the evolution of the Geosyncline, as well as the evolution and distribution of faunas and floras, especially where they have been of use for the purposes of stratigraphic correlation.

The Precambrian

The rocks which make up the western boundary of the Tasman Geosyncline in effect form a basement against which the Kanmantoo, Lachlan, Thomson and Hodgkinson - Broken River orogens evolved. Fig. 2.1 shows a pre-Mesozoic reconstruction of the Tasman Geosyncline and adjacent orogens.

Although this reconstruction gives a useful overview of the regional geological setting of the Tasman Geosyncline, particularly with regard to neighbouring continental areas, the western boundary of the Geosyncline has since been extensively revised and may best be seen on fig.   from Scheibner (1978). The western boundary of the Tasman Geosyncline in Australia will be briefly described from south to north, with reference, where possible, to the nature of the contact and the lithologies constituting the basement to the Geosyncline.

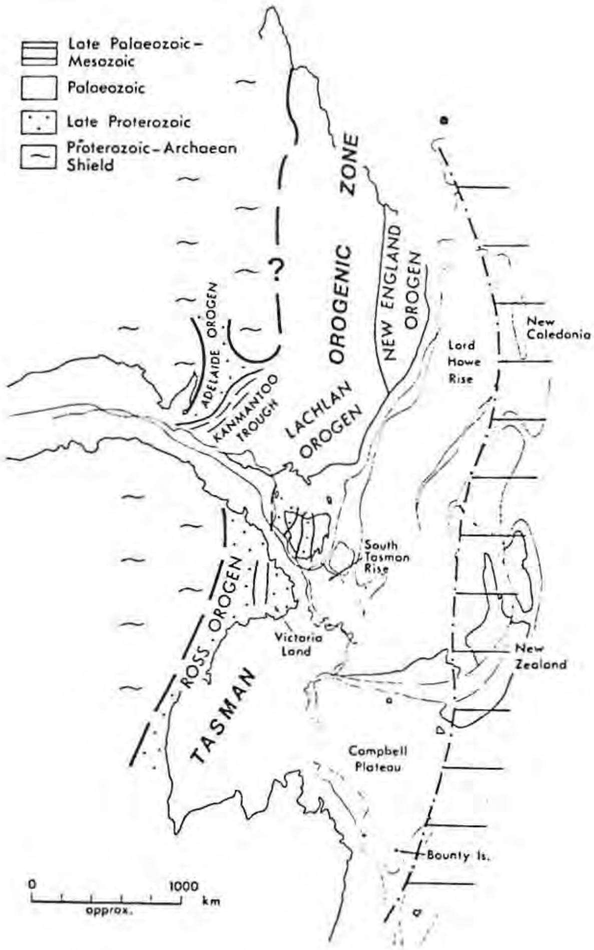

Fig. 2.1 Pre-Mesozoic reconstruction of the Tasman Orogenic Zone and adjacent orogens (after Griffiths 1971)
(from Solomon and Griffiths 1974)

In Tasmania the earliest sediments and volcanics of the Lachlan orogen were deposited in fault-bounded troughs. The most important of these is the Dundas Trough which occurs between two prominent Proterozoic crustal remnants, the Rocky Cape region to the northwest and the more extensive Tyennan nucleus to the southeast (see fig. 2.8). The geology of the Rocky Cape region consists of a stable shelf assemblage to the west, passing east across a pronounced hinge line, the Arthur Lineament, to a flysch-type assemblage. The Rocky Cape rocks probably extend northwestwards to King Island where granitic rocks indicate a minimum age of 715 m.y. The rocks of the Tyennan nucleus are composed mainly of quartz and quartz-muscovite schists, quartzites and phyllites that have been repeatedly deformed. They are older than the rocks of Rocky Cape region, and have undergone more intensive deformation and a higher grade of metamorphism. The Dundas Trough appears to be floored by oceanic crust (probably Cambrian in age) that has been deformed and obducted into the overlying Cambrian trough sediments.

Fig. 2.10 is a reconstruction indicating the possible relationship of the Proterozoic blocks of Tasmania with the Proterozoic of the Ross orogen in Antarctica.

The Kanmantoo fold belt began its development in the Late Proterozoic on a basement composed partly of crystalline rocks of Carpentarian age, but mostly of the partially cratonised sequences of the Proterozoic Adelaide geosyncline.

The Adelaide fold belt is flanked on the west by the Gawler Craton, on the east by the Willyama Block and to the north by the Mt Painter Block. All these cratonic blocks comprise Precambrian crystalline basement complexes exceeding 1400 m.y. in age (Thomson et al 1975). Within this framework was a rift-controlled area of platform downwarp, filled with over 24 000 m of Adelaidean and Cambrian sediments. The basement underwent periodic tectonism followed by quiescent times of gentle subsidence. The geosynclinal sequences were deformed mainly in the Adelaidean and in the Cambro-Ordovician Delamerian Orogeny. To the west of the Adelaide geosyncline shallow marine shelf conditions prevailed on the Stuart Shelf. Separating shelf and trough was the Torrens Hinge Zone, a complex transition zone, near-meridional in trend, that forms part of a continental fracture pattern of major tectonic and metallogenic significance.

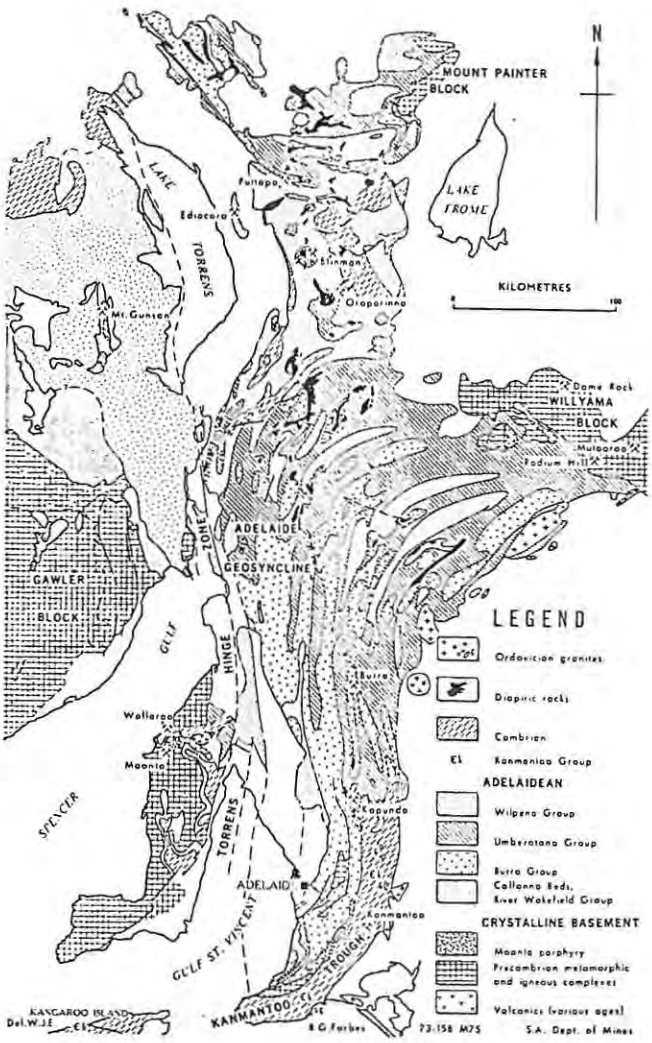

Fig. 2.2 Geological map of stratigraphic units of Adelaide geosyncline and Stuart Shelf (from Thomson et al 1975)

It was against the partly-cratonised trough fill of the Adelaide geosyncline that the Kanmantoo sedimentation commenced, with the present western boundary of the Kanmantoo fold belt being represented by a fault zone comprising the Snelling, Cygnet and Williamstown - Meadows faults (see fig. 2.5).

To the north and northeast of the present outcrop of the Kanmantoo fold belt, the western boundary of the Tasman Geosyncline is represented by the Anabama - Redan Fault (see fig. 1.2). This fault zone separates Adelaidean strata to the west from a probable northeast extension of the Kanmantoo fold belt to the east. However, the Anabama - Redan Fault also marks the westward limit of deposition of the Tertiary Murray Basin, thus obscuring earlier sequences.

In northwest New South Wales the Bancannia Synclinorial Zone occurs, forming a northwest trending half-graben where Palaeozoic sediments and volcanics accumulated (see fig. 2.6). To the east this trough is bounded by the Precambrian Wonominta Block (the most easterly outcropping Precambrian crustal fragment in this area), consisting of intensely deformed sequences of phyllite, slate, chert, meta-greywacke and volcanics, intruded by the Late Proterozoic Tibooburra Granite and regionally metamorphosed to green-schist facies. To the west occurs the Willyama Block, composed of a wide variety of Proterozoic gneisses and schists, intruded by granitic and pegmatitic rocks, and containing the very important silver-lead-zinc ores of Broken Hill.

Between the Willyama Inlier to the south and the Burdekin River Fault to the north, the extensive Late Palaeozoic, Mesozoic and Cainozoic cover obscures the western boundary of the Thomson orogen. In fig. 1.2 Scheibner (1978) has chosen a possible western boundary as including, from south to north, the Paralana Fault, Lake Blanche Fault, Diamantina River Lineament, Cork Fault and Weatherby Structure.

Murray and Kirkegaard (1978) have chosen the southwest margin of the Thomson orogen as the Lake Eyre Lineament, which connects the Denison and Mt Painter Blocks and marks the northeast limit of Precambrian rocks in this area (see fig. 2.17). This line occurs along the northern edge of the Muloorina Ridge and separates a region of craton-controlled Early Palaeozoic deposition and deformation to the southwest from a belt of thick, folded Cambrian and Ordovician sediments and volcanics to the northeast (in the eastern part of the Warburton Basin).

To the northeast, Murray and Kirkegaard (1978) concur with Scheibner's (1978) boundary as coinciding with the Diamantina River Lineament, Cork Fault and Weatherby Structure. They indicate that these structures appear to represent basement faults separating north-northwest trending gravity and aeromagnetic anomalies of the Precambrian Mt Isa Inlier to the north and generally northeast trending anomalies of the Thomson orogen. This lineament also separates thin, undeformed, carbonate-dominated Cambrian and Ordovician sediments of the Georgina Basin which were deposited on the Precambrian craton to the northwest, and folded, metamorphosed and intruded sediments and volcanics deposited at the same time in a geosynclinal setting to the southeast.

As may be seen from figs. 1.2 and 2.30 the western boundary of the Hodgkinson - Broken River orogen is made up of two continuous fault zones, the Palmerville Fault to the north and the Burdekin River Fault to the south. These fault zones formed a hinge line between the Precambrian craton to the west and the subsiding depositional area to the east and southeast. As such the fault zones exerted a considerable control on the processes of sedimentation to the east, though they were occasionally overlapped by clastic and carbonate sediments being deposited on shallow marine shelves adjacent to them in the Hodgkinson basin. However, according to Day et al (1978), these fault zones may not represent the eastern edge of the craton, as seismic evidence from the Hodgkinson Province suggests that the Precambrian basement might underlie the Palaeozoic geosynclinal sequences and extend at least as far east as the present coastline.

To the west of the Palmerville and Burdekin River Faults are a series of Precambrian cratonic blocks, the largest of which is the most southerly, the Georgetown Inlier. The areas in between these Precambrian blocks are obscured by Mesozoic and Cainozoic cover. The Precambrian cratons consist of a high grade metamorphic terrane, comprising the schists, gneisses, granulites, migmatites and amphibolites of the Dargalong Metamorphics. During the Palaeozoic development of the Hodgkinson - Broken River orogen these cratonic blocks were repeatedly intruded by orogenic granitic batholiths (see fig. 2.30).

The Cambrian

The earliest Cambrian geosynclinal activity in eastern Australia occurred in the flysch-filled Kanmantoo trough of South Australia, and its probable extension in New South Wales, the Bancannia Synclinorial Zone. In Tasmania, major clastic sedimentation and volcanicity occurred in fault-controlled troughs (especially the Dundas trough) while several small Cambrian remnants are known from Victoria. These latter occurrences are restricted in outcrop but probably were much more extensive originally. In Queensland, Cambrian sediments and volcanics in the Thomson fold belt are known from three localities, while elsewhere in the Thomson fold belt they are obscured by Permian and Mesozoic cover.

Syngenetic stratabound pyrite and cupreous pyrite deposits occur in the Kanmantoo trough, as well as many small epigenetic gold and base metal occurrences associated with late granite emplacement and strike and thrust faulting. In Tasmania important volcanogenic massive sulphides are hosted in rhyodacitic volcanics adjacent to the Dundas trough, while minor copper, nickel, and platinoids are associated with mafic and ultramafic intrusives. Cambrian rocks in Victoria appear to be of limited economic importance, with some gold hosted in Cambrian sediments and minor platinoids in the greenstone belts. Fig 2.3 shows the distribution of Cambrian rocks in the southern part of the Tasman Geosyncline.

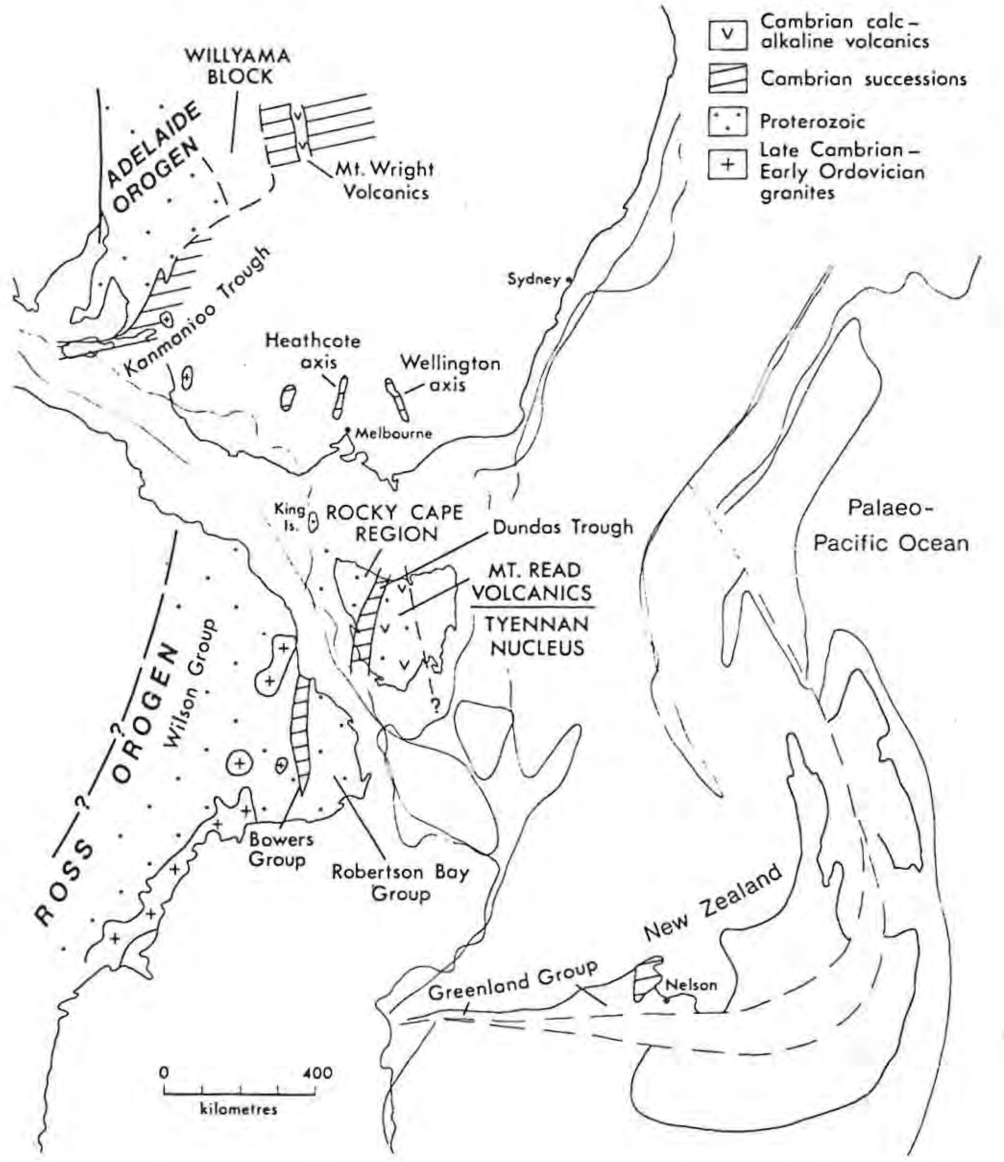

Fig. 2.3 Distribution of Cambrian and Precambrian rocks in the southern part of the Tasman Orogenic Zone, and of Late Cambrian and Ordovician granitic plutons. (from Solomon and Griffiths 1974)

The Kanmantoo trough is regarded as the earliest fold belt in the Tasman Geosyncline, and was active from late Proterozoic, through Cambrian, into Ordovician times. This deep, partly fault-controlled trough transects the Adelaide geosyncline of South Australia and is exposed for 300 km in a north-east trending arc from Kangaroo Island to the eastern Mt Lofty Ranges (see fig 2.4). The trough was filled with flysch-type meta-sediments of the Kanmantoo Group which host pyritic base metal deposits (for example, the Nairn Pyrite and Kanmantoo Copper deposits). Later tectonism has remobilised syngenetic ore and given rise to many small gold and base metal deposits associated with thrust faults.

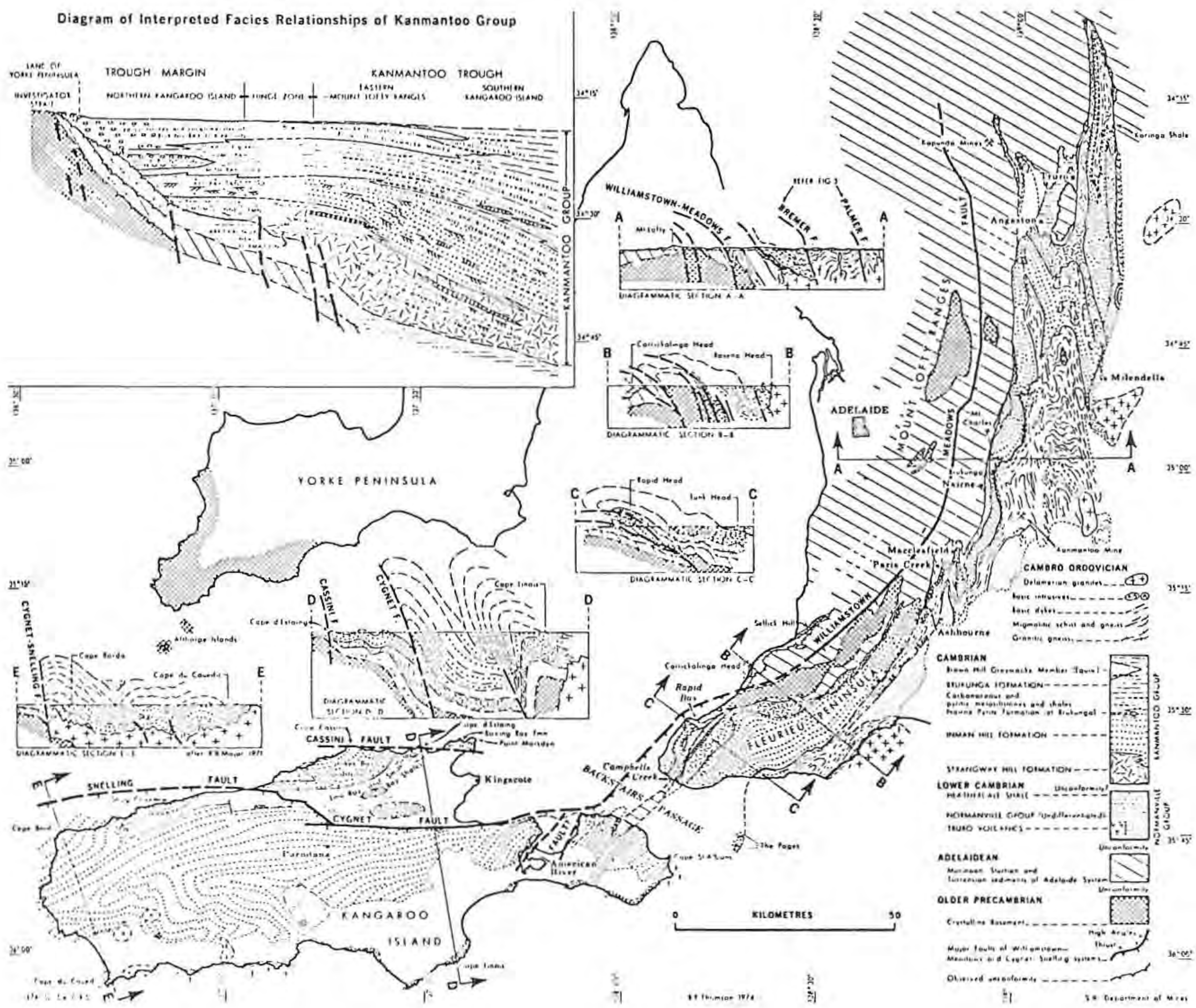

Fig. 2.4 Geological map and cross sections of Kanmantoo Trough fold belt (from Thompson 1975)

The Adelaide geosyncline, which was active for 250 m.y. in the late Proterozoic, became a shelf or shallow basin in the Cambrian. With a latitude of 20°N it had a warm climate and the fossil record indicates abundant life (including the Early to Middle Cambrian coral-like animals, Archaeocyatha, which are useful marker fossils). Sedimentation continued into the Cambrian, culminating in the deposition of the Grindstone Range Sandstone.

To the south and east of the Adelaide geosyncline, the Kanmantoo trough was formed. Subsidence was accompanied by rapid sedimentary accumulation, mainly unfossiliferous felspathic sandstones and greywackes derived from the area of the Adelaide geosyncline to the north and west (which was sporadically elevated in the Cassinian Uplift). The Kanmantoo Group sedimentary sequence overlies Adelaidean and Early Cambrian sedimentary sequences, and is thought to partially underlie the Phanerozoic Duntroon Basin to the west and (with the Delamerian granites) the Tertiary Murray Basin to the east. Present geological understanding of the trough is hampered by lack of useful marker fossils and regional lithological marker units, abundant strike and thrust faulting, and a complex structural and metamorphic history.

Fig 2.4(inset) shows an interpretation of facies relationships within the Kanmantoo trough. With land in the area of the Yorke Peninsula to the north, and shallow water sediments deposited in oxidising conditions between Yorke Peninsula and Kangaroo Island, an area of shelf sediments (the Normanville Group) were deposited along the northern shelf of the Kanmantoo trough. These sporadically developed sediments, consisting of carbonates, siltstones and shales, are contemporaneous with some minor metabasalts and meta-andesites (the Truro Volcanics) and are conformably and disconformably overlain by sediments of the Kanmantoo Group.

The Kanmantoo Group consists predominantly of flysch type sediments up to 12 km in thickness. The basal Strangway Hill Formation consists mostly of metamorphosed grey phyllitic siltstone and fine to medium grained greywacke with small scale crossbedding, and may locally attain 1200 m in thickness. It contains lenticular carbonate units and occasional clean, well-winnowed quartzites and may be metamorphosed to andulusite schist to the south east where the highest metamorphic grades are reached.

The Inman Hill Formation intertongues diachronously with both the Strangway Hill Formation and the overlying Brukunga Formation. It is the coarsest unit of the Kanmantoo Group and is composed largely of grey, medium to coarse grained greywacke and meta arkoses with large scale crossbedding. It contains conglomeratic lenses and phyllitic interbeds which are occasionally pyritic. The conglomerate lenses indicate periodic (Cassinian) uplift of the basement to the north, and though useful as marker beds, show rapid variations in thickness. These variations are apparently due to hinge line faulting during basin floor subsidence, and are especially well developed to the north, where slump structures are also found. Variable development of carbonates and carbonaceous silts within the Inman Hill Formation indicates quiescent periods between uplifts, when local deposition predominated.

The Brukunga Formation is finer grained than the Inman Hill Formation and comprises a complex sequence of phyllites (pyritic and carbonaceous in part), phyllitic greywacke and minor dolomite lenses. The basal unit (at Brukunga) is the Nairn Pyrite Member within which occurs the Nairn Pyrite deposit. This lens is the largest sulphide occurrence in the district, measuring about 32 km long and up to 100 m thick, and contains disseminated pyrite and pyrrhotite.

The Kanmantoo deposit occurs over 2 km stratigraphically above the Nairn Pyrite Member (but still within the Brukunga Formation). In this orebody syngenetic strata-bound sulphides (chalcopyrite, pyrite, pyrrhotite and magnetite), deposited in argillaceous sediments (now andalusite schists) and arenaceous sediments (now quartz mica schists) have been remobilised in the Delamerian Orogeny into favourable structural and stratigraphic zones.

The Kanmantoo trough was then deformed in the Cambro - Ordovician Delamerian Orogeny which affected much of South Australia. Within the trough region metamorphic zones were imposed with increasing intensity to the south and east, where a belt of granite bodies were emplaced. Mills (1973) distinguished three major periods of deformation. The first phase occurred during rising temperature and pressure, and the second occurred during peak temperature. It was associated with tight steep folding (often overturned to the west), granite gneiss development and in the later stage with steep thrusting. This was followed by retrograde metamorphism, and the third stage which occurred as temperatures waned, involved more brittle deformation which folded earlier structures and was associated with important mineral veining.

Major fault movements appear to have occurred late in the cooling history (e.g. up to 5 km movement along the Williamstown - Meadows Fault). The Williamstown - Meadows Fault (and the connecting en echelon thrust faults south of Rapid Bay) divides the area into two structural zones. To the west the area is anticlinorial with left-handed en echelon folding, while to the east the Kanmantoo trough is synclinorial with right-handed en echelon folding (and is affected by major movements on the Bremer and Palmer Faults, subparallel to the Williamstown - Meadows Fault). Kangaroo Island, west of American River and south of the Cygnet Fault, is anticlinorial with right-handed en echelon folding, while to the north of the Cygnet Fault the structure is synclinorial.

The majority of the gold and base metal ore deposits within the Kanmantoo trough are epigenetic veins and replacements associated with faults, shears and other lineaments (especially where intersecting)(see fig 2.5). The most favourable host rocks for base metal deposits are pyritic carbonaceous phyllites and schists in the intermediate to lower grade zones of metamorphism. A crude zoning has been distinguished, in the order gold, copper, lead and zinc, from high grade to low grade metamorphic zones.

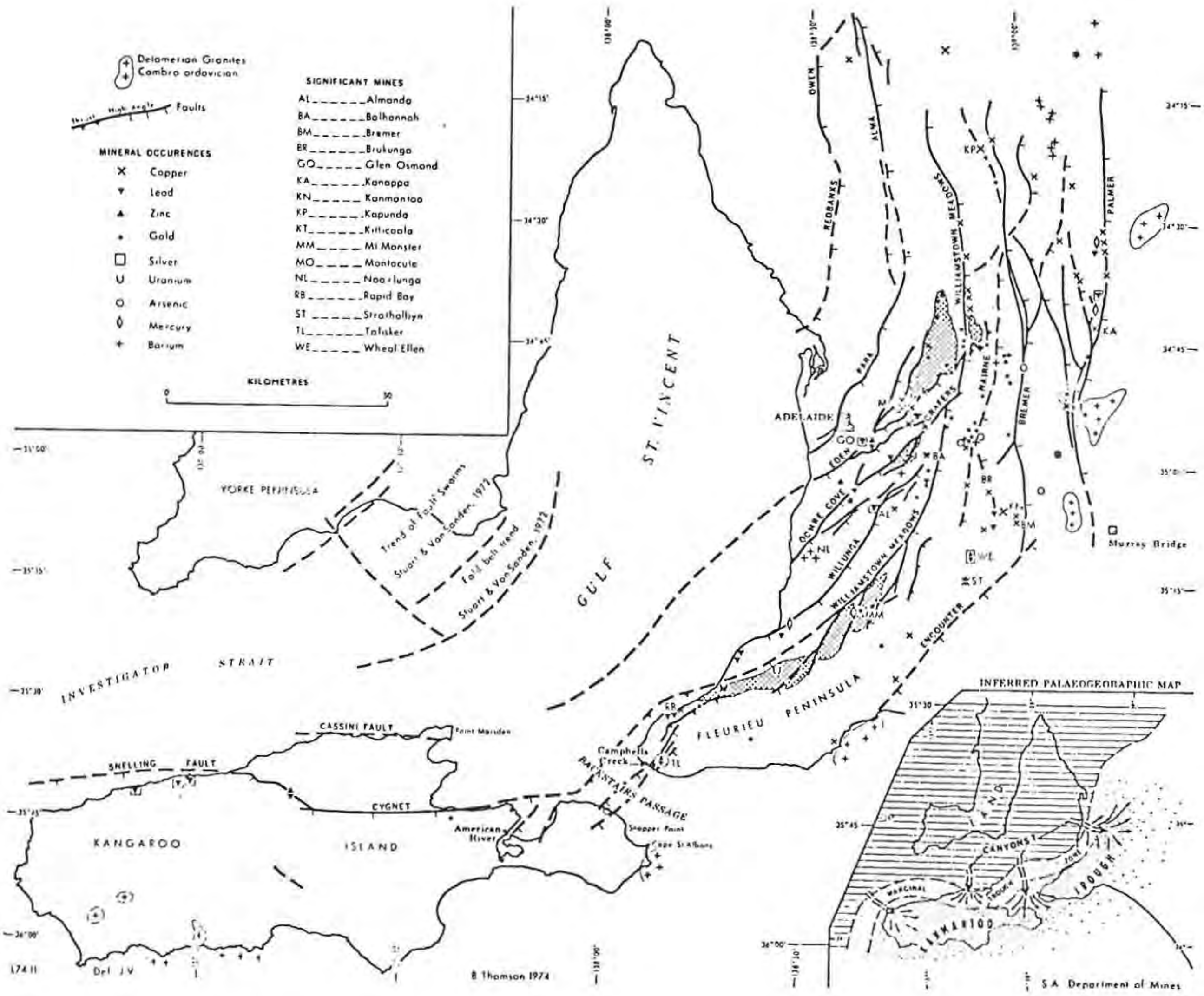

Fig. 2.5 Map of mineral occurrences and major faulting in Mt Lofty Ranges and Kangaroo Island. Inferred palaeogeography during Kanmantoo Group sedimentation.

(From Thomson 1975)

An early Palaeozoic fold belt, considered to be an extension of the Kanmantoo trough from South Australia, occurs in the north west part of New South Wales (see fig 2.6). It may be divided into the Precambrian Tibooburra-Wonominta Block, cropping out over an area 50 km wide by 410 km long, and the Bancannia Synclinorial Zone, measuring about 40 km wide by 150 km long, with a north - north west axis of maximum sedimentation.

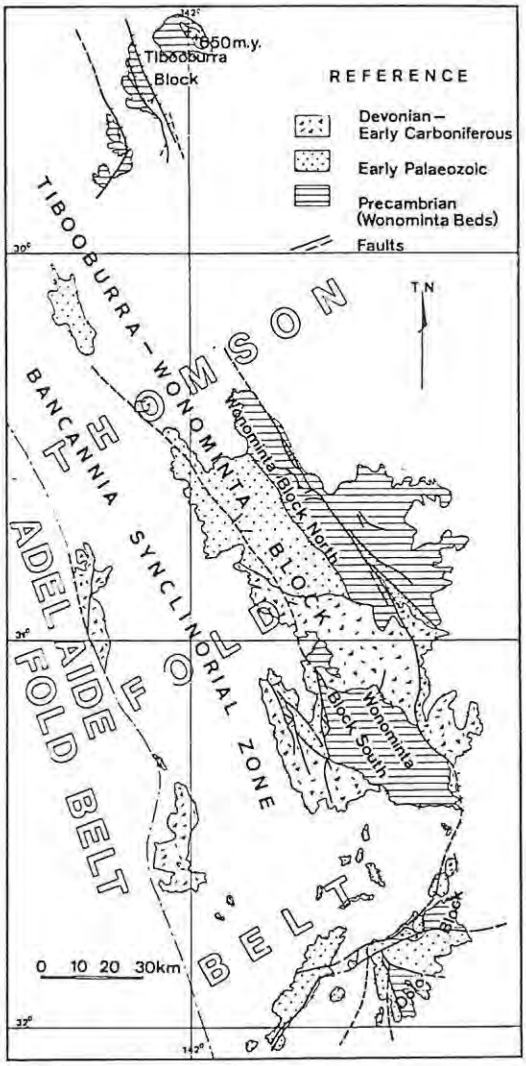

Fig. 2.6 Subdivision of the Kanmantoo fold belt in New South Wales (from Scheibner 1978)

The Wonominta Beds in this area represent the basement and the Early Palaeozoic rocks, much of them in the Bancannia Synclinorial Zone, represent the main orogenic Kanmantoo fold belt. These relationships are largely obscured by Late Devonian to Early Carboniferous strata, as well as extensive Mesozoic cover sequences.

The Precambrian Wonominta Beds consist of a dominantly slaty facies of phyllite and slate, chert, quartz muscovite schist, metagreywacke(some of which appears to be turbidite) and some volcanics. Locally developed banded quartz magnetite (hematite) rocks are usually related to copper mineralisation. They have been regionally metamorphosed to greenschist facies and intruded by the late Proterozoic Tibooburra Granite. Multiple folding is indicated by isoclinal folds, refolded folds, and crenulation cleavage.

The rocks of the main orogenic complex consist of the Gnalta Group (Early - Middle Cambrian) and Mootwingee Group (Middle Cambrian to Ordovician). The Gnalta Group sediments and volcanics (up to 2500 m thickness), accumulated in several tectonic settings, including, from west to east, a trough, a volcanic chain (the Mt Wright Volcanics) and a continental shelf (on a microcontinent). To the east of this the flysch-like rhythmically bedded Copper Mine Range Beds accumulated, perhaps on a continental slope.

In the late Middle Cambrian time, the Delamerian Orogeny commenced, and the Mootwingee Group followed with local unconformity and disconformity. This Ordovician group has a thickness of up to 2000 m and is a sequence of shallow water marine and continental sediments. It represents a transitional tectonic province. Terrestrial conditions are thought to have existed in the southern part of the zone during the Ordovician, with shallow shelf conditions to the north and deeper marine conditions to the east.

The Bancannia Synclinorial Zone is thought to have developed in a half-graben during Cambrian to Early Ordovician time, with most structures subparallelling the north - north west axis. The Middle - Late Cambrian and Ordovician sediments in the Mt Arrowsmith region form faulted, near isoclinal, overturned synclines. Open folds complicated by faulting occur in the Mt Wright region. The intensity of structural deformation appears to increase west of the Mt Arrowsmith Fault Zone towards the axis of the Bancannia Synclinorial Zone, while the underlying Gnalta Group is generally most intensely deformed with well developed slatey cleavage. Post-Ordovician sediments are seen to form a superimposed synclinal structure within the Bancannia Synclinorial Zone. Significant deformation occurred in the Late Devonian - Early Carboniferous Kanimblan Orogeny causing gentle open folding and reverse faulting.

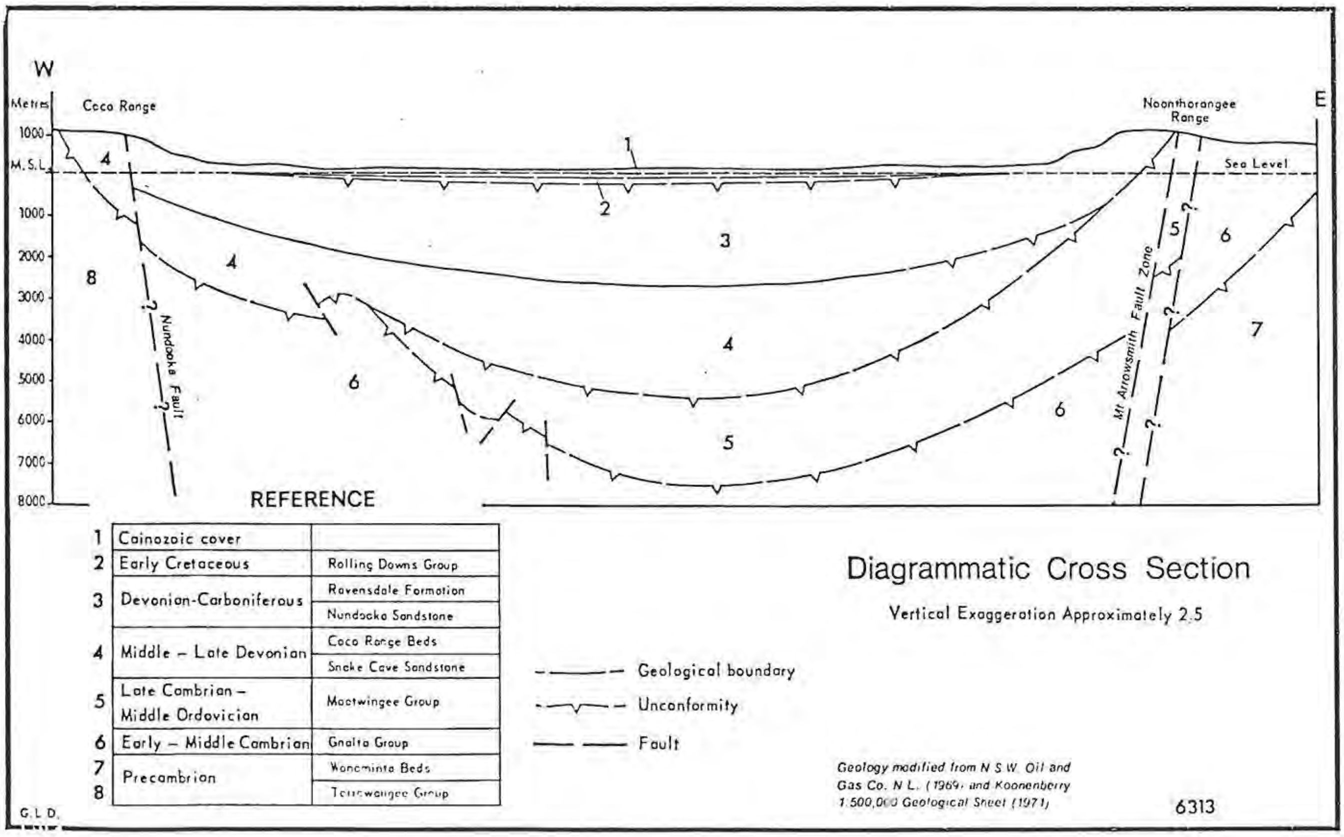

Fig. 2.7 Diagrammatic cross section, Bancannia Synclinorial Zone (from Bembrick 1974)

Weak copper, lead and barite mineralisation is known within the Bancannia Synclinorial Zone. Copper occurrences in Cambrian mafic volcanics (and possibly ultramafics) are known from near Bilpa Homestead, while near Bilpa barite occurs in Ordovician siltstones.

In Tasmania Proterozoic basement blocks (including the Rocky Cape and Tyennan Nuclei) separated by crustal extension and formed structural highs against which trough-controlled Cambrian sedimentation and volcanism occurred. Examples of these Cambrian Troughs in north and west Tasmania include the Smithton, Dundas and Adamsfield Troughs (see fig 2.8). The largest of these is the Dundas Trough which extends for nearly 200 km in a roughly north east - south west direction, and is probably continuous with the Dial Range and Fossey Mountain Troughs. Stratabound volcanogenic base metal sulphide mineralisation within the felsic to intermediate Mt Read volcanics is well known from this trough, and includes the important Rosebery and Mt Lyell deposits. Tin mineralisation contained within Cambrian rocks in the Dundas Trough appears to be largely related to the emplacement of Devonian granitoids. Other Cambrian mineralisation includes minor copper and nickel sulphides, PGMs and asbestos in mafic and ultramafic intrusives.

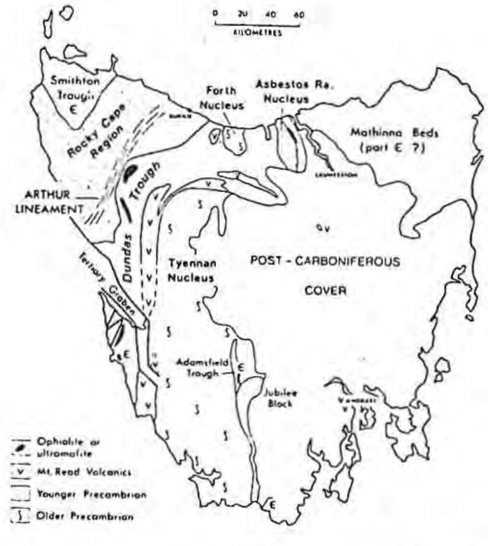

Fig. 2.8 Tectonic map of Tasmania showing the major elements consisting of Precambrian and Cambrian rocks (after Corbett et al 1972, Williams et al, in press) (from Solomon and Griffiths 1974)

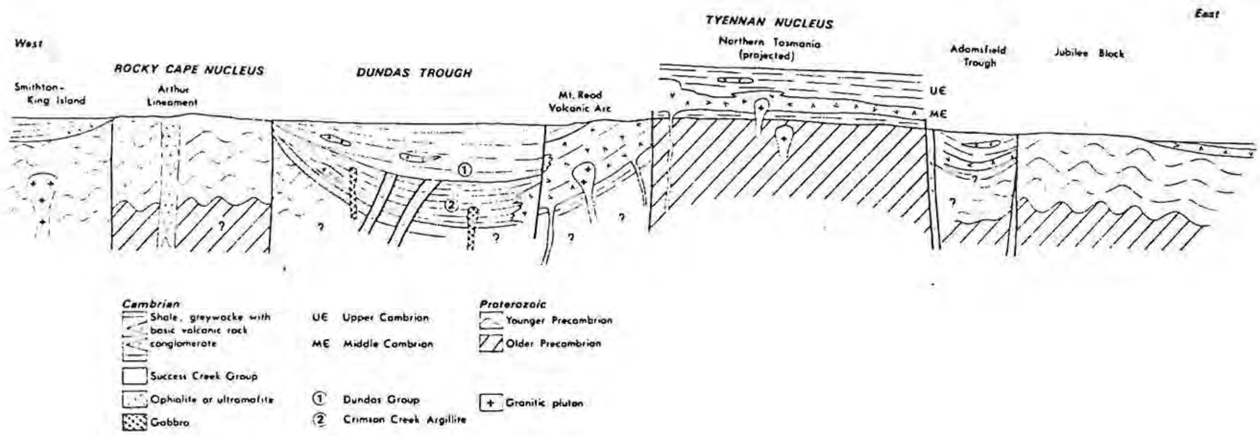

Fig. 2.9 Generalized and simplified east-west cross-section of Tasmania in the late Cambrian, with folding largely removed (from Solomon and Griffiths 1974)

Within the Dundas Trough the oldest Cambrian lithologies comprise the ophiolite-bearing Success Creek and Crimson Creek Groups. The rather restricted Success Creek Group and its correlates comprise sandstones, dolomites and conglomerates, and appear to represent shallow-water shelf-type sedimentation along the flank of the Rocky Cape Nucleus. The succeeding Crimson Creek Group (totalling 2500 m in thickness) is mainly composed of mudstone, characteristically red and green in colour, with chert, greywacke and basaltic volcanics. It apparently has a different provenance to the Success Creek Group. The source may have been the lower parts of the Mt Read Volcanics which accumulated from Lower to Upper Cambrian on the south east side of the Dundas Trough and were progressively covered by the Dundas Group and its correlates.

The Dundas Group is up to 3800 m thick and consists of interbedded mudstone, lithic wacke, chert breccia, conglomerate, paraconglomerate and minor volcanics. It appears to be a synorogenic flysch-type succession, with an overall coarsening towards the top of the sequence and cyclicity in sedimentary units probably resulting from tectonic instability. To the south and east Dundas Group sediments interfinger with the "western sequence" volcanics and sediments of the Mt Read volcanic belt.

The Mt Read Volcanics today appear in an arcuate outcrop around the Tyennan Nucleus, with sporadic occurrences near the north coast as well as in the Hobart area (fig 2.8). According to Solomon and Griffiths (1974), the Tyennan Nucleus may have been a less significant topographic feature in the early Cambrian than previously supposed, and the Mt Read Volcanics (and sediments of the Dundas Group) may have extended over much of it.

The Mt Read Volcanics consist predominantly of calc-alkaline rhyolites and dacites, with relatively minor andesites and basalts, now altered to spilites and keratophyres. Volcanic features include autoclastic breccias, lava flows, ash flow and ash fall tuffs, subaqueous pyroclastic flows and intrusive plugs. To the west and north the volcanics are intruded by granitic sills and dykes, which are probably subvolcanic porphyries, being chemically similar to the acid members of the volcanic pile. Solomon and Griffiths (1974) have classified the Mt Read Volcanics as being of Andean type, based on chemical comparisons as well as on their predominance of rhyolites and dacites. They relate the development of the volcanic belt to an east-dipping subduction zone under a continental mass (see fig 2.10) though various authors have put forward other alternatives.

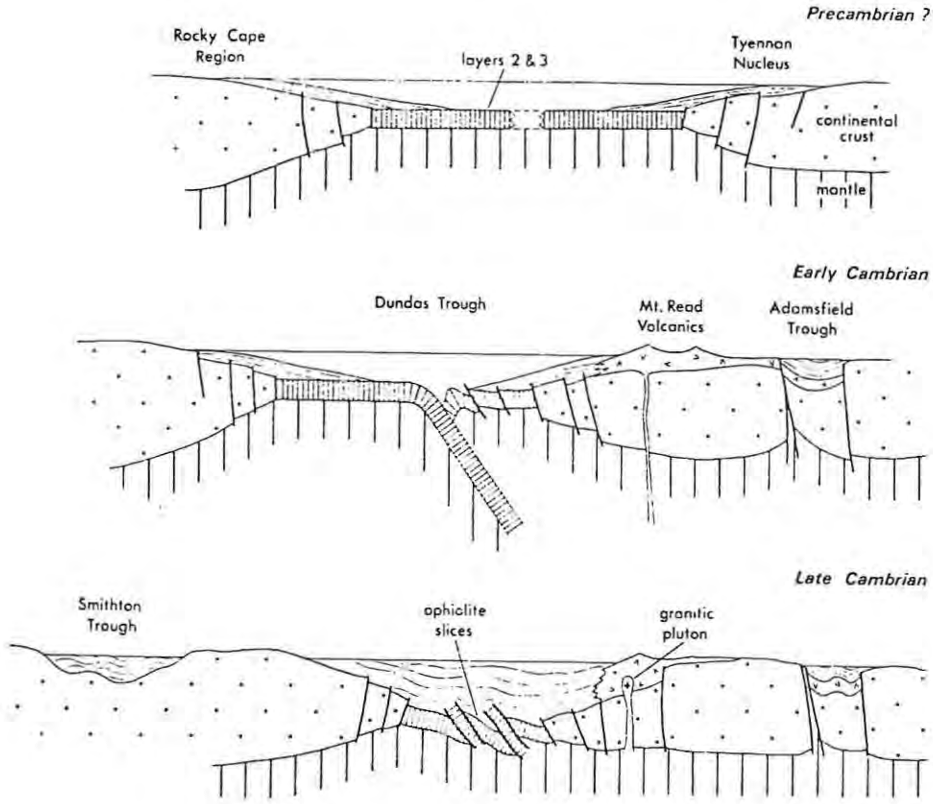

Fig. 2.10 A possible plate tectonic model for the development of western Tasmania in the Cambrian (from Solomon and Griffiths 1974)

A number of massive sulphide deposits occur in the Mt Read Volcanics, and include some of the largest of their type in the world. Most of the known sulphide mineralisation occurs within a central belt of rhyolitic, dacitic and andesitic volcanics, up to 12 km wide and 90 km long (see fig 2.11), which is characterised by abundant felsophyric lavas and ash flows but relatively few sediments. The volcanics appear to represent rhyolitic caldera complexes, largely subaerial, with localised development of marine embayments. It is with these marine sedimentary and tuffaceous units that the massive sulphide deposits tend to be associated, though subaerial sequences below many ore bodies suggest rapid subsidence possibly related to caldera collapse.

Most of the deposits of the Mt Read Volcanics occur in four zones: from Mt Lyell to South Darwin; the Mt Farrell - Red Hills area; the Pinnacles - Rosebery - Hercules zone; and the Que River area (see fig. 2.11).

The Mt Lyell - Darwin deposits occur in a complex volcanic unit (within the central sequence) consisting of felsic breccias, tuffs and lavas, with minor siltstone beds. No definite volcanic centres have been located, though cauldrons and composite volcanoes could be expected. Erosion (probably during the Late Cambrian) has resulted in most of the deposits south of Mt Lyell being of sub-surface type, though near Mt Lyell more complete volcanic sequences (with exhalative deposits) are preserved in a probable graben structure.

In the Red Hills - Mt Farrell area lithologies are similar to those at Mt Lyell - Darwin. The Farrell deposits lie on a prominent north-northeast trending fault zone (the Henty Fault) which marks the western limit of the Owen Conglomerate deposition in this area. The deposits of this area are relatively small, contain pyrite, sphalerite, galena, and chalcopyrite in varying proportions, and occur in stratiform or veinlike form within the volcanics and (structurally) overlying sediments.

The Rosebery line of deposits extends from Hercules in the south to The Pinnacles in the north, and occurs just within the fault-bounded western margin of the Mt Read Volcanics. The deposits are mainly of pyrite - sphalerite - galena - chalcopyrite type, though the Chester Mine contains mostly pyrite with low copper, lead and zinc contents. South of Rosebery several small deposits appear to be confined to one stratigraphic horizon, which may correlate with the Farrell deposits to the east across a possible faulted, synclinorial structure (Solomon 1981).

The Que River deposit occurs within the Mt Read Volcanics (though its exact age relative to other deposits is not known), and consists of five stratiform ore lenses, in part massive, separated by altered, west-dipping rhyolitic and andesitic volcanics. It is zoned, with a basal chalcopyrite-rich lens and pyrite - sphalerite - galena-rich upper portions.

An interesting feature is that north of the Red Hills area the deposits are mostly lead and zinc rich (the only exception being at Chester), while to the south they are copper and iron rich. In addition, the deposits to the north are predominantly stratiform, while those to the south are mostly of disseminated - replacement or vein type. A likely explanation is the observed northerly plunge to the major Delamerian folds, resulting in a deeper level of erosion to the south. Alternatively, the southern areas may have been more emergent at the time of mineralisation, resulting in more typically subaerial types of mineralisation.

It is likely that the Mt Read Volcanics were erupted from volcanic islands within a shallow marine basin. The siltstone lens covering the Rosebery orebody appears (from sulphur isotope data) to be of marine origin, like the more extensive siltstones containing and overlying the mineralisation at Farrell.

Fault zones seem to have played a major role in the location of ore deposits, with many deposits situated along north - south lines (e.g. at Rosebery), either adjacent to, or parallel to, fault zones. Major east-west trending Devonian graben structures may also have been active from the Late Cambrian. The meridionally-trending linear zones of deposits tend to be either along the margins of the Mt Read belt, or along its central axis. There also appears to be a correlation between the size of the deposit (measured in its tonnage of sulphur) and the distance to the nearest deposit (Solomon 1981).

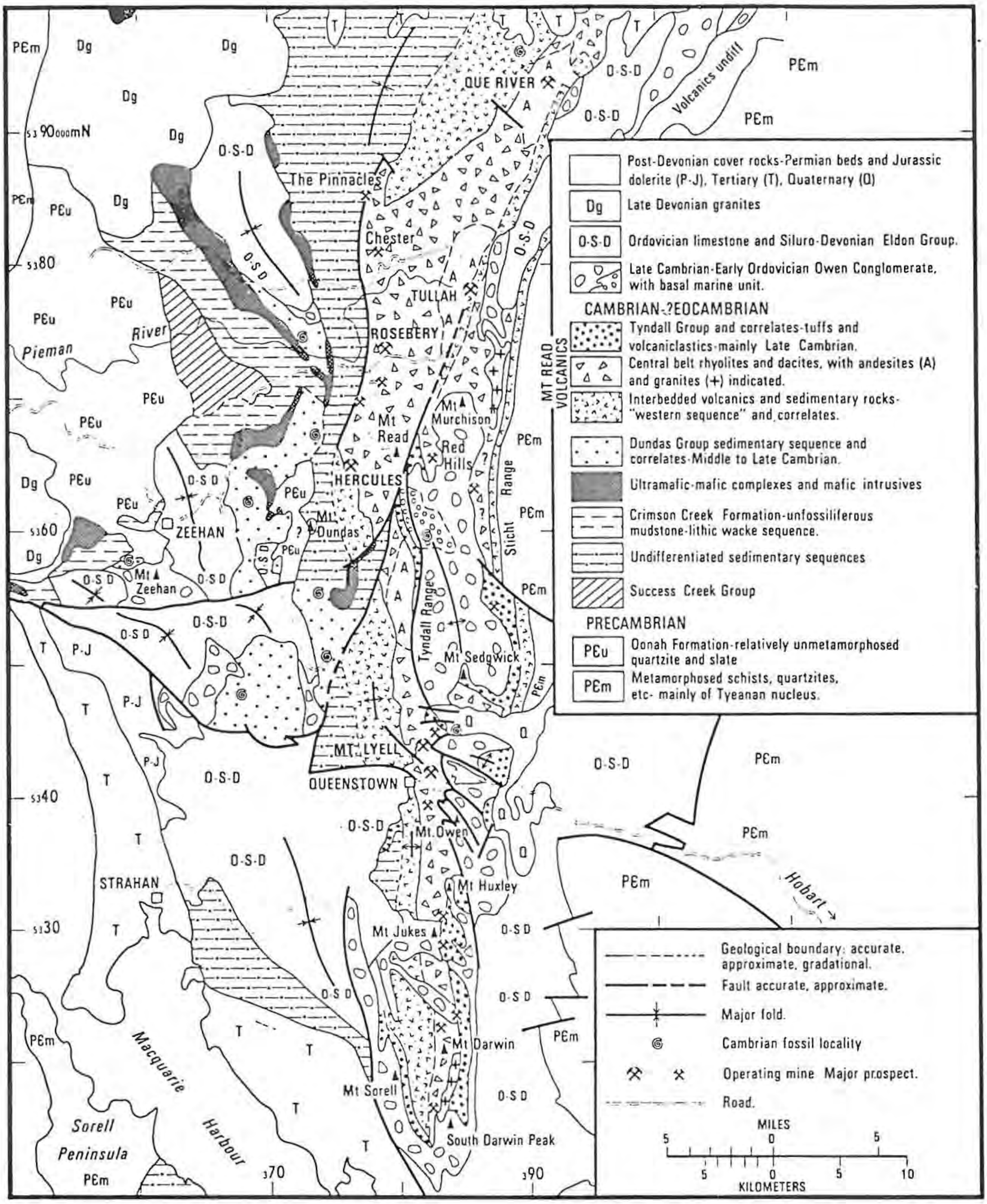

Fig. 2.11 Geologic map of central western Tasmania showing distribution of the Mt Read Volcanics and the major mines and prospects within the volcanic belt (from Corbett 1981)

The central belt is flanked to the west by folded marine sediments and volcanics of the so called "western sequence", which itself interfingers with the predominantly sedimentary Dundas Group further to the west. The relationships between the central belt and the western sequence are not fully understood, as the contacts range from conformable to abruptly faulted, but it appears likely that the mineralised central belt represents a volcano-tectonic rift structure superimposed on a larger marine basin.

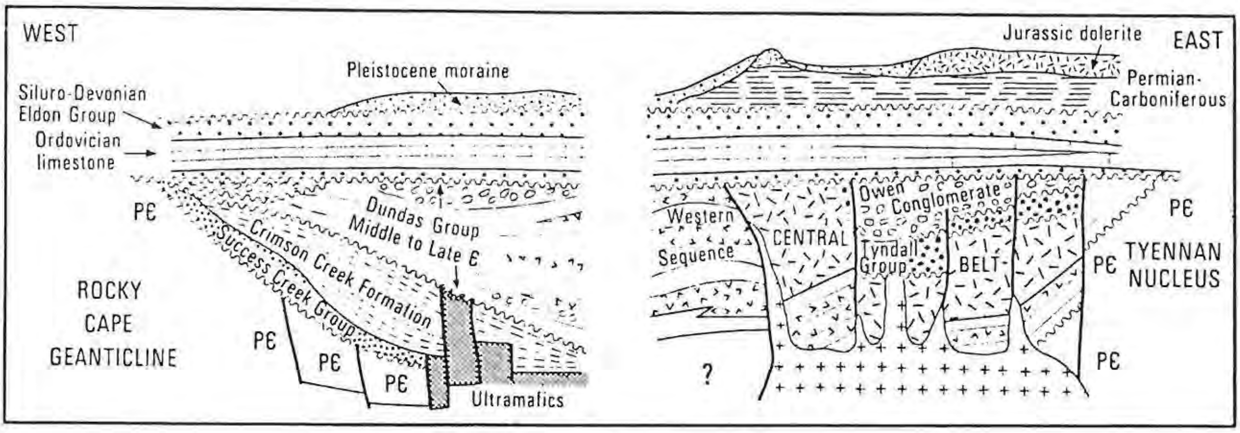

Fig. 2.12 Diagrammatic section across the Dundas trough and the Mt Read Volcanic belt showing the relationships of rock units adopted in this report. (From Corbett 1981)

Overlying the central belt in the Queenstown - Mt Darwin area is an unmineralised volcanic/volcaniclastic succession (the Tyndall Group) of Middle to Late Cambrian age. This sequence was deposited largely in localised graben structures and was accompanied by considerable erosion of earlier volcanics (which also removed mineralisation in the Darwin - Mt Lyell area).

During the Late Cambrian and Early Ordovician, longitudinal rifts or basins on the western margin of the Tyennan Nucleus were filled with siliceous sands and gravels (e.g. the Owen Conglomerate). North-south faulting at Mt Lyell forms the western flank of the Owen rift, and unconformities within and at the base of the Owen succession probably result from Jukesian (Delamerian) movements. Similar basins formed within the Tyennan Geanticline (e.g. Adamsfield

Trough) and on its northern flank folding and faulting related to Jukesian (Delamerian) movements coincided with the final closing of the Cambrian basin and resulted in uplifts within the Tyennan and Rocky Cape Nuclei.

A characteristic feature of the lower sedimentary successions within the Dundas Trough is the presence of fault-bounded serpentinised ultramafic bodies. These have been interpreted as oceanic crustal remnants thrust into the overlying Cambrian sediments during closing of the basin. The Heazlewood River complex near Mt Cleveland is the largest mafic/ultramafic body in Tasmania, and is probably part of an obducted ophiolite. It consists of orthopyroxenite, peridotite and dunite with interstitial plagioclase. Several smaller bodies occur at Serpentine Hill east of Zeehan, in the Dundas - Rosebery area and between Spero River and Macquarie Harbour.

These obducted ophiolites have been exploited for asbestos (e.g. at the Serpentine Hill complex) and locally contain minor nickel sulphides, while low levels of platinum group metals and chromite have been reconcentrated to yield alluvial osmiridium at Heazlewood and eluvial chromite near Beaconsfield. Copper and nickel sulphides have been mined from a dolerite sill of probable Cambrian age at Cuni, east of Zeehan.

Fig 2.13 illustrates the tectonic and lithological relationships of Tasmanian ore deposits and their enclosing rocks.

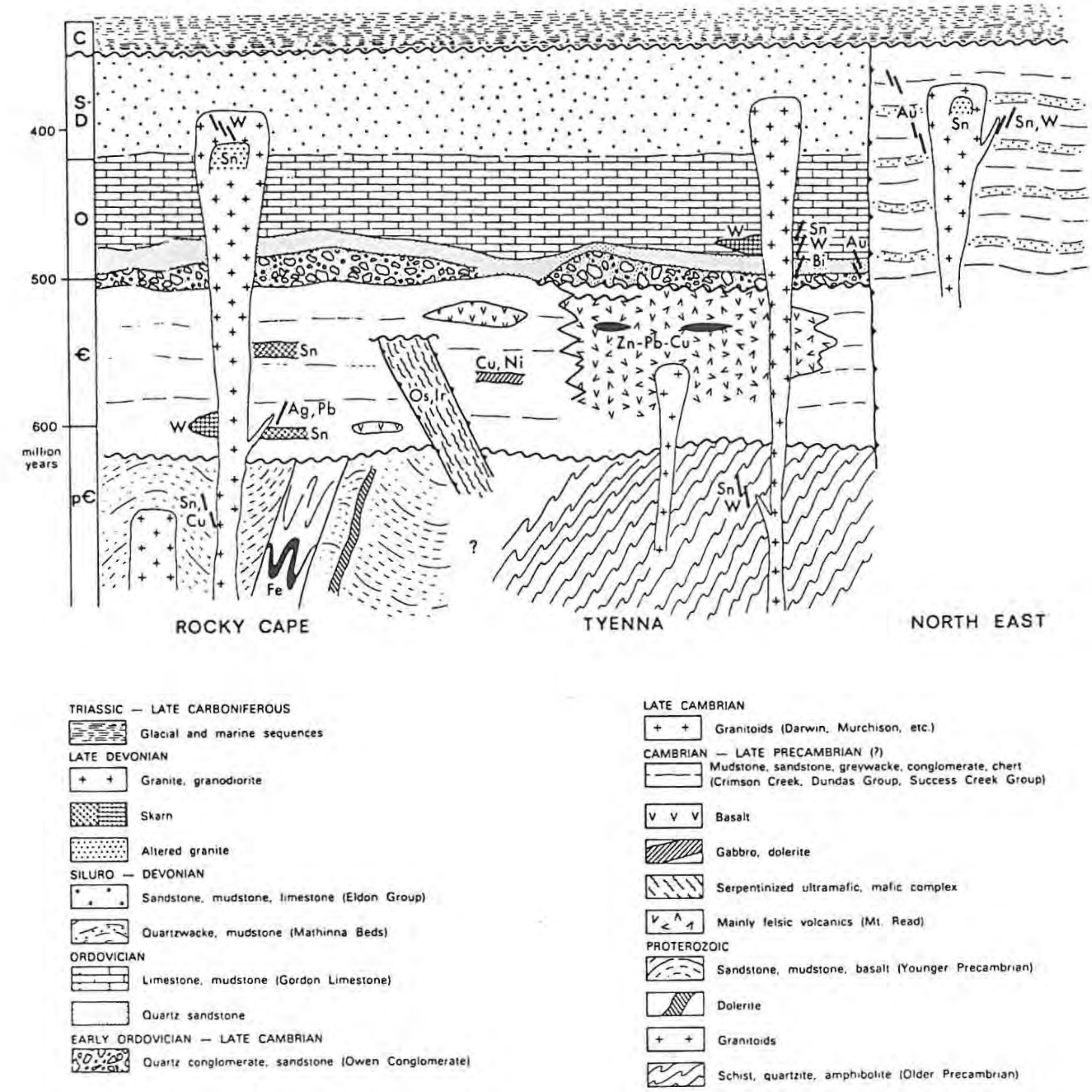

Fig. 2.13 Diagram displaying major pre-Carboniferous rock relationships in Tasmania. (From Solomon 1981)

Cambrian rocks are known from several localities in Victoria but understanding of their distribution is complicated by generally poor exposure, structural complexity and extensive later cover.

Proven Cambrian rocks outcrop in two linear, structurally complex belts - the Mt William - Heathcote Axis and the Mt Wellington Axis (see fig 2.14). The earliest rocks of these successions are "greenstones" up to 1500 m thick.

These greenstones consist of calc-alkaline basic to intermediate lavas, pyroclastics, and interbedded cherts, and they may pass gradationally up into black shales with ash bands as at Heathcote, or into bedded tuffs as at Mt Wellington. From their distribution in Victoria in structural belts as structural highs, it would appear that they were developed over a large part of the evolving Lachlan geosyncline.

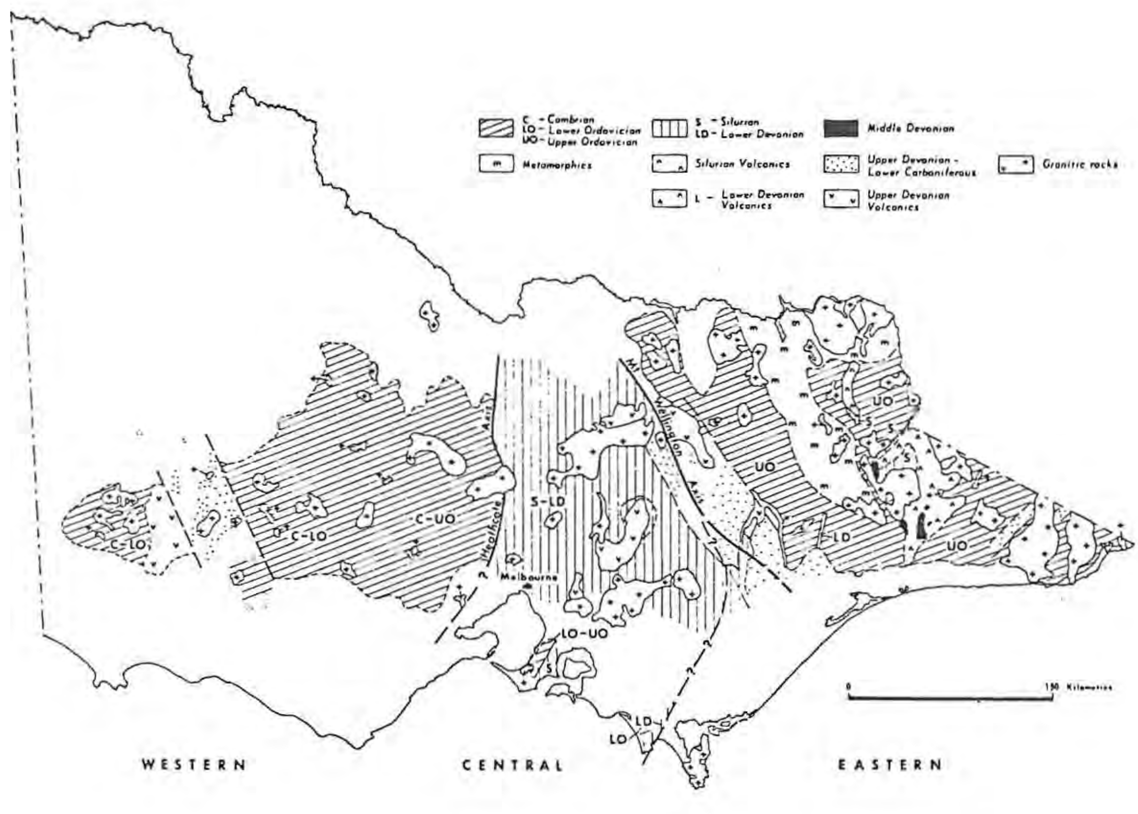

Fig. 2.14 Tasman Geosyncline in Victoria.
(From Spencer Jones & Vandenburg 1975)

The Heathcote Axis extends for about 130 km in a roughly north-south direction, between Corop in the north, to south of Monegeeta. The Cambrian greenstones, cherts and shales of the axis are bounded to the east by high angle reverse faults while to the west the boundaries range from faulted to conformable with the overlying Lower Ordovician rocks. At Heathcote the greenstones (totalling 1500 m in thickness) are overlain by Middle to Upper Cambrian marine sediments from which they are separated by a major fault (Spencer-Jones and Vandenburg 1975). The marine sedimentary sequence comprises the Knowsley East Formation, consisting of over 150 m of shales, pyroclastics and conglomerates, followed by the Goldie Shales which consist of 600 m of unfossiliferous cherts, black shales and mudstones.

The most westerly of the Cambrian occurrences in Victoria are within the Glenelg Zone, and have been correlated by Vandenburg (1978) with the Kanmantoo fold belt. This has been done largely because the Cambrian and Early Ordovician rocks of this area north of Casterton appear to have been extensively deformed by the Delamerian Orogeny, while elsewhere in the Lower Palaeozoic of Victoria the first major orogeny appears to have been Benambran (Early Silurian) in age.

Cambrian strata occur in the western part of the Ararat - Bendigo Zone where basal Cambrian greenstone type volcanics are overlain by over 700 m of Middle and Late Cambrian volcaniclastics, shale and chert.

Despite the problems in interpretation due to poor exposure, structural complexity and correlation difficulties in unfossiliferous sediments, it would appear likely that Cambrian sedimentary and volcanic activity was more extensive than earlier supposed. Basal greenstone type volcanicity and overlying shales and flysch-type sedimentation possibly occurred in localised basins or depressions, perhaps fault-bounded and tectonically controlled.

Fig 2.16 summarises sedimentary, igneous and tectonic activity in Victoria during the Palaeozoic.

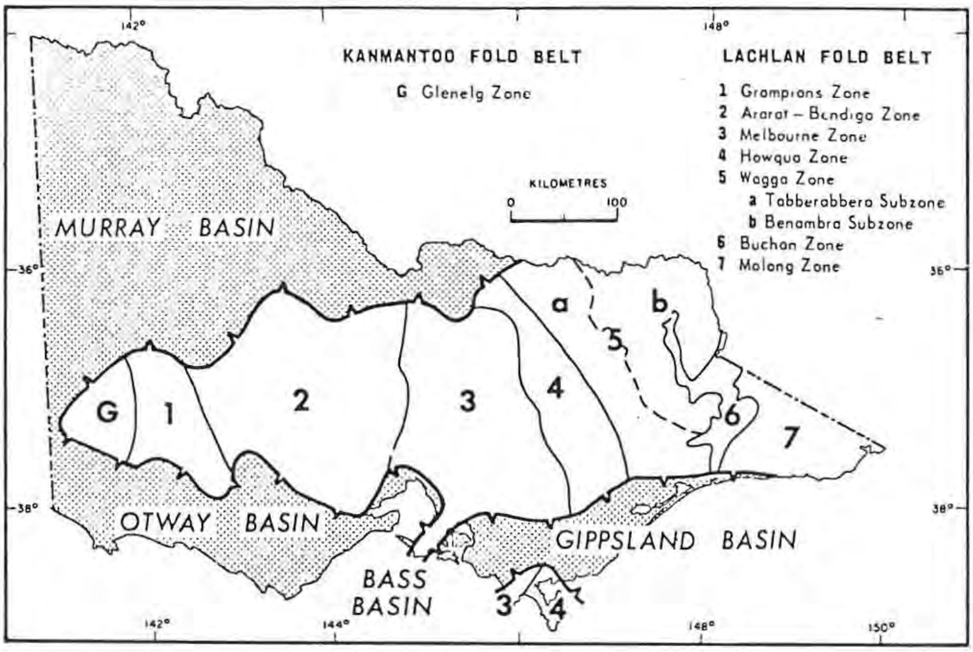

Fig. 2.15 Distribution of structural zones in Victoria (from Vandenburg 1978)

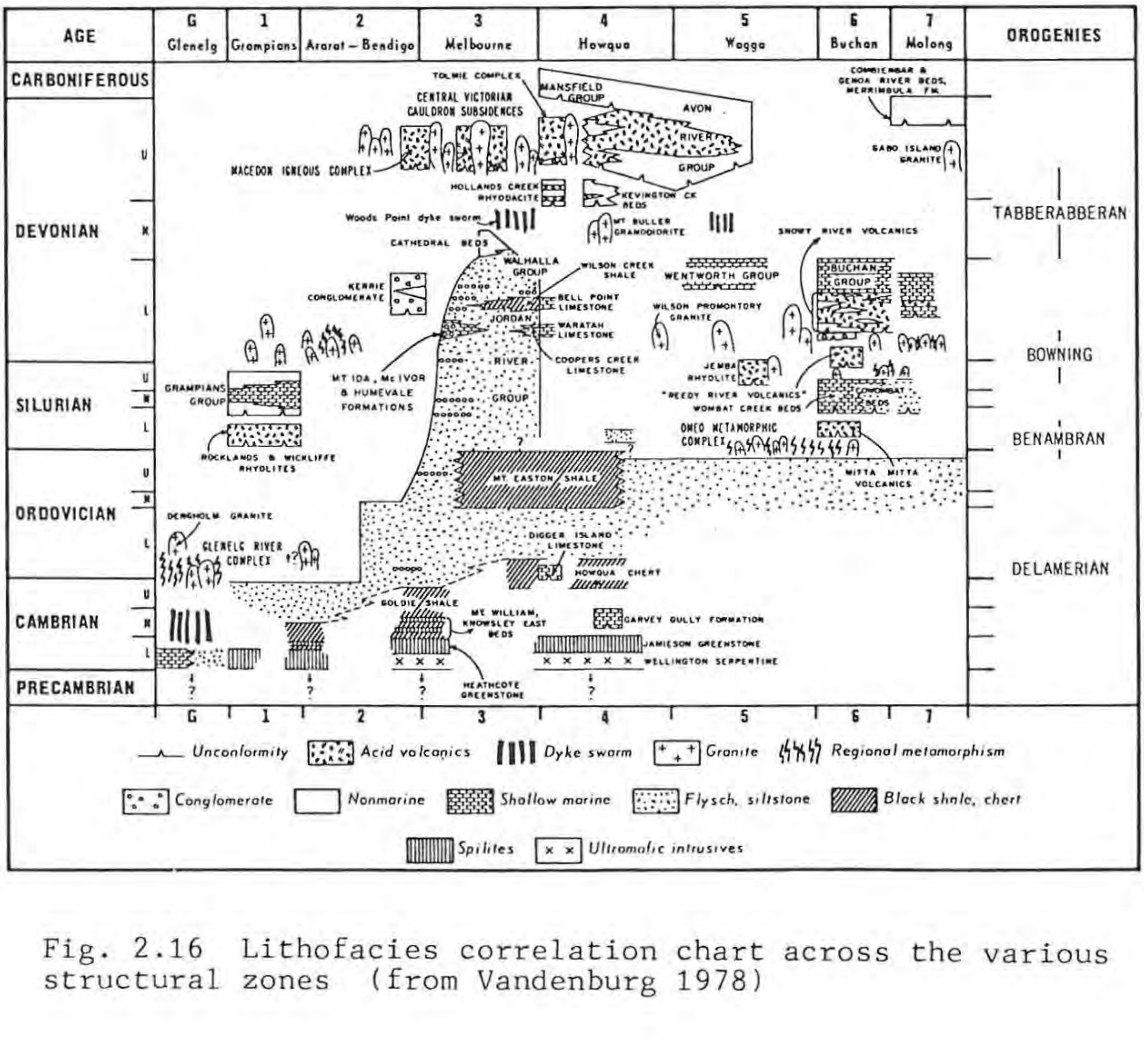

Fig. 2.16 Lithofacies correlation chart across the various structural zones (from Vandenburg 1978)

During the Cambrian in Queensland, early sedimentation in the Thomson orogen (or fold belt) commenced with carbonate and flysch-type deposition. These were deposited in a variety of settings within a deep marine basin bordered to the west, north west and south west by Precambrian crustal blocks. However, much of the Thomson orogen is obscured by Permian and Mesozoic sedimentary cover, and definite Cambrian rocks are known from only three localities in Queensland, each occurrence exhibiting different lithological and depositional environments (Murray and Kirkegaard 1978).

Within the Warburton Basin in the southwest, Middle and Late Cambrian carbonates interbedded with detritus derived from an active volcanic arc, accumulated on shelf areas built from Proterozoic volcanics. Further north, near the Fermoy I Well, a thick sequence of fine grained Cambrian sediments was probably derived from the Precambrian craton to the west. This locality occurs near the Diamantina River Lineament (generally regarded as part of the faulted western boundary of the Thomson orogen) and the sediments may have been laid down on a down-faulted basement of deformed Proterozoic rocks, with oceanic crust to the east. At the north end of the Thomson fold belt the Lolworth - Ravenswood Block contains Late Cambrian calc-alkaline volcanics which were probably deposited in an island arc separated from the Precambrian Georgetown Inlier by a marginal sea.

Isotopic dating of low-grade Cambrian metamorphics from the Fermoy I Well indicates a major deformation at the end of the Cambrian. This would be approximately equivalent to the Delamerian Orogeny of the Adelaide and Kanmantoo fold belts, and this event has not been recognised elsewhere in the Thomson orogen. There is evidence in the Warburton Basin that a marine regression at the end of the Cambrian was followed by a pronounced change from shallow water carbonate deposition to deep water clastic sedimentation, reflecting a downwarping of the basin and an uplift of its margins.

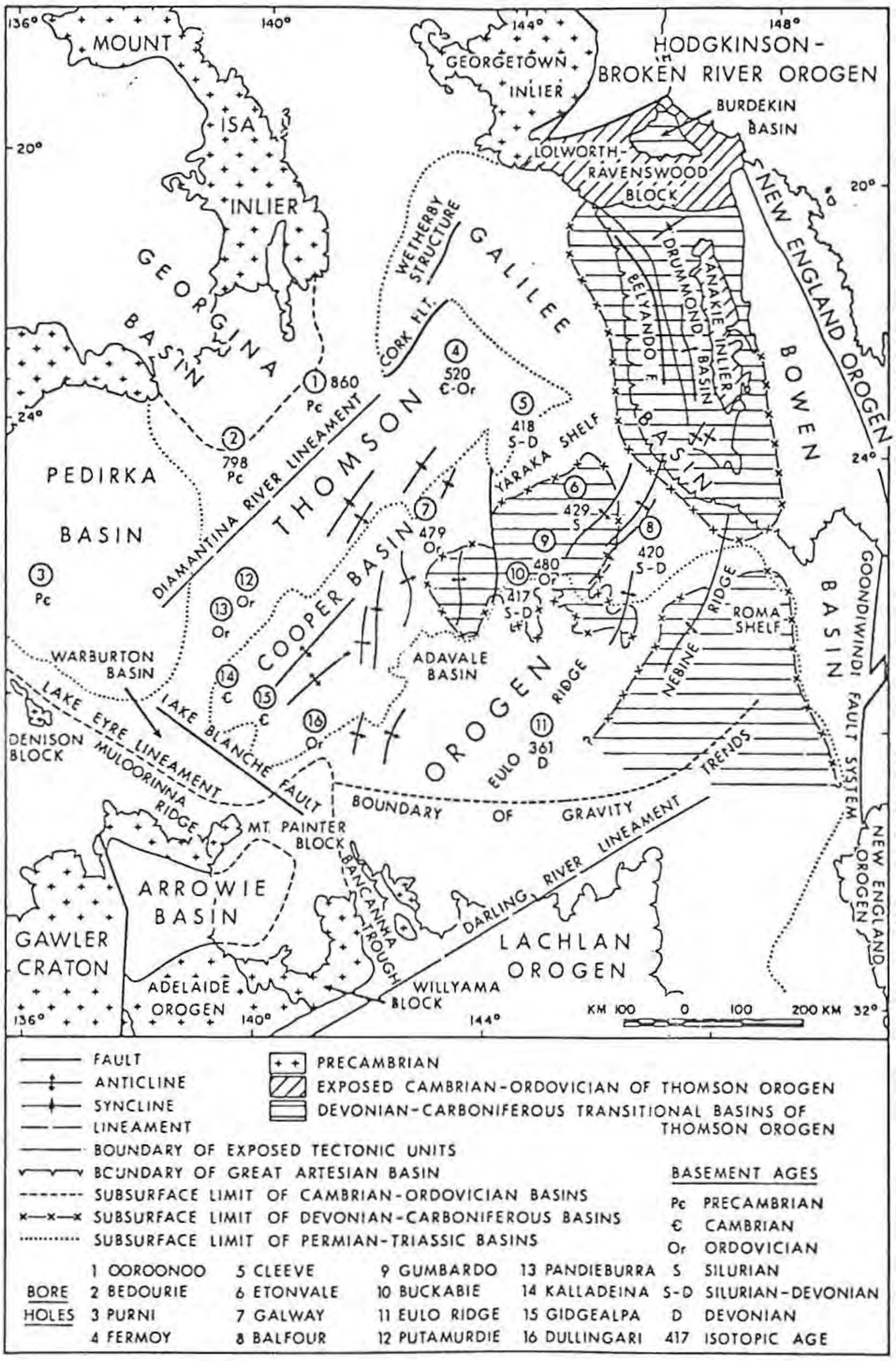

Fig. 2.17 Major tectonic elements of the Thomson orogen (From Murray & Kirkegaard 1978)

The Ordovician

By the close of the Cambrian, most of the area of the Adelaide and Kanmantoo troughs had become land, and was probably supplying sediment to the Lachlan geosyncline which continued to subside at a relatively rapid rate. The pattern of Ordovician sedimentation within the Lachlan geosyncline is generally clearer than that of the Cambrian, with trough-controlled deposition of both shelf and deeper water flysch-type. It is possible that an open seaway connected the Tasman Geosyncline during most of the Ordovician with the intracratonic Amadeus Basin to the west, perhaps extending as far as the Canning Basin on the west coast.

Fig. 2.18 Ordovician Palaeogeography
(from Brown et al 1968)

During the Ordovician, Tasmania occupied a small section of the north-south trending continental margin, stretching from northeast Australia to Antarctica. In Early

Ordovician times deposition occurred mainly in fault-bounded troughs within and peripheral to relatively stable geanticlinal areas. Later in the Ordovician shallow shelf-type conditions persisted over much of the island and carbonate deposition was widespread.

Much of the Lachlan geosyncline was metamorphised and deformed during the epi-Ordovician Benambran Orogeny.

In the Thomson orogen deposition was widespread in the Ordovician and included quartzose greywacke and shale trough-type sedimentation, as well as shelf-type carbonate deposition, and minor volcanics. This fold belt was affected by a mid-Ordovician Orogeny which appears to have predated the Benambran Orogeny in the Lachlan fold belt.

Geosynclinal activity in the Hodgkinson - Broken River orogen commenced in the Ordovician, with subsidence along major fault zones followed by rapid sedimentation derived from the Precambrian landmass to the west.

Important vein-type gold (and minor antimony) deposits are located in the Ordovician Ballarat Trough in Victoria. These epigenetic deposits would appear to be associated with remobilisation during deformation (with some possible syngenetic enrichment) rather than with later (Devonian) granitic intrusives. In the Molong Volcanic Rise of the Lachlan geosyncline, widespread andesitic volcanism appears to have been partly controlled by a major fossil fracture system, and hosts a wide variety of syngenetic and epigenetic gold and copper mineralisation. In the Wagga Trough a number of syngenetic cupreous pyrite deposits are associated with (tholeiitic) basaltic volcanism and flysch-type sedimentation. The Ordovician in Tasmania has not produced important mineral deposits to date. Vein-type gold is known from shear zones in Ordovician sediments, while a

Mississippi Valley-type lead-zinc deposit occurs in down-faulted carbonates. In the Thomson orogen probable Ordovician granodiorites have intruded Ordovician and Cambrian sediments to produce important vein gold deposits.

Fig 2.19 summarises Ordovician stratigraphy within eastern Australia.

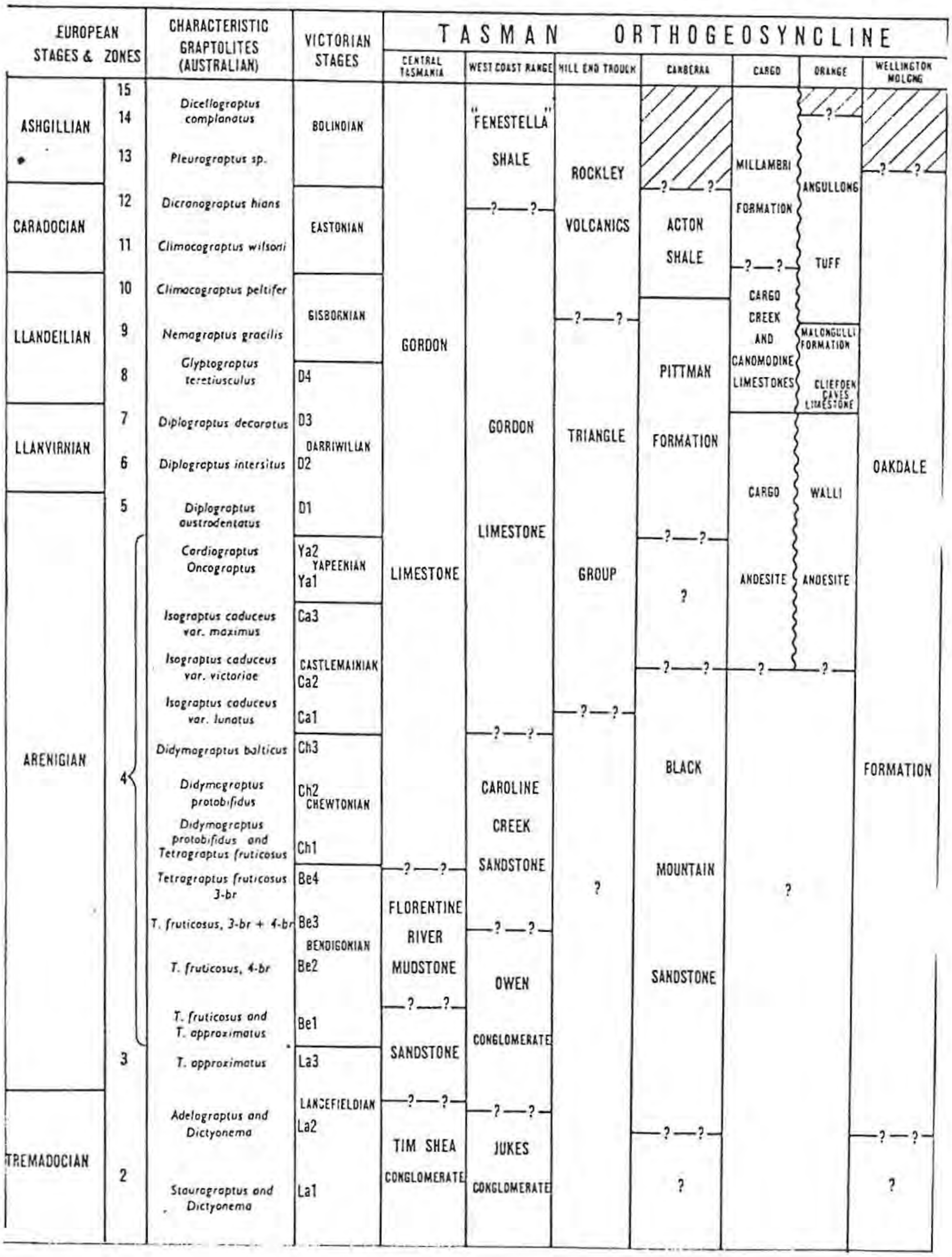

Fig. 2.19 Correlation table for Ordovician System (after Brown et al 1968)

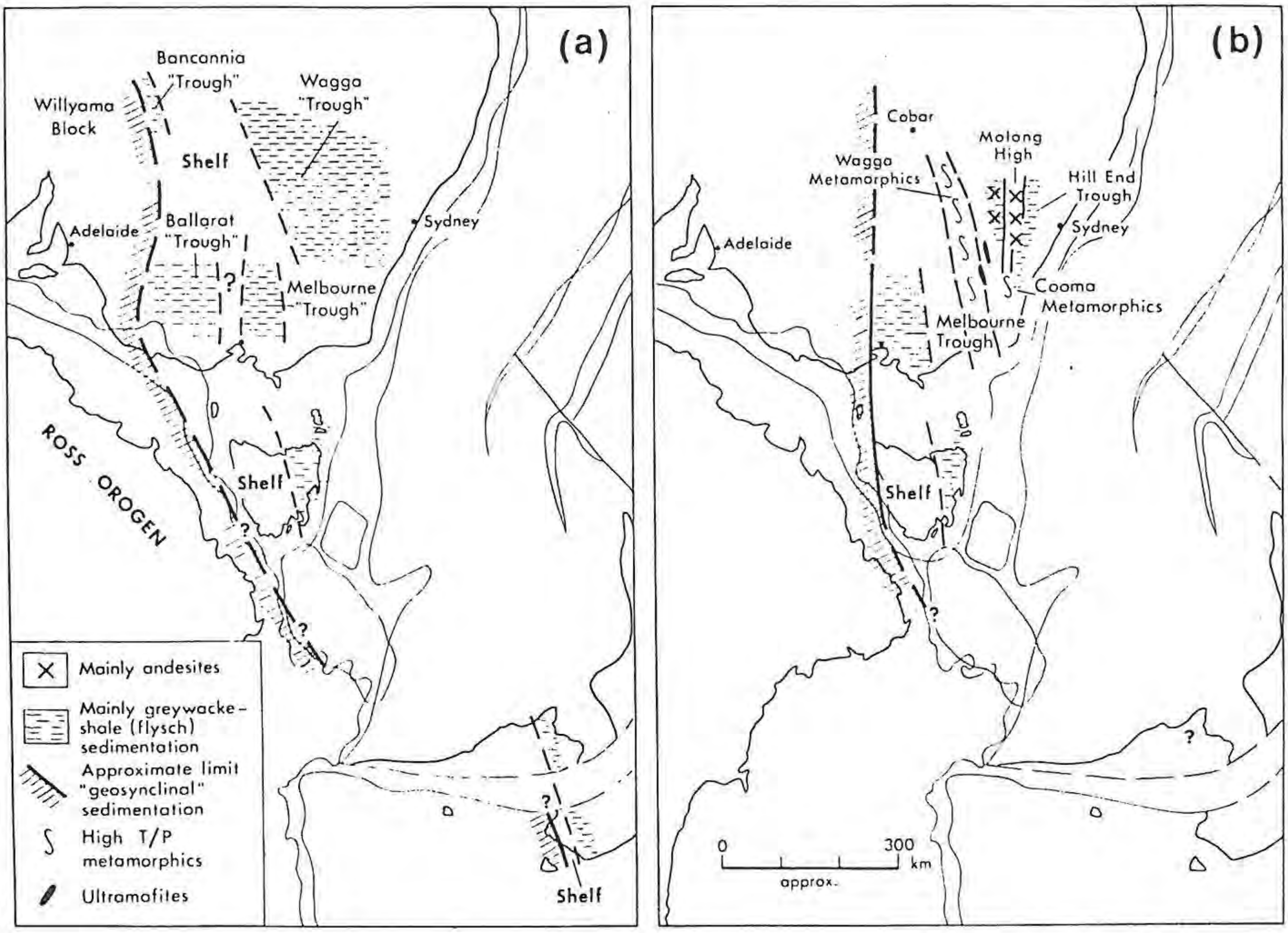

Fig. 2.20 Major tectonic features of the Southern Tasman Orogenic Zone in (a) the Early Ordovician and (b) the Late Ordovician/Early Silurian (from Solomon & Griffiths 1974)

Fig. 2.20 shows the major tectonic features of the southern part of the Tasman Geosyncline both at the beginning and end of the Ordovician. Within the Lachlan geosyncline there were several troughs and rising geanticlines. The Ballarat Trough was subsiding rapidly in western Victoria to the east of the Glenelg Zone in Lower Ordovician times. It was filled with up to 4 000 m of quartz-rich greywackes, black and red shales and black cherts, and contains one of the most complete sequences of graptolite fauna in the world (enabling mapping to be done using biostratigraphic units). The greywackes show both simple and oscillatory grading, with graptolites more abundant in the fine, upper parts of the graded beds.

During Middle Ordovician times in Victoria, the western shoreline of the Lachlan geosyncline moved well to the east, increasingly restricting the Ballarat Trough. As a result the Middle to Late Ordovician saw waning deposition of shales and greywackes in the area west of the Mt William - Heathcote Axis, until cessation of deposition was indicated by rudites, coarse sandstones and mudstones (the Riddel Grits) associated with a shelly fauna.

The Ballarat Trough has been a major source of gold in Australia. Many of the Victorian gold deposits occur as veins, replacements and fissure fillings in Cambro-Ordovician greywackes, slates and shales, and have until recently been generally regarded as being genetically related to various Devonian granitic intrusives. Some gold fields may be seen to be spatially associated with granitic intrusives (e.g. Stawell, Maldon, Glen Wills and Dunolly) and contain accessory minerals normally associated with granites (like molybdenite, wolframite and native bismuth). Other deposits, however, may be situated well away from granites (e.g. Daylesford, Blackwood and Harrietville) and in general the gold fields are not zonally distributed in relation to granite outcrops but retain their meridional trends (parallel to the structural grain of the country) even when adjacent to granite outcrops. Thus it would appear that many of the Victorian gold deposits are not genetically related to the Devonian granites. One possibility (Bowen and Whiting 1975) is the mobilisation of quartz and gold from within the sedimentary pile during folding, and subsequent localisation within structural traps.

The gold deposits of the Bendigo-Ballarat area occur mainly in Lower Ordovician sediments which were probably folded by the epi-Ordovician Benambran Orogeny, while at Stawell gold lodes occur in unfossiliferous Upper Cambrian (or Lower Ordovician) sediments. Gold may be syngenetically enriched in the Lower Palaeozoic sediments. Between Ballarat and Wedderburn occurs the "indicator belt" where pyritic carbonaceous slate horizons cause enrichment in the cross-cutting quartz reefs.

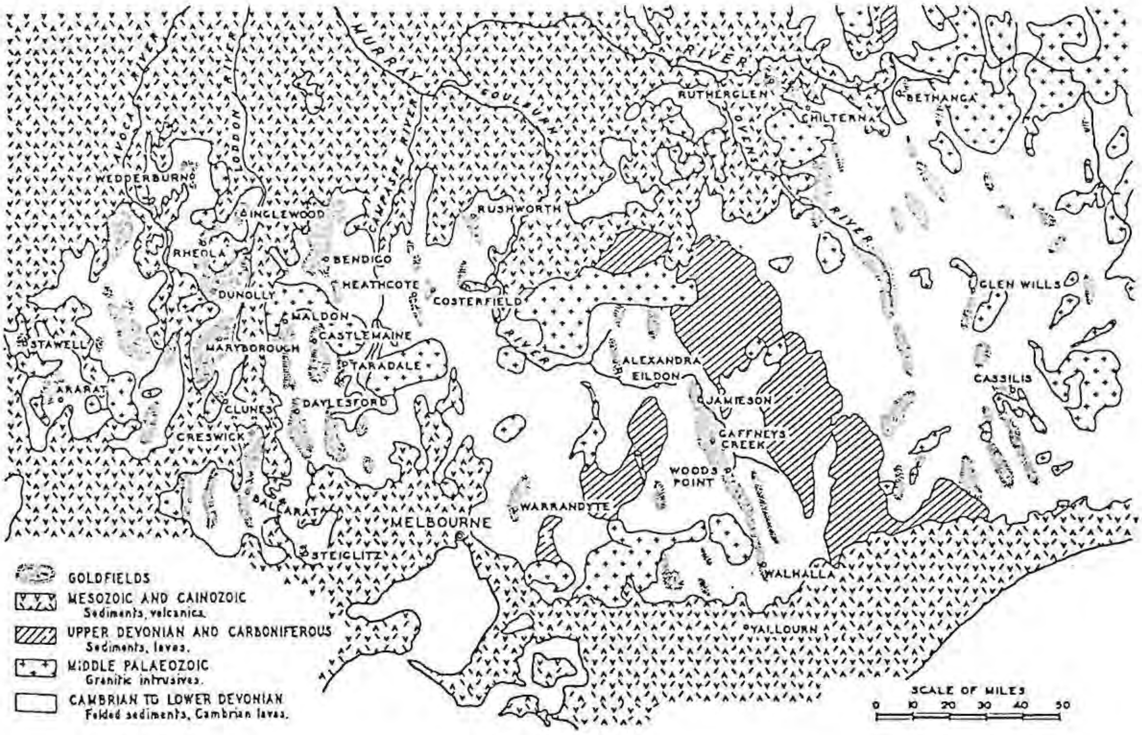

Fig 2.21 The distribution of gold fields in relation to the broad geological features of Victoria (from McAndrew 1965)

The Ordovician sediments of the Ballarat Trough also host several minor vein-type antimony occurrences, the largest being at Coimadai.

In central Victoria the Melbourne Trough is bounded to the east by the Mt Wellington Axis and to the west by the Mt William - Heathcote Axis. Both these structures were probably rising geanticlines in the Early Ordovician, but remained submerged by the sea. The Melbourne Trough, which they enclose, narrowed to the north, and may have extended no further north than the present Murray River.

Lower Ordovician rocks outcrop in the central parts of the trough as greywackes and slates, and as more cherty rocks on the marginal highs. Sedimentation continued in the Melbourne Trough for most of the Ordovician, with quartz-rich greywackes and slates. Correlation has been aided by the abundant graptolite faunas.

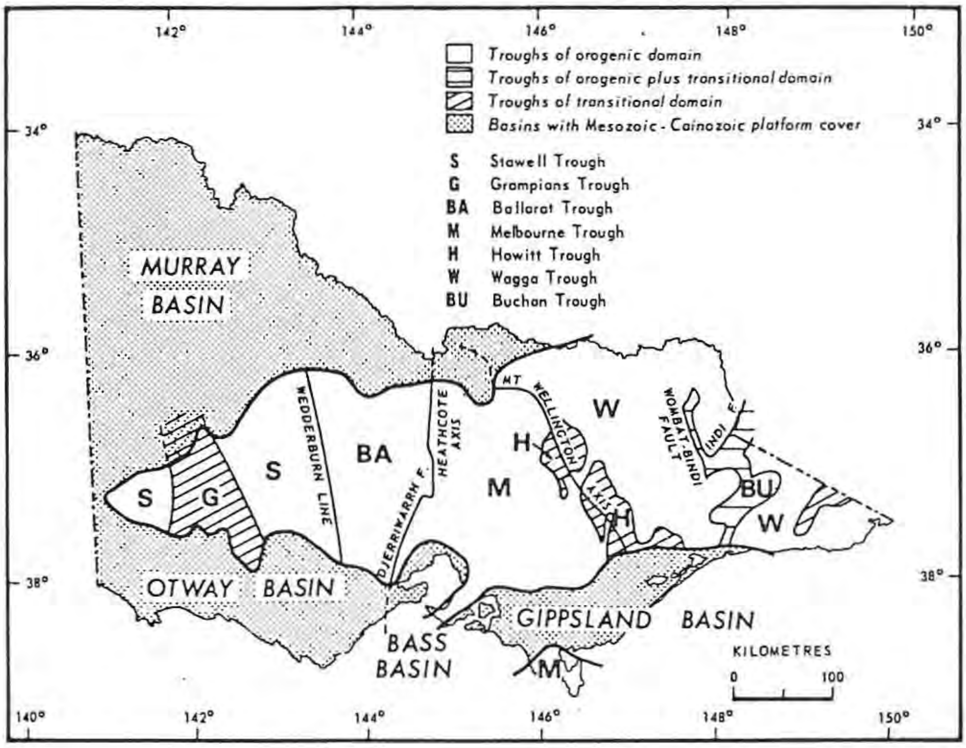

Fig. 2.22 Distribution of the main sedimentary basins of the Tasman Fold Belt in Victoria (from Van den berg 1978)

As in the Ballarat Trough, vein-type gold deposits occur in Lower Palaeozoic sediments. These are associated with deformation of the sediments (producing concordant and discordant veins) as well as occurring in intermediate to basic dykes.

To the east of the Melbourne Trough, the Wagga Trough (or Marginal Basin) was an active downwarp extending from southeastern Victoria to as far north as Bourke in New South Wales (probable northward extensions are obscured by Mesozoic cover). Most of the sediments in this trough were greywackes and shales, with locally abundant graptolites, while further north in the Cobar district, cross-bedded quartz-rich sandstone, slate and chert (the Girilambone and Tallebung Groups) may indicate a shallowing of the trough. Sedimentation continued conformably in the Middle and Upper Ordovician with up to several thousand metres of slates and quartz-rich greywackes.

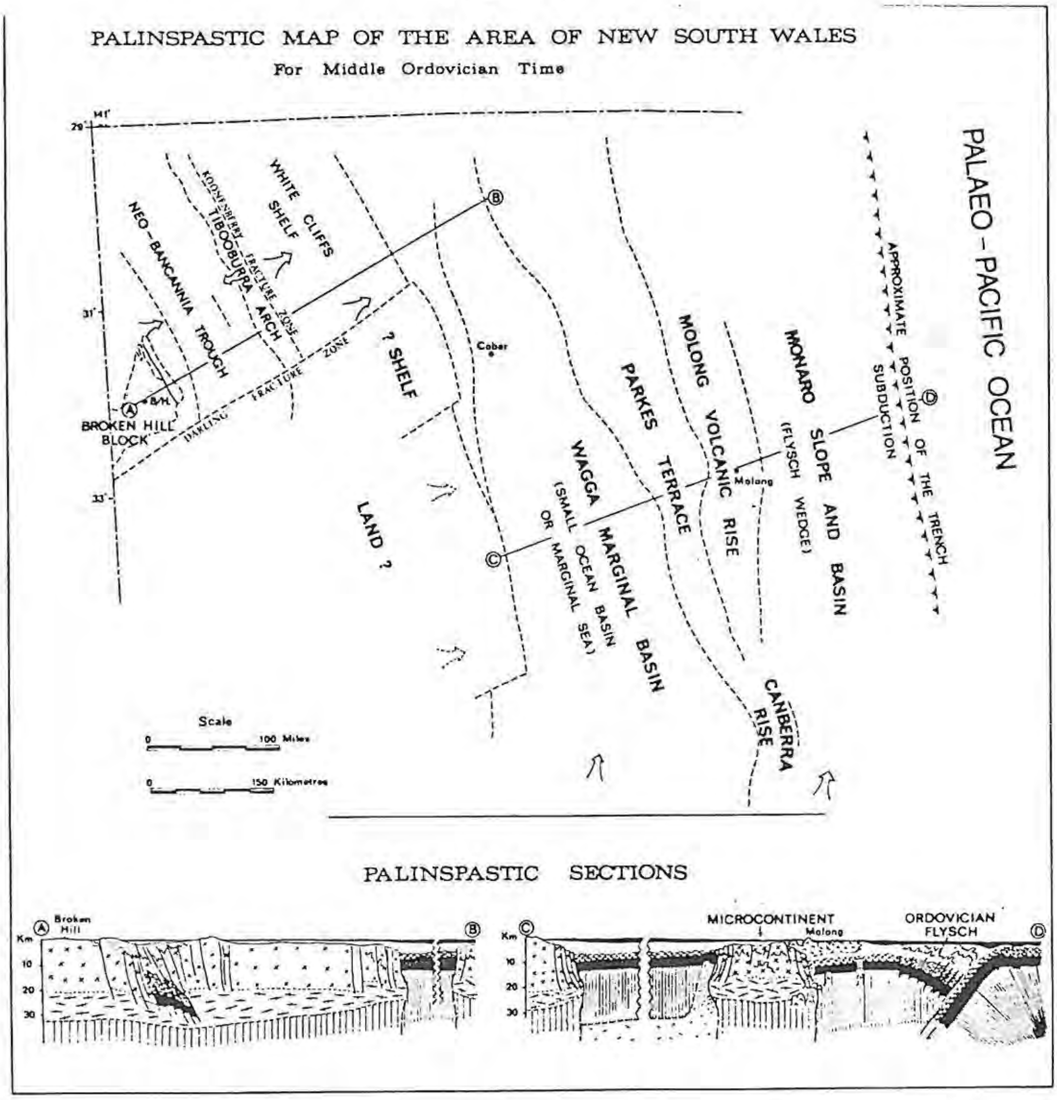

Fig. 2.23 Palinspastic map of the area of New South Wales for Middle Ordovician time (from Scheibner 1973)

In the Cobar region the Girilambone Beds host a number of syngenetic cupreous pyrite deposits. Many examples of this type of mineralisation occur in the Girilambone - Hermidale, Honeybugle, and Tottenham - Albert Districts. Well-known deposits in the Girilambone - Hermidale District include the Girilambone, Budgery, Budgerygar and Bonnie Dundee deposits. These deposits are spatially related to exhalative cherty horizons (now magnetite quartzites) within sequences of alternating tholeiitic basaltic volcanics and flysch-type sediments. Suppel (1974) suggests that the basaltic volcanics and nearby related mafic and ultramafic intrusives represent a now-deformed and metamorphosed ophiolite sequence, with the massive cupreous pyrite mineralisation being syngenetically formed at sites of rifting and oceanic crust formation.

Mineralisation of the "Tottenham type" consists of conformable tabular bodies, up to 1,5 m thick, with fairly simple mineralogy (pyrite-chalcopyrite, with lesser chalcocite/digenite, covellite and very minor sphalerite). These bodies are developed at three horizons in the basic volcanic sequence of the Tottenham Formation.

The "Girilambone type" of mineralisation may be massive or laminated (pyrite-chalcopyrite-sphalerite with minor pyrrhotite) or desseminated (pyrite-chalcopyrite with accessory sphalerite, marcasite, pyrrhotite, arsenopyrite and trace galena and chalcocite). Graphite found in the quartz provides some evidence for reducing conditions. A further type of mineralisation, the "Bonnie Dundee - Budgery type", consists of pyrite.

Other types of gold and base metal mineralisation are associated with veins and replacements resulting from later folding and metamorphism. Abundant vein-gold deposits (especially towards the Victorian border and into Victoria) are related to the emplacement of later (Siluro-Devonian) granites.

East of the Wagga Trough was an area of relatively shallow water sedimentation, the Parkes Terrace. According to Scheibner (1972c), this area may have formed a microcontinent, with an older basement built partly of Girilambone Beds.

To the east of the Wagga Trough and Parkes Terrace is the Molong Volcanic Rise (also called the Molong - Canberra High), a calc-alkaline volcanic arc along which andesitic volcanics and shallow-water sediments accumulated. Pauses in volcanism allowed shallow-water marine sediments and limestones to be deposited (these are best seen in the Middle

Ordovician, in the Walli - Cargo areas). The Molong Volcanic Rise was not a continuous structure, and had wide passages through it, one south of Mandurama and another south of Canberra. To the east of the Molong Volcanic Rise was the Monaro Slope and Basin, an Ordovician flysch wedge or trench complex.

Lower Ordovician graptolites occur north of Molong in the Oakdale Formation, which consists of spilites, quartz keratophyres, tuffs, greywackes and scattered limestone lenses. The shallow-water Black Mountain sandstone in the Canberra area is of probable Lower Ordovician age.

Near Orange in the northern part of the volcanic rise the Malongulli Tuff and Angullong Formation are equivalent to the upper parts of the Oakdale Formation. They consist of interdigitating andesites, andesitic tuffs, keratophyres, bedded limestones and sandstones, and volcanic-derived shales. They feature rapid facies changes in all directions, contain common graptolite and shelly faunas, and may attain 1 000 m in thickness.

During the Darriwilian, a general subsidence resulted in shallow-water sedimentation over much of the Molong Volcanic Rise. Volcanic activity was less intense than before and was entirely absent in the south around Canberra (see below). In the Orange - Wellington area sediments were calcareous, often with an appreciable bioclastic component. Carbonate developments include the Cliefden Caves, Bowan Park, Cargo Creek, Canomodine and Reedy Creek Limestones. Between Cowra and Orange, the Cliefden Caves Limestone exceeds 800 m in thickness. It consists of fine and coarse bedded limestones and shales, with small biohermal masses and a profuse fauna (including brachiopods, trilobites, asaphids, pliomerids, gastropods and corals).

Within the Ordovician andesites of the Molong - South Coast Anticlinorial Zone (two branches of volcanics separated by the Hill End Trough - see fig 2.24), two distinctive metalliferous associations may be observed, related to depositional and tectonic environments. The volcanics to the west of the present Hill End Synclinorial Zone feature more basic varieties of andesites, contain major copper mineralisation with minor gold and silver, and accumulated in a shallow-marine environment on a volcanic rise. In contrast the Sofala Volcanics, east of the Hill End Synclinorial Zone consist of "true andesites", which were extruded in deep water and host major gold mineralisation with minor copper. Some of the diversity of zoning in the mineral deposits has been related to an eastward migration in the axis of volcanism during the Ordovician.

Of major importance to the distribution of the andesitic volcanics (and their associated ore deposits) is the presence of the Lachlan River Lineament, a probable fossil fracture zone cutting across regional structures and passing close to Bathurst and Orange. Within and north of the fracture zone, andesitic volcanism was much better developed than to the south of it (perhaps indicating more intensive subduction to the north?). North of the fracture zone, both the Cowra and the Hill End Troughs opened by different mechanisms, and possibly at different times, compared with their southern parts. Intermediate and ultramafic intrusives, best developed in the Carcoar - Orange area, occur within the fracture zone, and mineral deposits in the andesites are most strongly concentrated within and to the south of the fracture zone. Generally lineaments within the fracture zone do not appear to control mineralisation, notable exceptions being the Copper Hill porphyry copper, similar deposits near Cargo and some disseminated copper - gold deposits to the south.

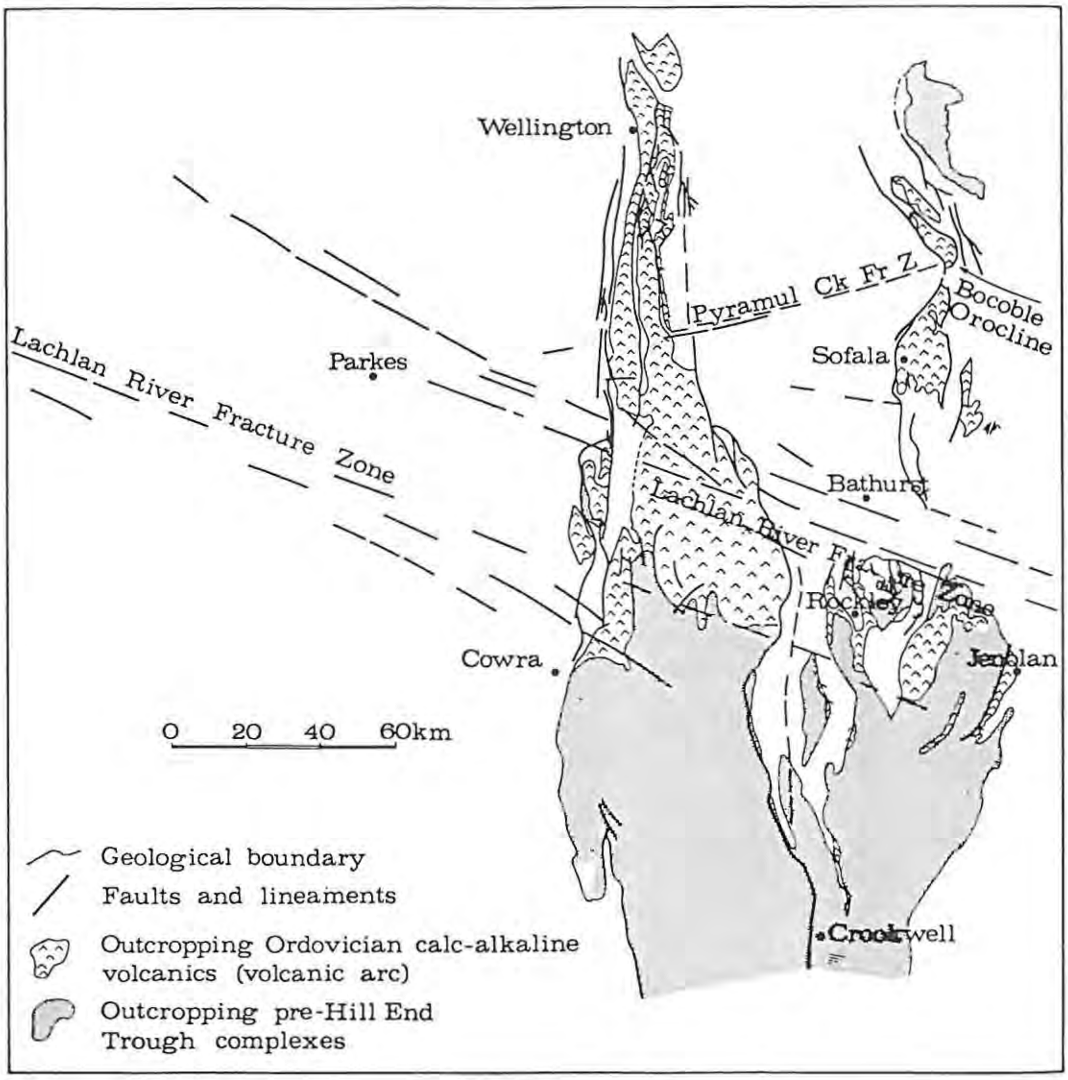

Fig. 2.24 Pre-Hill End Trough complexes in their present outcrop distribution (from Scheibner 1974)

The northern part of the Molong Volcanic Rise contained predominantly andesitic to basaltic lavas and pyroclastics, and these hosted several types of copper and gold mineralisation (in contrast, the southern part of the Molong Volcanic Rise, now seen as the Molong - South Coast Anticlinorial Zone, consisted mainly of flysch-type sediments hosting mostly auriferous quartz vein-type mineralisation derived from later granites).

Types of mineralisation hosted in the volcanics include disseminated native copper in altered andesitic and basaltic lavas; stratabound magnetite - pyrite - chalcopyrite bodies in andesitic tuffs (e.g. Cadia); subvolcanic hydrothermal stockwork vein and disseminated deposits (e.g. Cargo); pyrite - chalcopyrite veins; and deposits related to near surface intrusions of the andesite by bodies of (probably later) quartz felspar porphyry (e.g. Copper Hill). Important gold deposits include those at Lucknow, where gold - calcite veins are located along a contact between andesite and a (possibly Devonian) serpentinite, and Junction Reefs - Mandurama, where stratabound gold mineralisation may be of pyrometasomatic type.

At Cadia several magnetite - pyrite - chalcopyrite - gold ore deposits occur in the andesitic Angullong Tuff, the two most important of which are the Iron Duke and Little Cadia (see fig 2.25). The base of the Angullong Tuff consists of over 200 m of andesitic lavas with subordinate volcanic breccias, agglomerates, lavas and tuffs. This is overlain by up to 30 m thick lenses of sparsely fossiliferous marine limestone, in turn succeeded by tuffs and shales, locally calcareous and well-banded. The ore bodies are contained in the lower 50 - 100 m of this tuffaceous, shaley unit. This grades up into massive andesitic tuffs, breccias, agglomerates and possible lavas frequently hosting low-grade copper mineralisation. It appears that the copper and gold may have hydrothermally replaced calcareous shales and tuffs and chemically precipitated (or replacement) iron oxide bands (Welsh 1975).

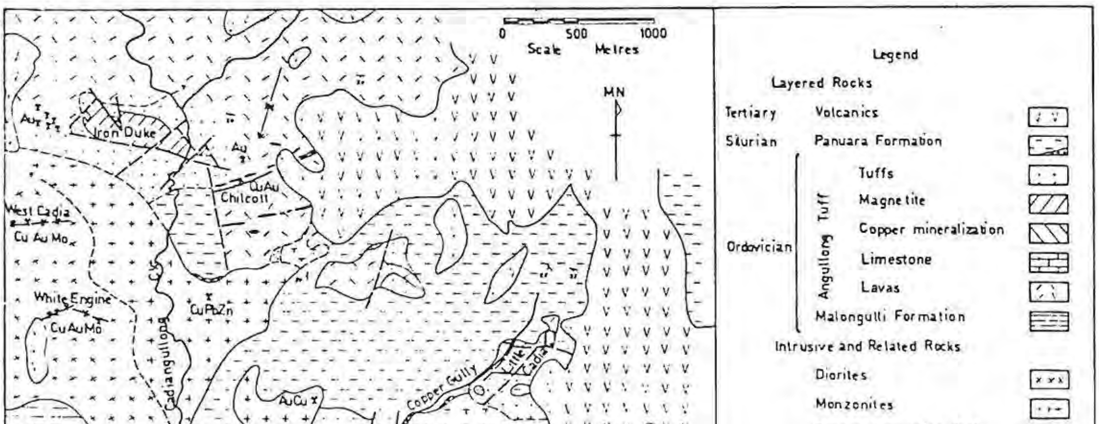

Fig. 2.25 Geological plan of Cadia area (from Welsh 1975)

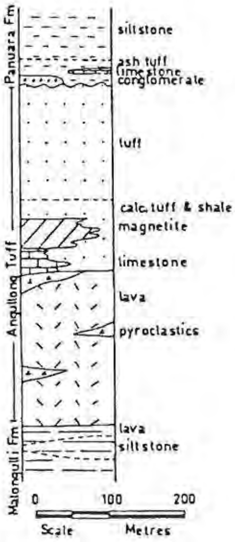

Fig. 2.26 Stratigraphic column at Cadia (from Welsh 1975)

At Junction Reefs strong stratigraphic control is evident on copper-gold mineralisation. Up to twenty mineralised horizons (with a pyrrhotite - pyrite - chalcopyrite - gold assemblage) are present in Ordovician sediments. Although an epigenetic origin has been accepted in the past (with mineralisation emanating from the many nearby intermediate intrusives), a syngenetic exhalative origin has been proposed (Felton 1974) with later modification from faulting and intrusion.

In the Sofala area gold occurs as veins, stockworks and disseminations in andesites and andesite - derived sediments, usually in association with carbonate alteration. A possible mode of formation of these deposits could be leaching of gold from the volcanic pile by late action of circulating water and carbon dioxide, to be redeposited in favourable structural sites. Alternately the gold could be deposited during hot spring activity in late stages of andesitic volcanism, or perhaps during later regional metamorphism (Felton 1974).

The Early Ordovician in Tasmania saw the culmination of the Jukesian Movement, represented by extensive faulting and uplift. Geanticlinal areas in the west and northwest parts of the island became more prominent. The largest of these was the Tyennan Geanticline, around the outer edges of which a series of fault troughs (or fault angle depressions) developed. Similar structures occurred within the geanticlines, as at Adamsfield. In these depressions the earliest rocks of the Junee Group, the Jukes and Owen Conglomerates, and their correlatives, were deposited. These rocks are conformable on the Cambrian Dundas Group away from the areas of major uplift, but where uplift occurred the contact is marked by an angular unconformity or disconformity.

The earliest units of this sequence appear to be fanglomerates (Jukes Conglomerate) which are coarse at the base, poorly stratified, thin rapidly laterally, and contain volcanic detritus. Later lithologies became finer grained, more regularly bedded and more siliceous, these features indicating a reduction in the relief of the Tyennan Geanticline, a decrease in the rate of subsidence of the troughs, and more efficient sorting of the sediments. These rocks are mostly unfossiliferous and are generally regarded as having been deposited in a terrestrial environment, except for some thin marine beds at the top of the Owen Conglomerate. These rocks average 200 - 500 m thick, but may exceptionally attain 2 000 m in thickness.

By the Early Arenigian the highlands formed by the Jukesian Movements were considerably reduced, and were being transgressed by the sea (which had already covered areas of Owen Conglomerate deposition). The well-washed sandstones and siltstones of the Caroline Creek Formation were deposited in this shallow marine setting. In some areas these rocks are succeeded by the finer-grained calcareous siltstones and mudstones known as the Florentine Valley Mudstones. These two units may reach 2 000 m in thickness, and the fossil record indicates abundant life, including brachiopods, trilobites and graptolites.

The remainder of the Ordovician in Tasmania was dominated by deposition of the Gordon Limestone, a sequence of well-bedded calcilutites with lesser calcarenites and calcirudites accumulating in stable shelf conditions. To the northwest the limestone thins out (and terrigenous material increases) while the greatest thicknesses (1 800 m) are reached in the south and east where the unit is thought to persist beneath Permian and Jurassic cover. Towards the close of the Ordovician, the limestones were succeeded by shales and sandstones.

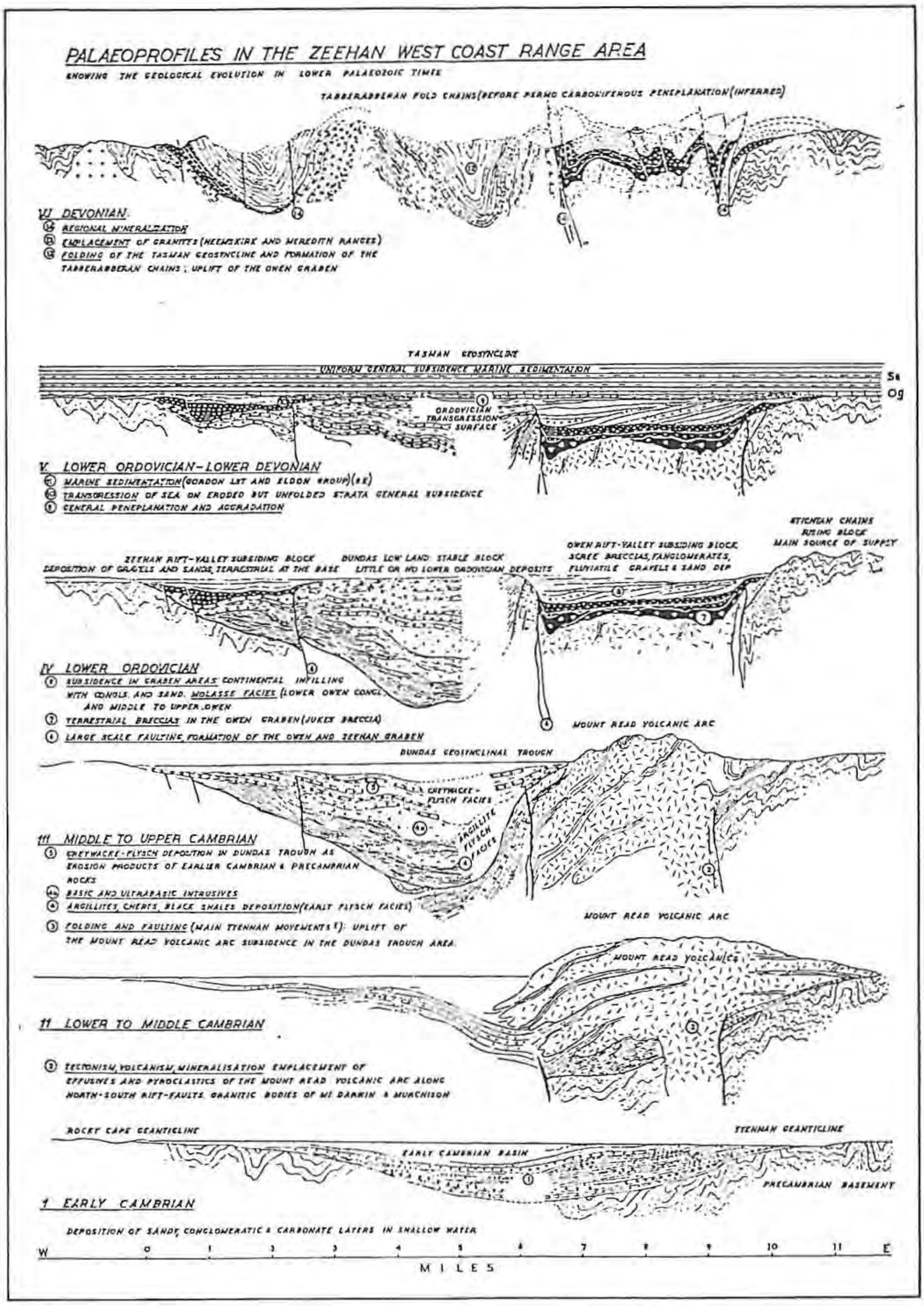

Fig. 2.27 Palaeoprofiles of the West Coast Range of Tasmania showing Palaeozoic geological evolution (after Campana and King 1963, from Brown et al 1968)

To date, mineralisation in the Ordovician rocks of Tasmania has not proved to be important. At Bubbs Hill, 17 km east of Queenstown, Gordon Limestone downfaulted into Precambrian rocks contains Mississippi Valley-type galena - sphalerite mineralisation. At Beaconsfield and Mathinna (in the north and northeast of the island), gold-quartz lodes occur in north-northwest trending shear zones in Ordovician sandstones and limestones, and are not obviously related to igneous rocks.

The Benambran Orogeny at the end of the Ordovician was probably caused by relative eastward rotation of the Australian plate. Orogenic activity was very strong in the Wagga Trough (decreasing in intensity to the east) causing structural deformation and metamorphism of the trough's sedimentary fill. Metamorphism was in a high temperature - low pressure environment, and progressed in some places to anatexis with the emplacement of synkinematic anatectic granites. No obvious metallogenic processes were related to the emplacement of these granites, and though some mobilisation of gold probably occurred, these effects are difficult to separate from those of later orogenic granites. The Molong Volcanic Rise and adjacent areas to the east were also deformed and metamorphosed, but with less intensity, with no evidence of Benambran deformation visible from the eastern part of the Monaro Slope and Basin.

In the Thomson fold belt, deposition was widespread in the Ordovician. In the Warburton Basin quartzose turbidite sequences and black graptolitic shales of Early and Late Ordovician age overlie Cambrian carbonates. Metasediments and metavolcanics of possible Ordovician age occur as basement to the Adavale Basin, and in the Anakie Inlier, where the association of basic volcanics with serpentinite lenses in the Argentine Metamorphics suggests an oceanic crust. In the Lolworth - Ravenswood Block, Early Ordovician tuffaceous sediments overlie the Late Cambrian volcanics.

Cambrian and Ordovician sediments and volcanics (and possible Precambrian metamorphics) were deformed in a Middle to Late Ordovician Orogeny, which probably first imposed the dominant northeast trend of the orogen. The only exception to this structural trend is the Lolworth - Ravenswood Block, which has an overall east - west trend, and appears to have a complex structural history. This orogeny resulted in extensive plutonism, greenschist facies metamorphism (locally up to amphibolite facies), a prominent slaty cleavage in argillaceous sediments, and large scale thrusting or overturning (which is required to explain the sequence of trilobite faunas in Gidgealpa I). Rocks folded by this orogeny are unconformably overlain by Late Ordovician sediments in the Anakie Inlier, giving the orogeny a probable Middle Ordovician age. Local folding of this age has been recognised in the Lachlan fold belt but this tectonism was earlier than the widespread Late Ordovician - Early Silurian Benambran Orogeny.

Within the Lolworth - Ravenswood Block Ordovician and Cambrian sediments intruded by the Ordovician (?) Ravenswood Granodiorite Complex host gold deposits. The deposits are typically epigenetic quartz - sulphide veins occupying fissures and may best be seen at Charters Towers, where all the important deposits are located within the biotite granodiorite of the Ravenswood Granodiorite Complex near its contacts with metamorphic rocks.

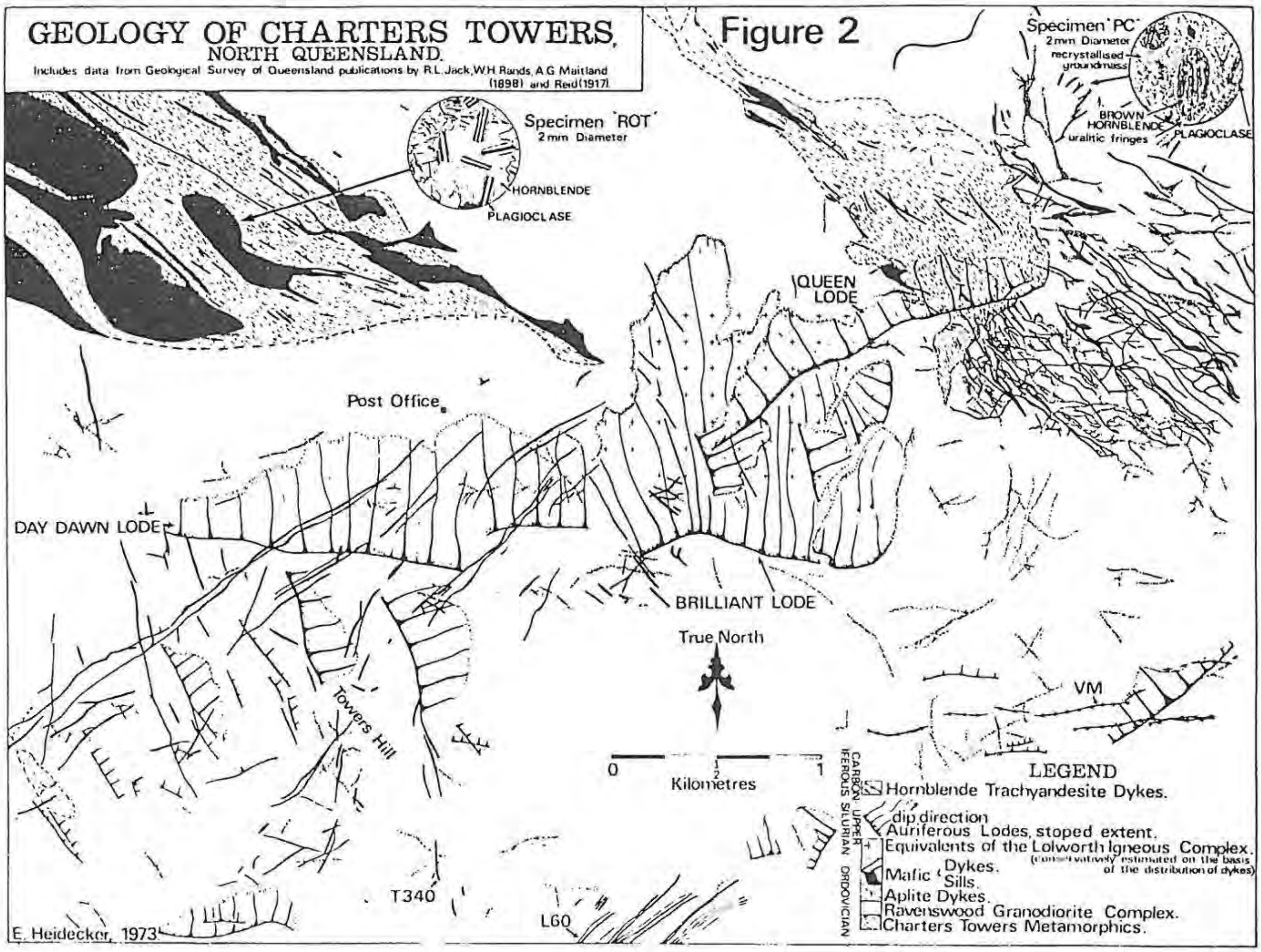

Fig. 2.28 Geology of Charters Towers, North Queensland (from Heidecker 1974)

The Hodgkinson - Broken River orogen appears to represent a mobile belt whose development commenced after the Mid-Ordovician Orogeny in the Thomson fold belt. It is characterised by a north to north-northwest trend and transects the northeast trend of the Thomson fold belt.

In the Hodgkinson - Broken River orogen (divided into the Hodgkinson Province to the north and the Broken River Province to the south) Ordovician to Early Carboniferous sequences of volcaniclastic flysch with subordinate shelf facies were deposited. This sedimentation occurred immediately east of, and partly on, Precambrian crust. Major fault zones formed a hinge line between the Precambrian craton to the west and the subsiding depositional area to the east and southeast. Seismic evidence from the Hodgkinson Province suggests that the Precambrian basement may underlie parts of the province as far east as the present coastline.

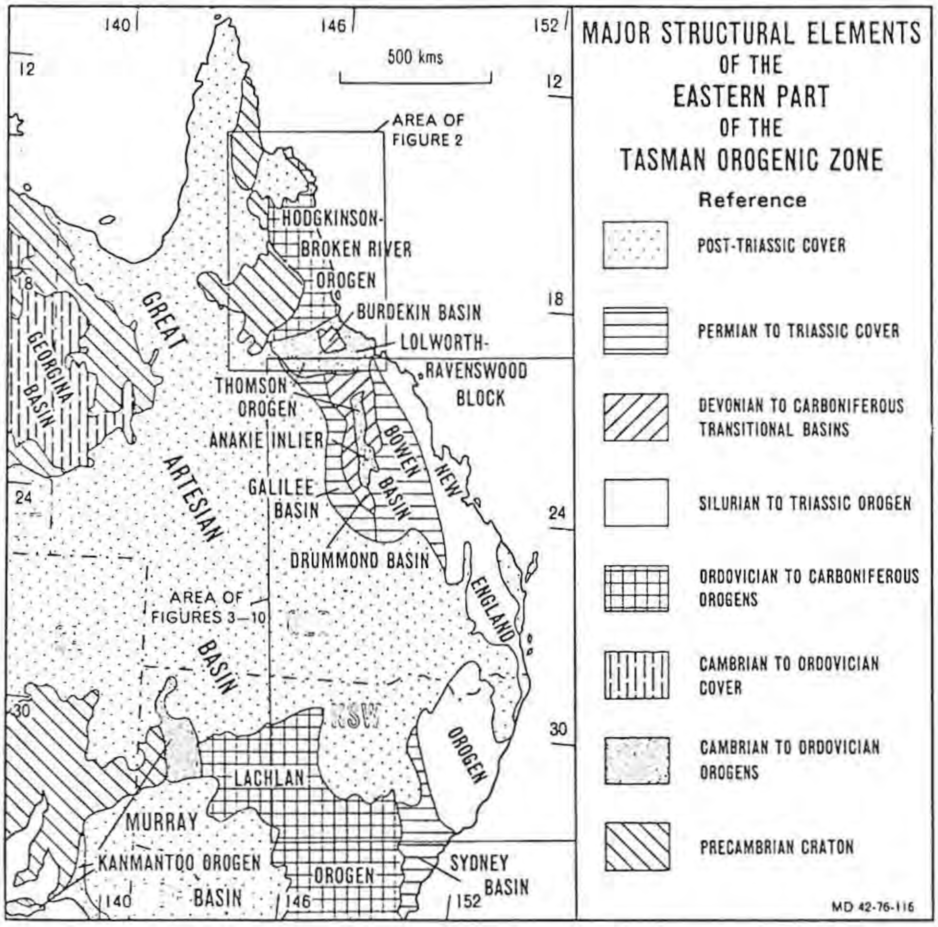

Fig. 2.29 Major structural elements of the eastern part of the Tasman Orogenic Zone (from Day et al 1978)

The Broken River Province can be divided into two distinct subprovinces with different histories of sedimentation and deformation. These are the Graveyard Creek Sub-Province to the west and the Camel Creek Sub-Province to the east, and they are now separated by a major fault zone (fig 2.30). The earliest rocks within the province are quartzose flysch and spilite of probable Ordovician age, best known from the Graveyard Creek Sub-Province but possibly also occurring to the east. These sediments appear to overlie deformed ultramafic complexes of Proterozoic age and show recumbent folding (caused by preconsolidation slumping ?) and slaty cleavage.

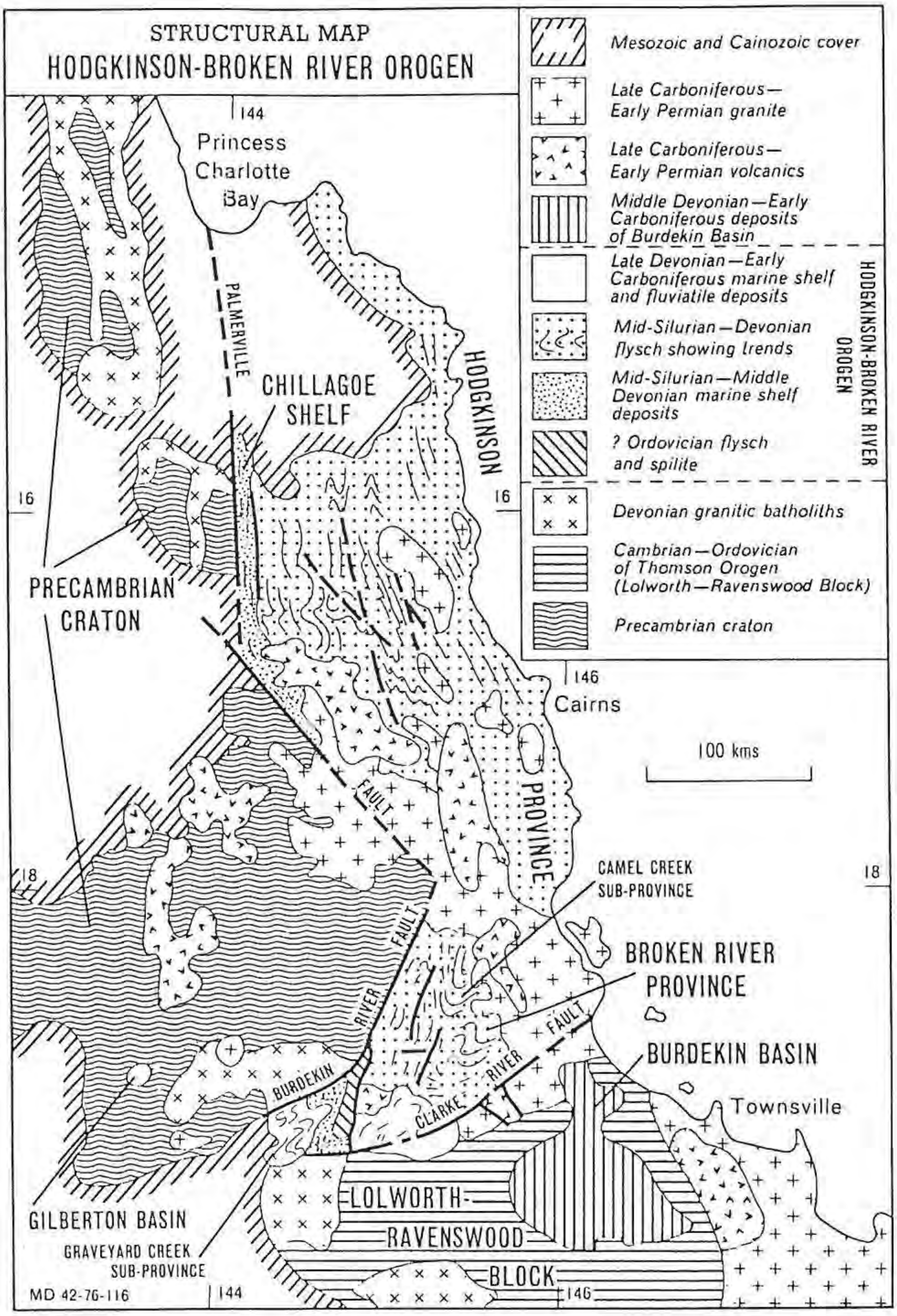

Fig. 2.30 Simplified geological and structural map of the Hodgkinsin - Broken River orogen (from Day et al 1978)

The Silurian

During Silurian times most of the igneous and sedimentary activity in Australia was confined to the Tasman Geosyncline.

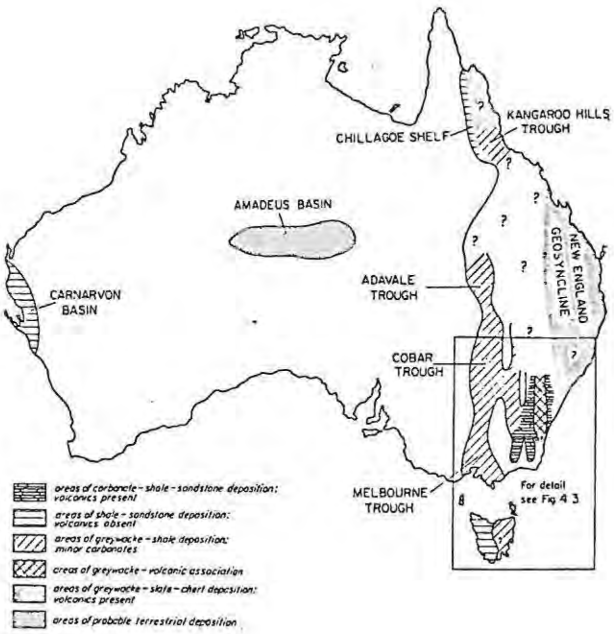

Fig. 2.31 Silurian palaeogeography (from Brown et al 1968)

In the Lachlan geosyncline the pattern of troughs and highs had been altered by the epi-Ordovician Benambran Orogeny, but trough-controlled flysch and shelf-type sedimentation continued. Acid volcanism, largely confined to fault-bounded troughs, commenced in the Middle Silurian (following crustal extension after the close of the Quidongan Orogeny) and was widespread before waning in the Late Silurian. Tasmania received shelf and trough-type sedimentation and was a southern extension of the Lachlan troughs of the mainland.

No sedimentation is known from the Thomson orogen during the Silurian, but major sedimentation and Andean-type volcanism occurred in Hodgkinson - Broken River orogen in northern Queensland.

The New England geosyncline commenced its development during the Silurian, and contained volcanic arc activity with unstable shelf sedimentation on the west and submarine basic volcanism and flysch sedimentation to the east.

Two major orogenies occurred during the Silurian, both affecting the Lachlan geosyncline to a major degree. The Quidongan Orogeny occurred at the beginning of the Middle Silurian, while the Bowning Orogeny of the Late Silurian continued into the Early Devonian. The stratigraphy of the New England geosyncline has been affected by a major pre-Lower Devonian deformational event, while Middle Silurian deformation has been observed in the northern Queensland basins.

Silurian mineralisation in the Tasman Geosyncline is dominated by stratabound volcanogenic massive sulphides hosted in Middle to Late Silurian submarine acid volcanics within the Lachlan geosyncline. The best known examples of these deposits are Woodlawn and Captains Flat. These rhyolitic to dacitic sequences (with associated sediments) also host a variety of gold, silver and base metal vein, disseminated and stockwork mineralisation, in both submarine and subaerial settings.

Also of importance in the Silurian are the copper-rich deposits of the Cobar Trough. These deposits are stratabound (though deformed and remobilised due to later tectonism) and occur within sedimentary sequences in (possibly fault-bounded?) troughs. The genesis of these deposits is not unequivocal though a syngenetic origin from fumarolic sources is becoming increasingly accepted.

The Silurian saw the beginning of the major mid-Palaeozoic emplacement of orogenic granites. These include foliated, gneissic and massive "granites" of syn-, late, and postkinematic types, and give rise to abundant and varied (but generally minor) vein-type, disseminated, pipe-like and skarn mineralisation.

Silurian mineralisation in Tasmania was of minor importance, as in the case for the Thomson and Hodgkinson - Broken River orogens of Queensland. However, it must be pointed out that in comparison to the Lachlan geosyncline, the geology of the Thomson and Hodgkinson - Broken River orogens is poorly understood, with correspondingly less intensive mineral exploration, so potential for important undiscovered mineralisation in these areas may exist.

Within the New England geosyncline Cyprus-type pyritic copper occurrences (as well as syngenetic stratiform manganese mineralisation) are associated with siliceous cherty horizons in sequences of flysch-type sediments and basic volcanics.

Several lines of evidence indicate that Australia during the Silurian lay in a warm to tropical climatic belt. Evidence includes evaporites interbedded with calcareous marine rocks in the Carnarvon Basin of Western Australia, extensive coral biostromes that were common over much of eastern Australia as far south as Victoria, and aeolian sandstones containing halite pseudomorphs within the Amadeus Basin. The fossil record indicates abundant life, with especially profuse corals, brachiopods, trilobites and graptolites. The faunas as a whole seem to have had a cosmopolitan character. For example, there has been no difficulty recognising the sequence of European zones in the Australian graptolite faunas, and some tabulate and rugose corals appear to have occurred within an Australo-East Asian province in the Llandoverian and Wenlockian.

Within the Lachlan geosyncline in Silurian times, a series of troughs and topographic highs were present to the east of the mainland of Australia. These were probably a response to a west-dipping zone of subduction further to the east and include, from west to east, the Melbourne Trough (merging into the Cobar Trough further north), the Yass Shelf, the Trundle Trough, the Cowra Trough, the Molong - Canberra

High, the Hill End Trough (with its southern extension the Captains Flat Trough) and the Capertee High. These units will be described from west to east, with attention drawn to the tectonic setting and controls of ore-forming processes operating within the units.

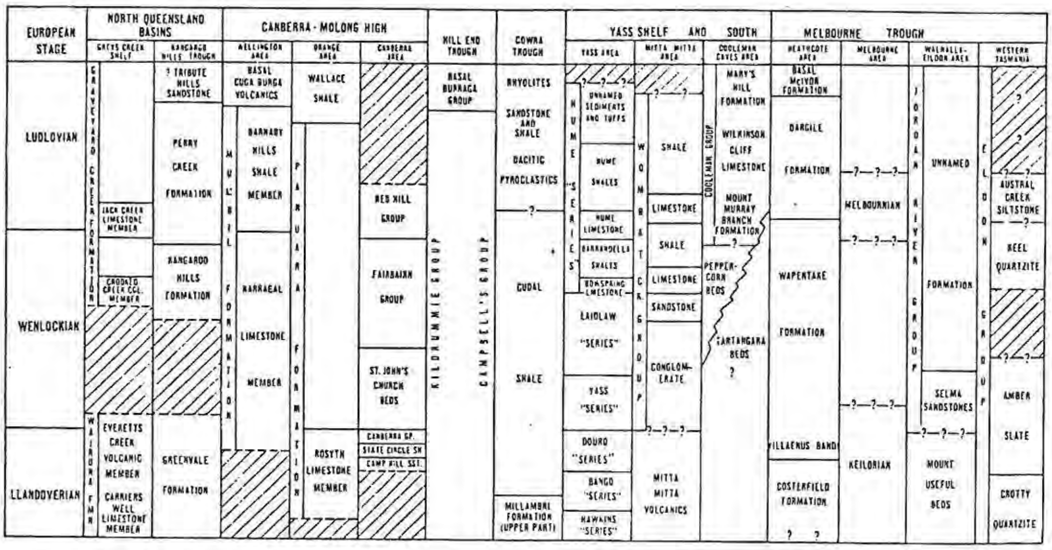

Fig. 2.32 Correlation Table for the Silurian System (from Brown et al 1968)

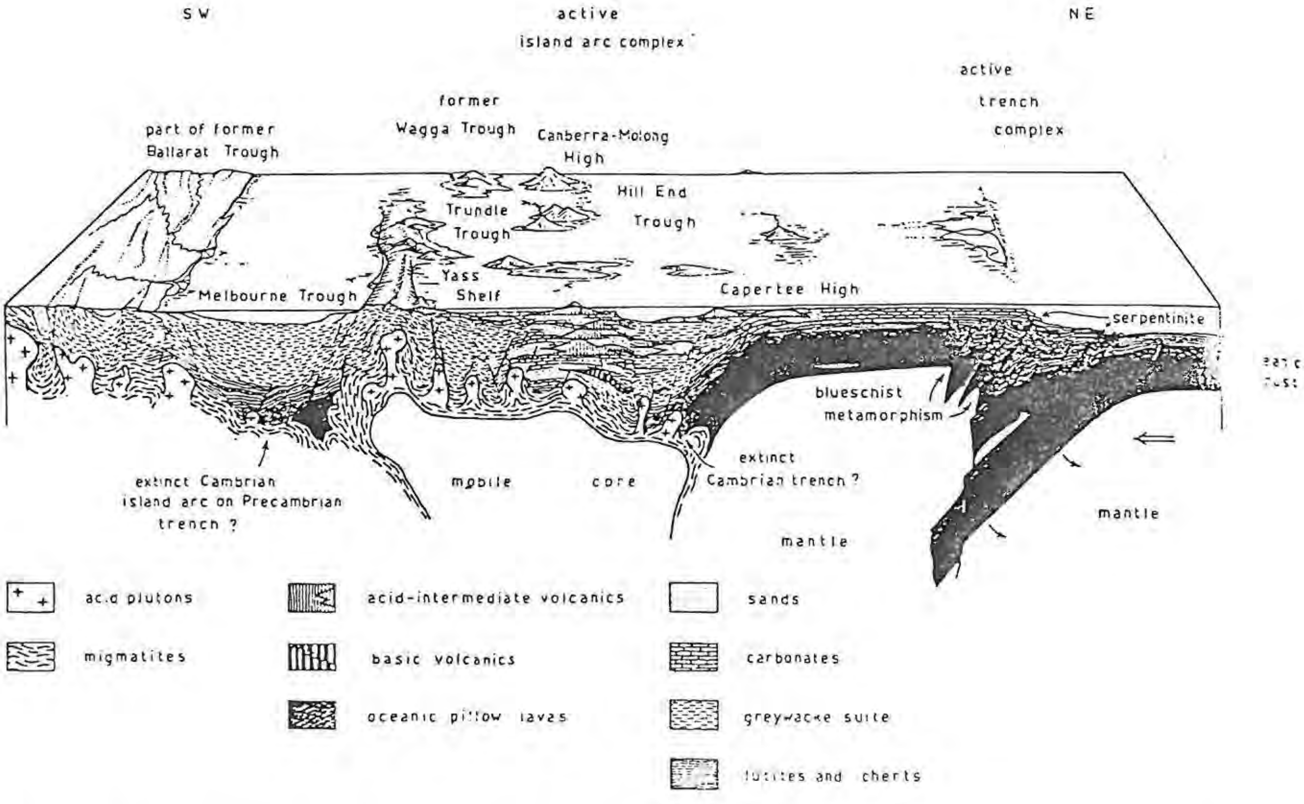

Fig. 2.33 Hypothetical southwest to northeast section through the southern Tasman Geosyncline during medial Silurian time. Not to scale. (from Oversby 1971)

In the Melbourne Trough Silurian sediments are largely conformable on the Upper Ordovician. Sediments are mostly flysch and siltstones and the lack of shelf deposits on the west side suggests a steep slope into the trough. Overall the sedimentary source was from the southwest, though growing anticlines within the trough may have been subsidiary sources.

In the Heathcote area to the west the sequence is about 4 500 m thick and begins with the Costerfield Formation, consisting mainly of green mudstones whose base is not exposed. This is succeeded by the Wapentake Formation, comprising mudstone and interbedded greywackes with a Llandoverian fossil assemblage at its base, containing graptolites, trilobites and ostracods. The overlying Dargile Formation has a similar lithology but Ludlovian fossil faunas. The topmost Silurian unit, the McIvor Formation, consists of fossiliferous sandstones and probably indicates shallowing conditions.

In the Melbourne District the Silurian is spanned by the "Keilorian" below and the "Melbournian" above, and consists of relatively homogenous massive and thinly-bedded mudstones and greywackes, minor lenticular polymictic conglomerates, slump breccias and ripple marked sandstones (sometimes with shelly fossils). Monograptids are common in the Lower Keilorian, while shelly fossils are most common in the upper parts of the succession. In eastern Victoria a subsidiary trough developed within the main Melbourne Trough in the Early Silurian. Within it the basal succession is the Mount Useful Beds, up to 1 700 m of green, yellow and purple slates. They are conformably overlain by the Jordan River Group which overlaps them to the west and consists of mudstones and shales, with coarser lithologies (sandstones and conglomerates) developed towards the western side. Graptolites are common in the sequence and indicate ages from Wenlockian to Early Devonian.

It appears that the southern end of this eastern sub-trough within the Melbourne Trough extended southwards to the northeast corner of Tasmania, and is represented by the Mathinna Beds. The Mathinna Beds consist of over 2 000 m of mudstones or graded sandstone-mudstone lithologies, with relatively sparse fauna and appear to be disconformable on the Ordovician Gordon Limestone.

Meanwhile, western Tasmania appears to have been a southwestern shelf of the Melbourne Trough, and experienced deposition of the Eldon Group. Relative lack of deformation in the Ordovician Gordon Limestone indicates that this area was largely unaffected by the Benambran Orogeny, and the Gordon Limestone was overlain, conformably and locally disconformably, by the Eldon Group. This group consists of six formations, ranging in age from Early Silurian to Early Devonian, and totals some 1 000 m of locally fossiliferous quartzites, siltstones and mudstones.

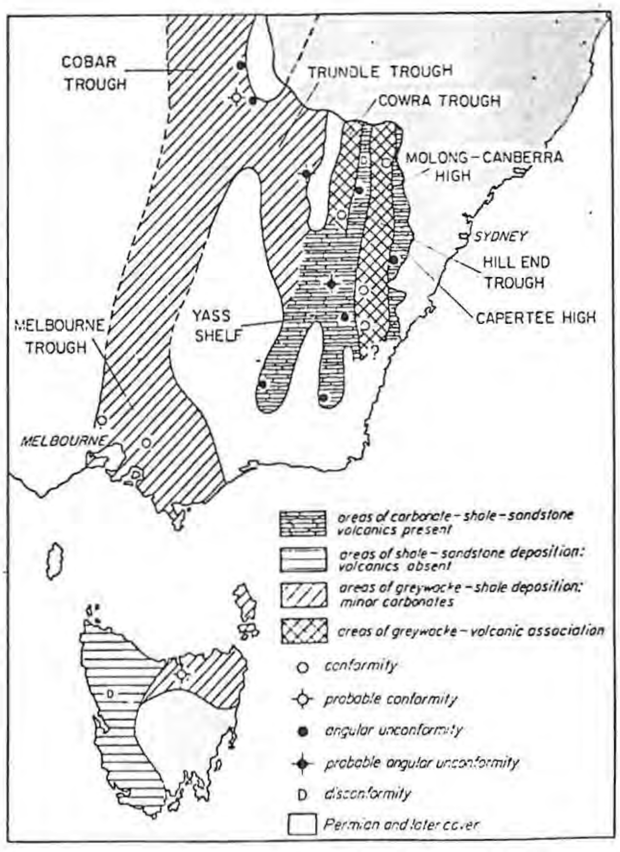

Fig. 2.34 Palaeogeographic map of southeastern Australia during the Silurian Period (after Brown et al 1968)

Within the Melbourne Trough antimony occurrences are found in Silurian sediments. The best known examples are Costerfield and Ringwood, where quartz-stibnite reefs broadly parallel the strike of folded and faulted Silurian mudstones and turbidites.

The geology of the Cobar Trough is poorly understood due to poor outcrop, structural isolation, differing degrees of metamorphism and sedimentary facies changes. However, the Silurian succession here does include thick sequences of greywacke, quartzite, conglomerate and slate with minor limestone (interpreted as discontinuous reef masses) towards the top. Fossils are relatively abundant.

In the Cobar area several copper-rich ore bodies occur in quartz-filled shear zones subparallel to the regional cleavage within the slates and siltstones of the sedimentary Cobar Group. McClatchie (1970) described the "Cobar type" mineralisation as consisting "chiefly of chalcopyrite, pyrite, pyrrhotite, marcasite, and magnetite, with variable sphalerite, galena and native silver and gold, and with minor arsenopyrite, tetrahedrite, cubanite, bornite and cobaltite."

The Cobar Group unconformably overlies the more strongly folded pre-Upper Ordovician Girilambone Group to the east and is itself conformably overlain by the Upper Silurian - Lower Devonian Amphitheatre Group sediments to the west. Although no volcanic rocks occur in the vicinity (the nearest igneous rocks are some acid porphyries at Queen Bee mine, see fig. 2.35), sandstones within the Cobar Group have been described as "tuffaceous" and some opinions now favour a syngenetic exhalative (fumarolic) origin for the deposits, with later deformation and remobilisation causing their discordant aspect (Markham 1974). An interesting feature of the Cobar mineralisation is the fact that many of the ore-bodies occur (in shear zones) along a lithological contact, separating medium to coarse grained sediments below from finer grained sediments above. This occurrence of copper mineralisation along a contact separating an earlier high-energy sedimentary environment from a later low energy environment, invites comparisons with African sedimentary copper occurrences such as the Copperbelt (in Zambia/Zaire) and Klein Aub (in Namibia).

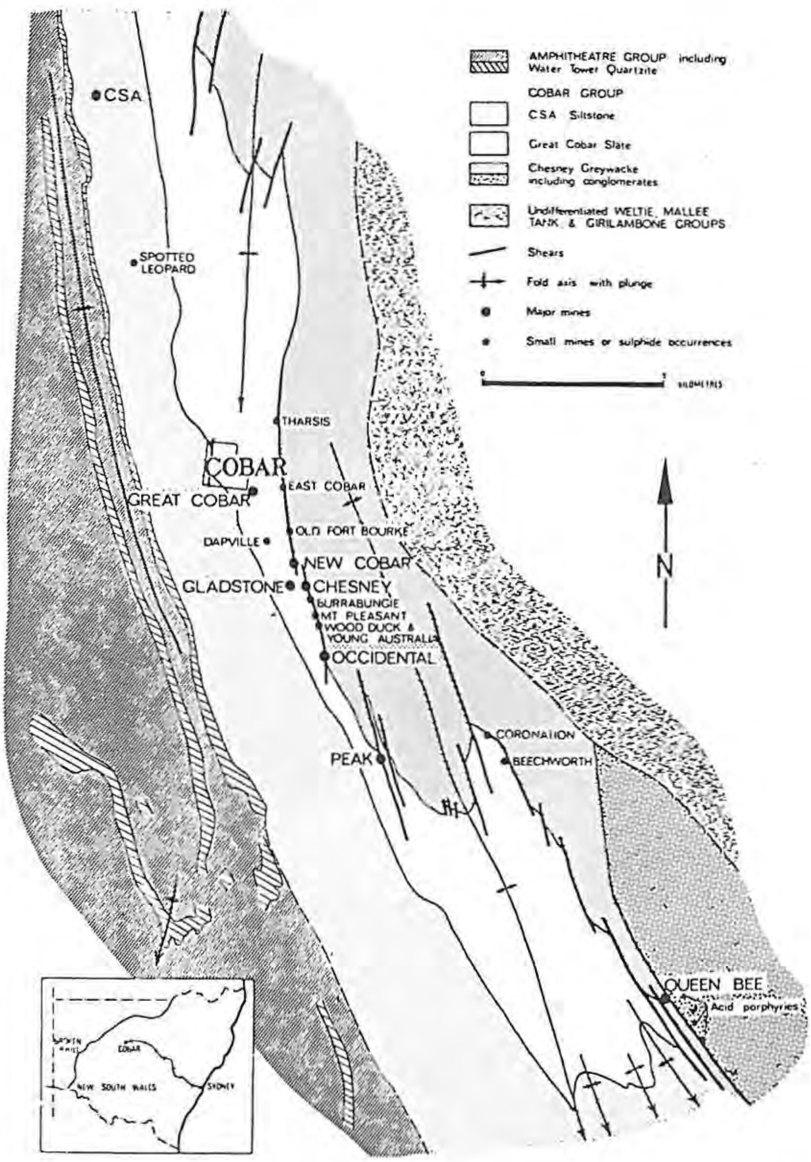

Fig. 2.35 Geological map of the Cobar mining field (from Brooke 1975)

Earlier interpretations in favour of an epigenetic hydrothermal origin had cited evidence such as mineralisation within fault zones and along competency contrasts of (sheared) lithological boundaries. However, definitive wallrock alteration or vein zoning is lacking (though alteration present does include broad irregular haloes of silicification and chloritisation), while further evidence for a syngenetic sedimentary origin includes framboidal and euhedral pyrite (at CSA) as well as a minor carbon content in the sediments suggesting a reducing environment.

"Cobar type" mineralisation occurs within the Cobar Group to the south at Nymagee, Shuttleton, Gilgunnia and Mt Hope.

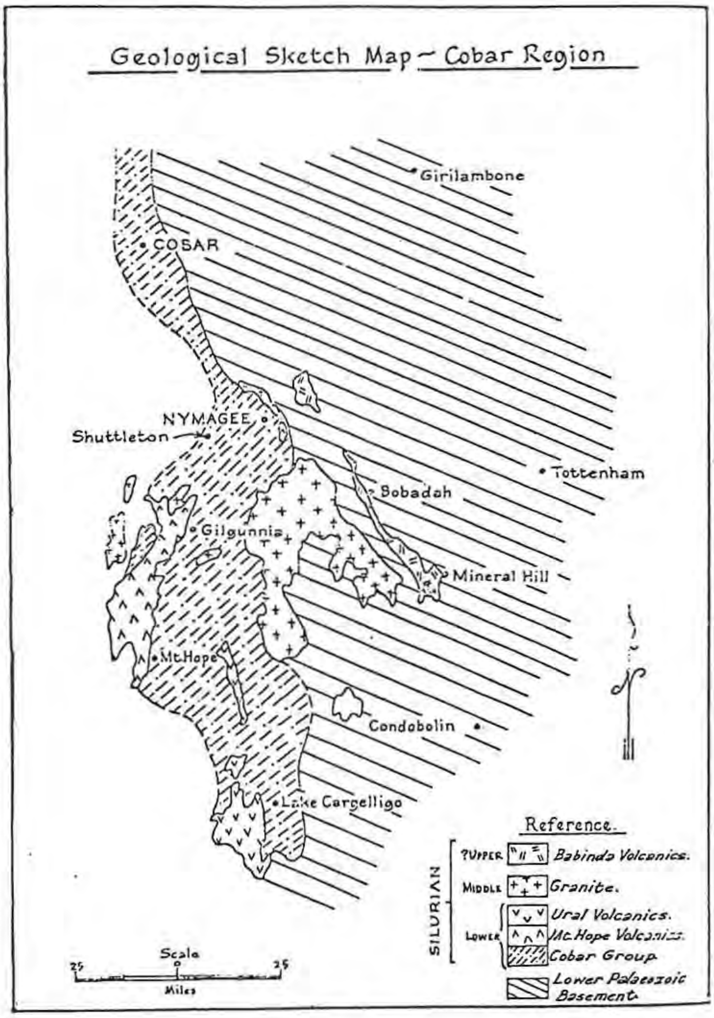

Fig. 2.36 Geological sketch map - Cobar Region
(from Bryan 1974)

"Captain's Flat type" zinc - lead - copper deposits occur in Silurian acid volcanic sequences south of Cobar in the Cobar Trough (see fig. 2.36). The Bobodah - Yellow Mountain - Mineral Hill area hosts copper - lead - zinc mineralisation in the Babinda Volcanics which are of probable Late Silurian age. Southwest of Gilgunnia the Cobar Group is conformably overlain by the Mt Hope Volcanics which host three types of volcanogenic mineralisation; (a) copper mineralisation (with subordinate lead - zinc - silver) within shales on or adjacent to the contact with pyroclastics, occurs in the lowest 600 m of the sequence; (b) disseminated pyrite - pyrrhotite - sphalerite - galena - chalcopyrite mineralisation in partially sheared coarse tuffs between 600 m and 900 m above the base of the Mt Hope Volcanics; (c) massive pyrite - sphalerite - galena - chalcopyrite in dolomitic shales and tuffaceous siltstones adjacent to a thick pyroclastic unit about 1 000 m above the base of the volcanics.

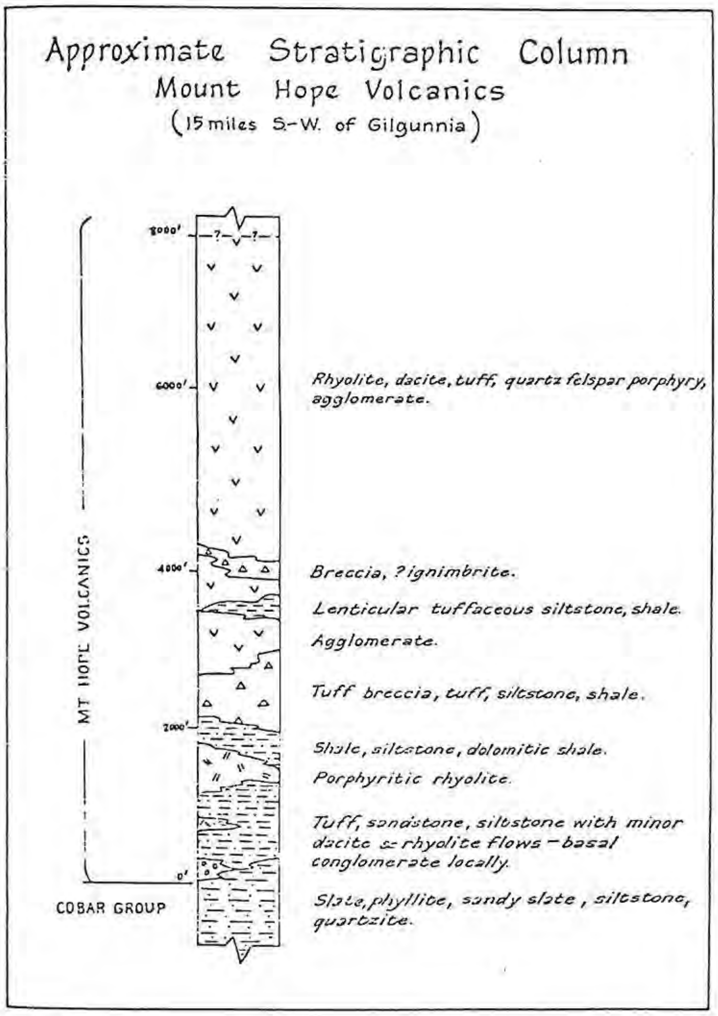

Fig. 2.37 Approximate Stratigraphic Column, Mount Hope Volcanics (from Bryan 1974)

The Trundle Trough was bounded to the east by the Parkes Terrace on which shallow marine deposition occurred, with sandstones and limestones containing abundant shelly faunas. Some records indicate slate and greywacke sedimentation towards the axis of the trough. It would appear that during the Silurian this trough and the Cobar Trough to the west were separated by a ridge of Ordovician rocks. Overall, however, little is known about this trough and its geological and topographical development during the Silurian.

The Cowra Trough occurred to the east of the Trundle Trough. Sedimentation occurred in the Lower to Middle Silurian, for example at Cargo in the southeast end of the trough the upper part of the Ordovician Millambri Formation extends into the Llandoverian and is conformably overlain by the Cudal Shale. The Upper Silurian consists of widespread volcanics (see fig. 2.38), for example the Blowering and Goobarragandra Beds, and includes dacitic breccias and tuffs, and rhyolites, as well as interbedded shales and sandstones.

Mineralisation is closely related to the distribution and nature of the Silurian acid volcanic rocks. A brief account of the known types of mineralisation from north to south is given.

Near Canowindran minor quartz - gold veins occur in the Canowindra Porphyry. These appear to be largely related to late-stage volcanic processes, but quartz veins with minor gold also occur in shales both above and below the porphyry. A further grouping of deposits occurs near the Young Granodiorite (Devonian age?).

In the vicinity of Boorowa, a number of subvolcanic hydrothermal base metal vein type deposits occur in the Douro Volcanics. The largest of these deposits is Kangiara where apparently joint-controlled copper - lead - zinc vein type mineralisation is located within a "bomb tuff" in the largely subaerial rhyodacitic volcanics.

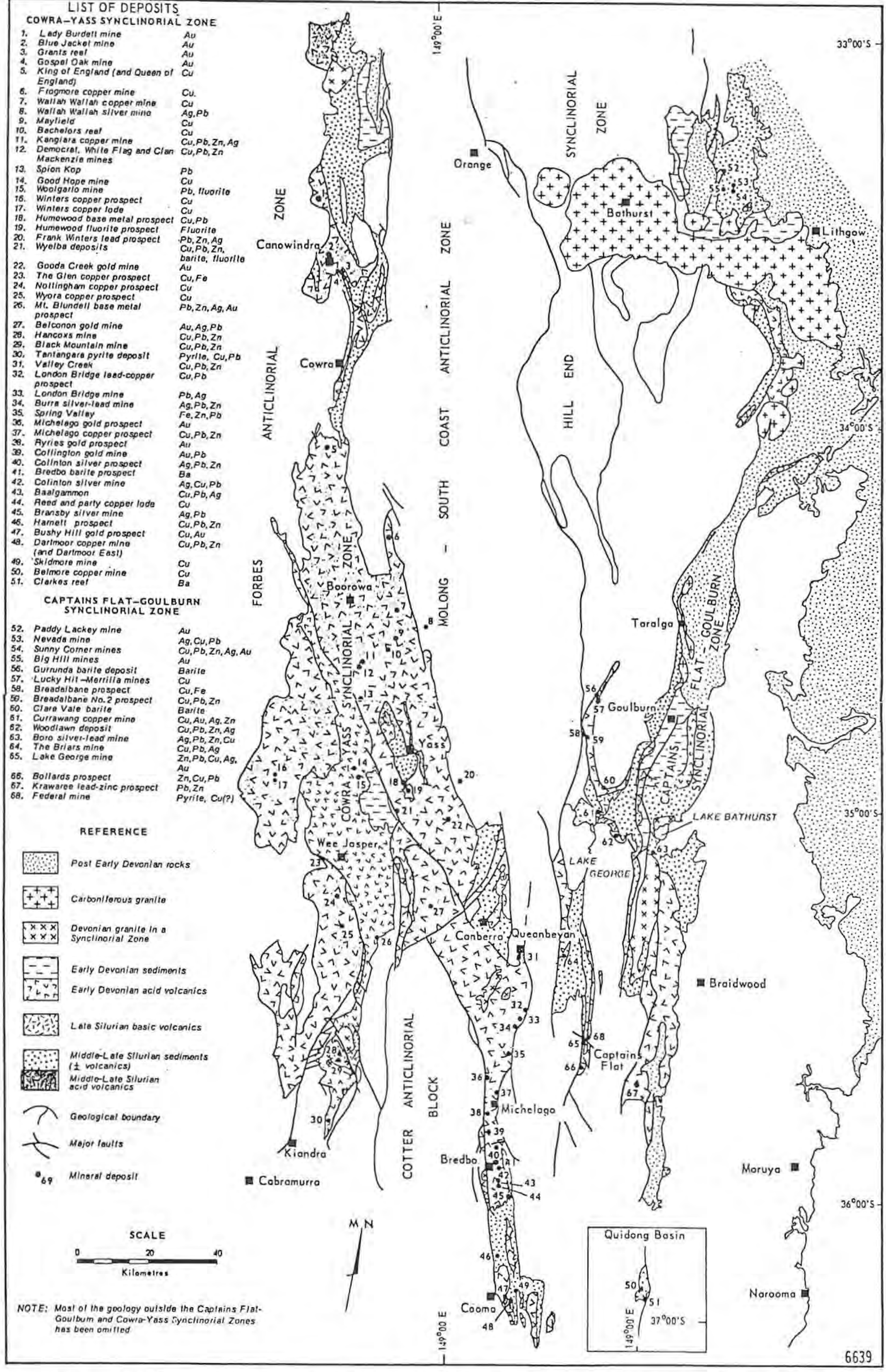

Fig. 2.38 Mineral deposits of the Cowra - Yass and Captains Flat - Goulburn Synclinorial Zones (from Gilligan 1974)

Further south, stratabound, disseminated and stockwork-type base metal deposits associated with submarine acid pyroclastics are known from the Michelago - Bredbo - Cooma area. Many of these deposits (including Harnett, Colinton, Michelago and Bushy Hill) appear to represent the disseminated, stockwork-type mineralisation stratigraphically below the massive sulphide lenses as found at Captains Flat. Only at Harnett Prospect and the Dartmoor mine are massive banded sulphides found associated with this more disseminated type of mineralisation. The reason for the relative lack of massive banded sulphides could be that ideal conditions of deposition were not present, or that such massive bodies may have been removed by later erosion.

During the Llandoverian, acid volcanism occurred on the Yass Shelf and further to the south. Two volcanic units, the Hawkins and Douro "Series", of unknown thickness, are separated by the Bango "Series", consisting of tuffs, sandstones, shales and occasional limestones. These are followed by the Yass and Laidlaw "Series" (totalling 500 m in thickness) containing water-laid tuffs, tuffaceous sandstones, mudstones and thin, sparsely fossiliferous limestones. Their shallow water origin is indicated by washouts, cross-bedding, mudcracks, chemically deposited limestone and some limestone breccia. Conformably overlying this sequence is the Hume "Series", a 200 m thick succession of shales and mudstones, with two prominent limestones. Fossils are particularly abundant and useful for correlation, and include brachiopods, trilobites, corals and graptolites.

There were at least two gulfs to the south of the Yass Shelf, an eastern one running through Cooma to Delegate and Bombala, and a western one through Yarrongobilly to the Mitta Mitta River in Victoria (see fig. 2.34). They contain Lower Silurian volcanics resting unconformably on steeply-dipping Ordovician sediments, the volcanics overlain (and sometimes overlapped) by later sediments. In the heads of the gulfs the relief must have been considerable. For example in the Mitta Mitta area the earliest rocks are acid volcanics (Mitta Mitta Volcanics) and these are overlain by about 1 000 m of conglomerates (base of the Wombat Creek Group) representing rapid erosion of the borderlands. However, by the late Wenlockian relief was greatly reduced and all the areas had become sites of deposition of well-bedded shales, sandstones and limestones with rich coral, brachiopod, mollusc and trilobite faunas. This major reduction in relief is also reflected to the east in the Cowombat Group where the sediments low in the sequence enclose enormous lenticular masses of conglomerate, and become increasingly finer higher in the succession, with siltstone and limestone deposition.

The extensive Silurian acid volcanic succession (like the Frampton and Cootamundra Volcanics) host several gold deposits (including the Cullinga and Bongongalong - Burra Gold Fields) as well as minor copper and mixed sulphide occurrences. The gold is thought to be associated with Devonian acid to intermediate intrusives emplaced after the Siluro-Devonian Bowning Orogeny. The volcaniclastic Silurian Ravine Beds host vein copper deposits, and includes the Yarrongobilly Limestone which contains minor skarn-type mineralisation.

Along the Molong - Canberra High the Benambran Orogeny had only minor effects, and there was a notable deficiency here in the Silurian of volcanic rocks, when compared to the underlying Ordovician, and the Silurian of the Yass Shelf. In general, sediments are similar to those of the Yass Shelf, and apart from temporary bursts of volcanic activity conditions of sedimentation must have been uniform over much of the arch. For example, the Panuara (near Orange) and the Mumbil (Near Molong) Formations are widely developed, ranging from upper Llandoverian to lower Ludlovian, contain only minor amounts of tuffaceous material, include shelly and graptolite faunas and are about 700 m in thickness. There are rapid east-west changes across the rise in the relative proportions of sandstone, shale and limestone within these formations.

The Silurian sequence is capped by the tuffaceous Wallace Shale which may extend into the Devonian. However, in areas between Wellington and Orange, volcanic rocks occupy most of the Lower and Middle Silurian, while in the Canberra area, volcanics are present only in the Middle and Upper Silurian.

Thick sections of a Silurian greywacke-volcanic assemblage are known from the Hill End Trough over a north-south distance of some 250 km. Near Bathurst, 6 000 m of greywackes, shales and conglomerates, with prominent bioclastic limestones have been described. Both the greywackes and the shales contain andesitic volcanic material, while the patchily distributed limestones probably indicate the presence of local "highs" within the trough, and contain locally abundant tabulate corals and brachiopods. The stratigraphic succession in the Hill End area contains shales, greywackes, tuffs and andesites, and several minor breaks in the succession indicate considerable mobility during the Silurian.

Following the Middle Silurian Quidongan Orogeny acid volcanism was widespread and was represented in the Hill End Trough by the Mullions Range, Bells Creek and Kangaloolah Volcanics.

Within the Hill End Trough a number of stratabound and vein-type base metal deposits formed in association with Silurian acid volcanism in "volcanic rift environments" (Stevens 1974). The mineralised acid volcanics in volcanic rifts are interpreted as having formed during initial opening stages of marginal seas, while acid volcanism developed later in the history of the marginal sea (e.g. the Merrions Tuff) tend to be barren of base metal mineralisation. Exceptions include the Belara and Native Bee deposits which are associated with acid volcanics in the Chesleigh Formation towards the north end of the trough. The environment of deposition is inferred to be shallow marine, with local emergent volcanic islands. The volcanics comprise large quantities of rhyolitic and/or dacitic porphyry (often interpreted as ash flow tuffs, possibly with subvolcanic intrusives), slaty metasediments largely derived from fine ash, sandstones composed of volcanic detritus, agglomerate and crinoidal limestones. Units are lenticular and facies changes are rapid in most directions.

Along the western margin of the Hill End Trough the Copperhania Thrust Fault separates Silurian acid volcanics to the east (in the Hill End Trough) from Ordovician rocks to the west (along the Molong Volcanic Rise). The Silurian volcanics east of the fault zone contain a number of strata-bound, pyritic zinc - lead - copper deposits of the "Captains Flat type" (including Mt Bulga, the Lewis Ponds group, the Peelwood group, and Junction Point) as well as stratiform barite (e.g. at Kempsfield). This belt also contains the gold - quartz veins of the Trunkey - Tuena field.

To the south of Bathurst the trough is restricted to a number of fault-bounded segments. Stratiform pyritic zinc - lead - copper deposits in acid volcanics in this area include Wiseman's Creek and Burraga, while at Cow Flat copper - zinc mineralisation occurs in basic volcanics.

North of Bathurst the central part of the Hill End Trough is largely a gold province. Deposits are of quartz vein type, hosted in Siluro-Devonian slates and greywackes, and generally bear no spatial relationship to the later post-kinematic granites. Well known gold deposits here include the Hill End, Hargreaves, Stuart Town and Ophir.

The Captains Flat Trough occurred as a southern, en echelon continuation of the Hill End Trough. It appears to have resulted from extension following the Quidongan Orogeny at the beginning of the Middle Silurian. Extensive calcalkaline acid volcanism occurred in fault-bounded troughs under shallow marine conditions. The volcanism evolved from dacitic to rhyodacitic to rhyolitic, and waned in the Late Silurian (see fig. 2.38).

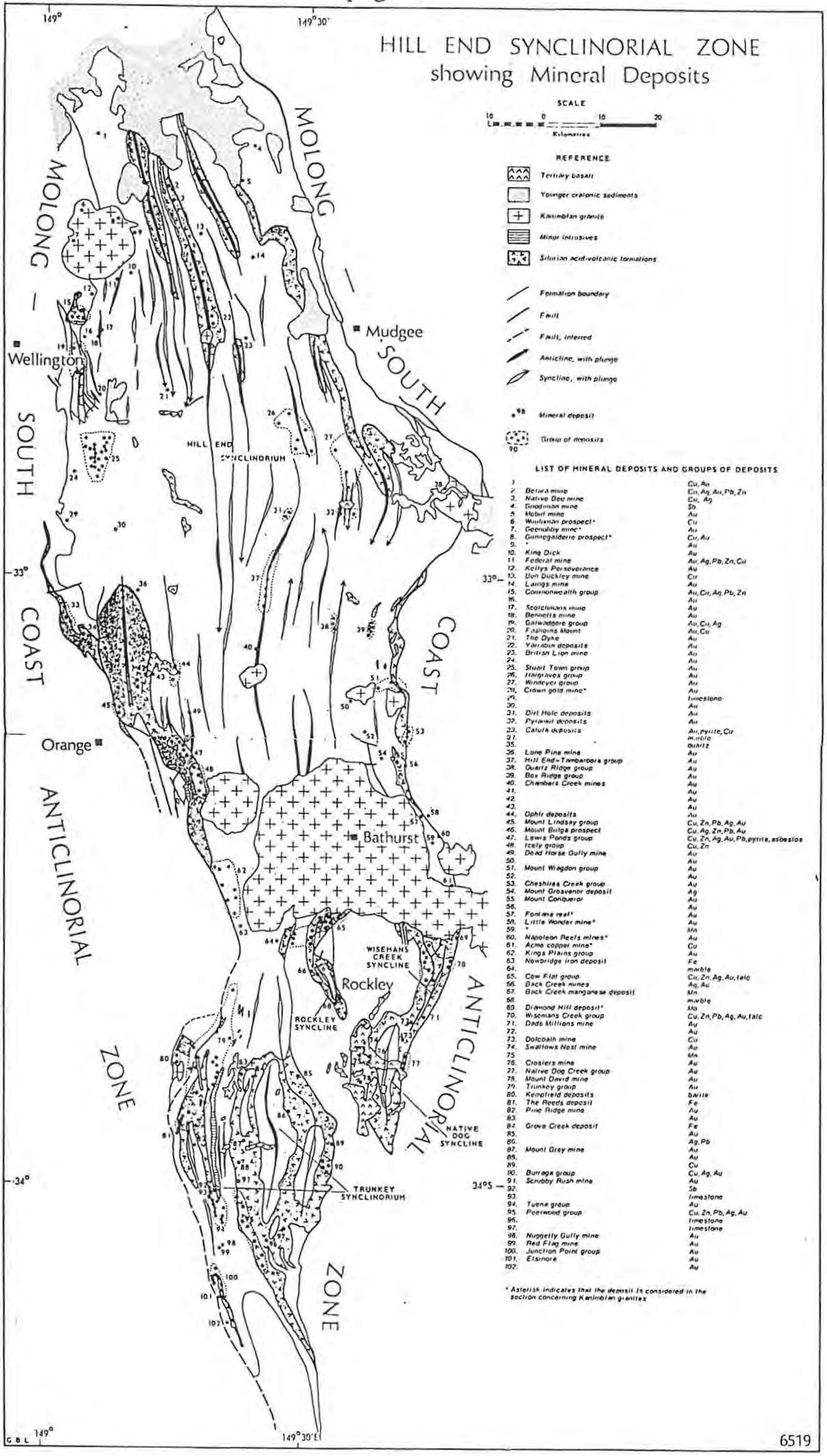

Fig. 2.39 Mineral Deposits of the Hill End Synclinorial Zone (from Stevens 1974)

Several stratabound pyritic zinc - lead - copper - silver ore bodies (the best known of which are the Captains Flat [Lake George] and Woodlawn deposits) occur in fine grained tuffaceous shales adjacent to coarser pyroclastics.

At Captains Flat, the acid volcanics of the Kohinoor Formation were deposited in a graben 2 to 8 km wide on a basement of Ordovician sediments (which were strongly folded, probably during the Benambran Orogeny). The three most important ore bodies occurring at Captains Flat are Elliot's, Central and Keating's. Sulphide deposition probably occurred in reducing conditions in restricted topographic depressions with adjacent coarse pyroclastics and fumarolic activity. Sediments overlying the massive sulphides thin rapidly laterally, probably indicating the margins of a small basin. More widespread deposition of ferruginous cherts may represent the "ore horizon" under more distal oxidising conditions, where only chert and iron were precipitated. Individual ore bodies, which may reach 20 m in thickness and 600 m along the long axis, generally have a mineralogical zoning pattern with a pyrite - chalcopyrite rich "feeder zone" below, passing up to a sphalerite - galena rich top.

The Woodlawn deposit occurs some 60 km north of Captains Flat and comprises rich zinc - lead - copper mineralisation in approximately the same stratigraphic setting as Captains Flat. The Middle - Upper Silurian age of the volcanics has been confirmed by graptolite evidence from nearby contemporaneous shale sequences. The volcanics which host the deposit comprise rhyolitic, rhyodacitic and dacitic lavas and tuffs, alternating (with rapid facies changes) to volcaniclastic sediments including limestone, black shale and lithic sandstone. The presence of ignimbrite indicates that at least part of the volcanic pile was subaerial. North of the deposit this succession is overlain by andesites and spilites followed by a thick sedimentary sequence.

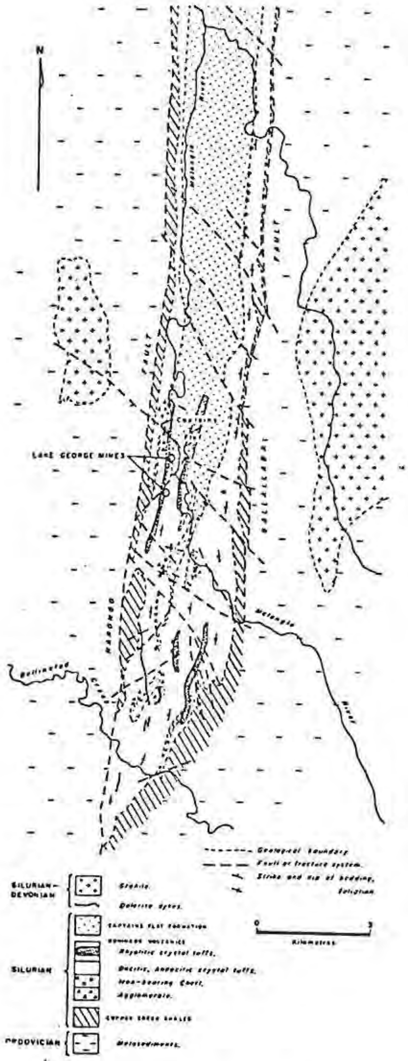

Fig. 2.40 Regional geology of the Captains Flat area (from Davis 1975)

Sulphides were probably deposited in sediment-filled basins in the acid volcanics under shallow marine conditions. Sulphide deposition caused chloritic alteration in the underlying rocks, and as at Captains Flat the mineralisation can be divided into a zinc - lead (silver) rich upper zone and a lower "stockwork" type ore consisting mainly of chalcopyrite, with pyrite abundant throughout. The acid volcanic succession was intruded by Late Silurian dolerite sills. The Siluro-Devonian Bowning Orogeny resulted in strong deformation (with the Silurian volcanics contained in open synclines), regional greenschist metamorphism and intrusion of hornblende - biotite granite stocks.

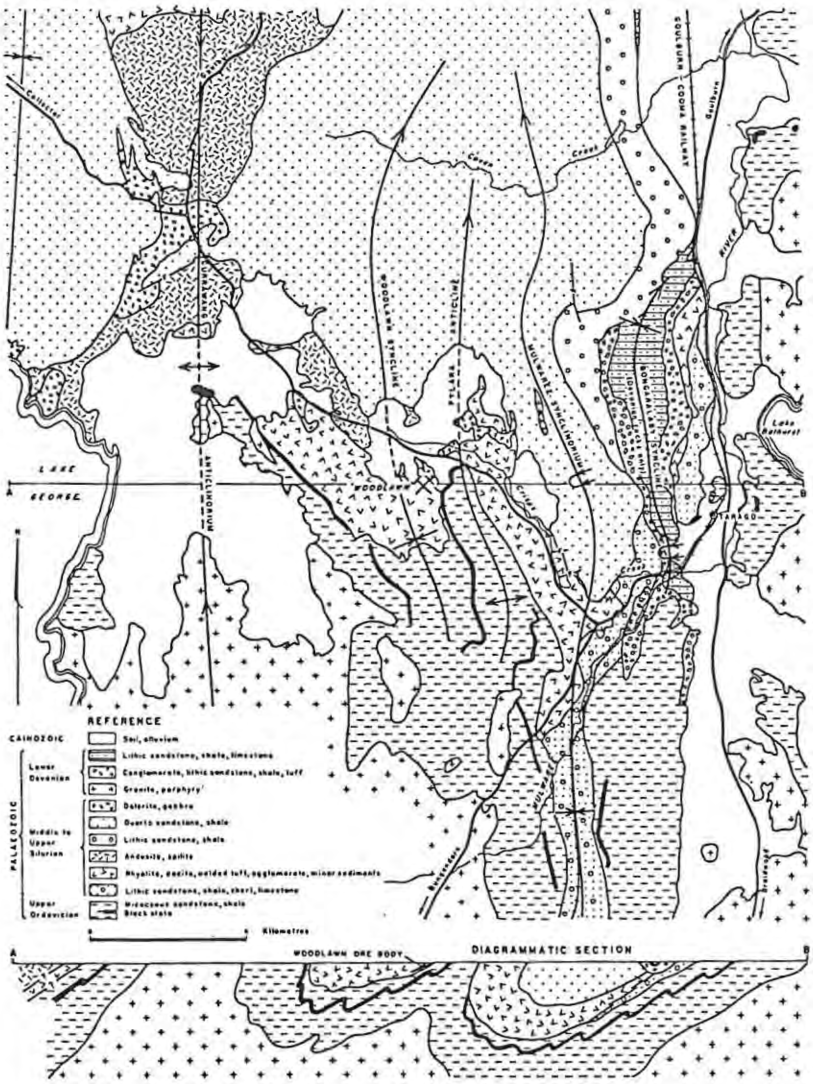

Fig. 2.41 Regional geological map of the Woodlawn area (from Malone et al 1975)

To the north of Lake George a series of magnetite - pyrite - chalcopyrite bodies (including the Breadalbane deposit) occur apparently in a more basic succession within the volcanic pile. Stratiform barite mineralisation is also known from this belt at Gurunda, near Goulburn. Further to the north within this trough, the Sunny Corner mines occur east of Bathurst (see fig. 2.38). In these deposits zinc - lead - copper mineralisation occurs at or near the contact of a fine rhyolitic tuff and overlying shale. Though severely faulted, this mineralisation appears to be of "Captains Flat type". At Boro near Lake George vein type lead - silver mineralisation occurs in tuff and tuffaceous sandstone of the Late Silurian DeDrack Formation. This mineralisation could be of "Captains Flat type", or could be associated with Devonian granites which have intruded nearby.

To the east of the Hill End Trough the trough sediments thin out onto the Capertee High. This high must have begun to rise in the Late Ordovician or Early Silurian times, as it contains Llandoverian rocks lying unconformably on Upper Ordovician. Its structure is now obscured by Permian cover, but it contains thick lenticular limestones interbedded with graptolitic slates, conglomerates, tuffs and andesitic flows, which have been recorded in the north near Mudgee.

The Quidongan Orogeny at the beginning of the Middle Silurian terminated sedimentation in the Cobar Trough, while at this time the Canberra - Yass Rise was largely elevated and intruded by syn- and postkinematic granites. The Hill End Trough and its southern en echelon equivalent, the Captains Flat Trough, were formed, separated from the Murruin Basin to the east by the developing Capertee Rise.

Towards the end of the Silurian the Lachlan geosyncline was again deformed, this time during the Bowning Orogeny. The greatest deformation appears to have been from eastern Victoria north to the Yass Shelf and along the Trundle Trough, where uplift (due to granite intrusion as well as folding) was so marked that no further deposition occurred on it until the Late Devonian. The Melbourne, Cobar and Adavale Troughs to the west, and Canberra - Molong High, Cowra Trough and Hill End Trough to the east were relatively unaffected by the orogeny.

Even where maximum deformation occurred, relatively few areas seem to have been intensely folded by the Bowning Orogeny. A meridional belt passing through and to the east of Canberra contains recumbent folding in Silurian rocks, but in many areas broad open folding with flank dips as low as 20° are common.

In Victoria Bowning movements have been dated at the end of the Late Silurian or earliest part of the Early Devonian. In contrast two phases have been observed at Canberra, one during the early Ludlovian and the other in the late

Ludlovian - Early Devonian.

According to Murray and Kirkegaard (1978) there is no evidence for Silurian deposition in the Thomson orogen, in marked contrast to the extensive trough controlled volcano-sedimentary activity in the Lachlan orogen. They consider that the precratonic development of the Thomson orogen ceased with the emplacement of the post-orogenic Siluro-Devonian batholiths in the northern part of the fold belt.

Mineralisation within the Thomson orogen in Silurian times was generally unimportant.

Within the Lolworth - Ravenswood Block, the Kean's molybdenite prospect occurs as quartz veins within granodiorite. The veins may be up to 1,5 m wide, are steeply dipping (but discontinuous vertically) with two prominent directions (approximately north-south and east-west) and carry molybdenite with lesser magnetite, pyrite and chalcopyrite.

In the Anakie High, the Peak Downs Copper mine has many features similar to Cyprus-type cupreous pyrite deposits. It contains stratabound, massive and disseminated, pyrite - chalcopyrite - magnetite mineralisation occurring within a siliceous ferruginous horizon in what appears to be a eugeosynclinal sedimentary succession with associated mafic volcanics.

In the Hodgkinson - Broken River orogen, the Silurian was a time of extensive sedimentation and Andean-type volcanism. Sedimentation was of both shallow marine shelf and deep water flysch types, and persisted from Early or Middle Silurian to Middle Devonian time.

The carbonate-rich sediments are found mainly on the west side of the fold belt, where they were deposited on shallow marine shelves against the Precambrian landmass to the west. The main sites of deposition were the Chillagoe Shelf along the western margin of the Hodgkinson Province and the Jack - Broken River Shelf in the southwest of the

Broken River Province (see fig. 2.42). These shelves were separated from the landmass to the west by major fault zones, including the Palmerville and Burdekin River faults, though locally sediments did overlap onto the Precambrian craton.

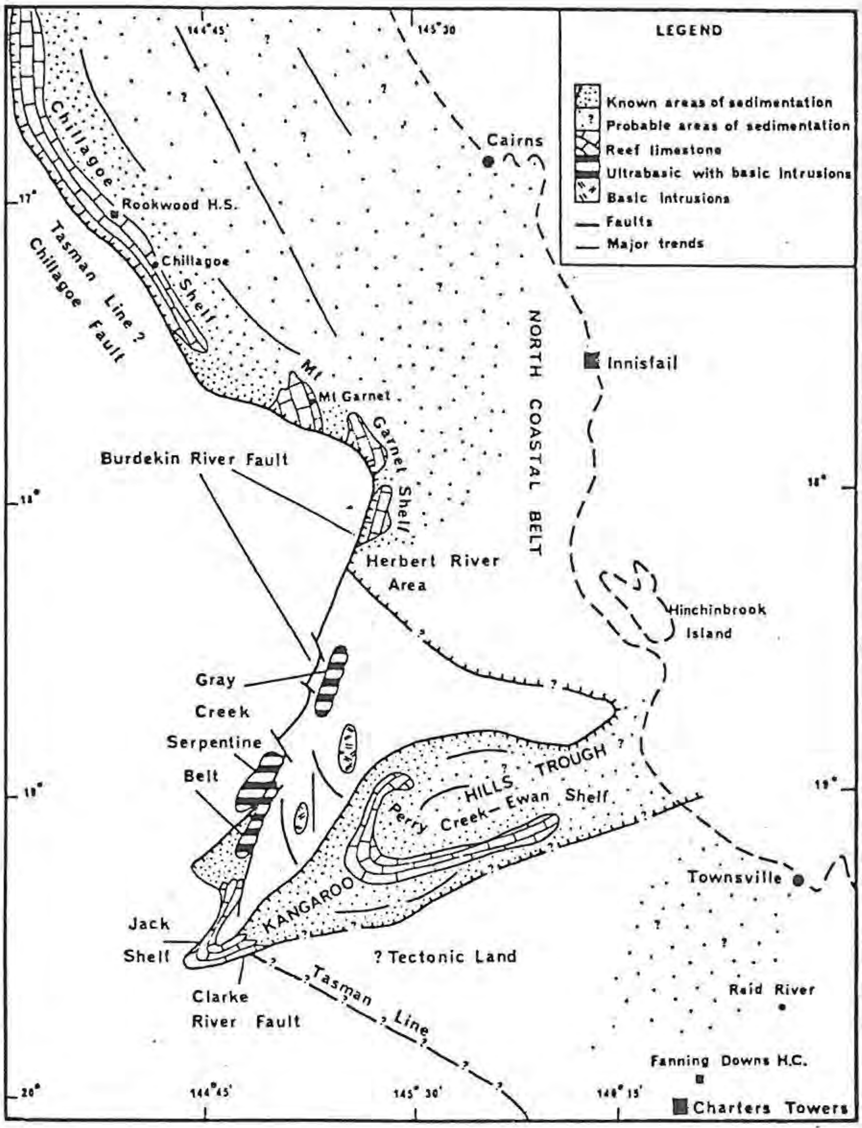

Fig. 2.42 Depositional pattern in the North Queensland Basins during the Late Silurian and the Early Devonian (Modified after White, 1961) (from Brown et al 1968)

To the east of this carbonate deposition flysch sequences were laid down in deeper water slope and basin conditions. Due to structural complexity and uniform lithology the stratigraphic succession of the flysch is poorly understood, though limited palaeontalogical data suggests that the flysch in the Hodgkinson Province is younger than in the Broken River Province (Day et al 1978).

Abundant evidence exists for volcanic activity contemporaneous with the Silurian sedimentation. Spilitic pillow andesites and limestone at the western edge of the Camel Creek Sub-Province have been interpreted as the remnants of a volcanic arc (Arnold and Rubenach 1976). Elsewhere, volcanics of variable composition occur throughout the sequence, and Silurian to Devonian flysch contains abundant volcanic-derived material. The major source of this detritus has been regarded as an intermediate to acid Andean-type volcanic chain which appears to have developed on the Precambrian craton at this time. The only remaining trace of this volcanic chain is a north-south trending zone of Devonian batholiths (see fig. 2.30).

Movements during the Middle Silurian in the north Queensland basins caused north-east trending fold axes in the sediments of the Burdekin River area, and widespread uplift resulted in angular unconformities between Lower and Upper Silurian sediments. Faulting (which was predominantly vertical) occurred parallel to the border faults of these basins.

Most of the mineralisation in the Hodgkinson and Broken River Provinces appears to be related to adamellite and granodiorite intrusives of Early Carboniferous age, and will be dealt with in the appropriate section. It is possible, however, that base metal mineralisation in shears and faults (e.g. in the Chillagoe District) could to some extent represent remobilised syngenetic exhalative mineralisation.

The New England orogen (or fold belt or geosyncline) forms the most easterly of all the fold belts making up the Tasman Geosyncline, and commenced its development during the Silurian. It may conveniently be divided into three parts, the Yarrol Province in the north, the New England Province in the south, and the Gympie Province to the east. The Yarrol and the New England Provinces are separated by Mesozoic Platform cover, which makes direct correlation of their structures and tectonic elements difficult. However, they had a similar geological history from the Late Silurian to the Triassic and may both be divided into contrasting western (volcanic arc and unstable marine-shelf sediments) and eastern (submarine basic volcanics, flysch and pelagic sediments) zones, separated by major belts of ultramafic rocks. The Gympie Province lies to the east of the Yarrol Province (from which it is separated by a discontinuous serpentinite belt), and comprises Permian and early Triassic shallow marine and fluviatile sediments and basic to intermediate volcanics.

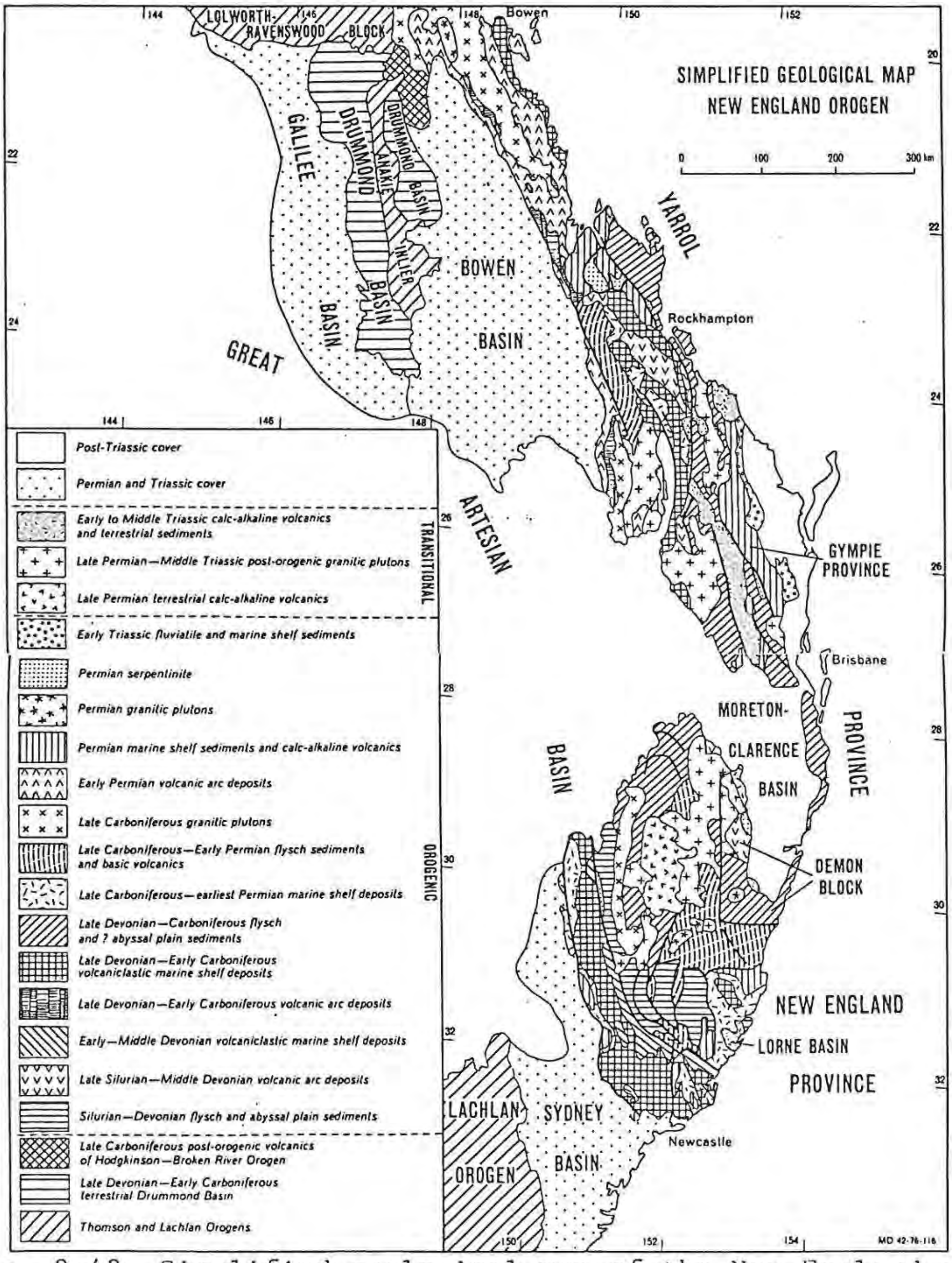

Fig. 2.43 Simplified geological map of the New England orogen (from Day et al 1978)

Widespread deposition in the New England orogen commenced in Late Silurian time.

In the Yarrol Province Late Silurian - Mid-Devonian calcalkaline volcanics, volcaniclastic sediments and limestones are preserved in isolated fault blocks. Volcanics range from acid to basic; andesitic flows and pyroclastics are dominant, though dacitic and rhyolitic pyroclastics are widespread and tholeiitic basalt flows occur on a more localised scale. Associated with these are medium to fine grained volcanic-derived sediments, coralline limestones, and minor cherts and conglomerates. These rock types are typical of island arc environments and it is postulated (Day et al 1978) that the Calliope Island Arc extended from north of Rockhampton to southwest of Brisbane in Late Silurian to Mid-Devonian time. The arc may have developed on either oceanic crust or unexposed early Palaeozoic basement, and may have been separated from the landmass to the west by a marginal sea (see fig. 2.44). Shallow marine deposition continued as far west as the Anakie Inlier, and an Early to Mid-Devonian shoreline extended southwesterly across the partly terrestrial Adavale Basin. A southern continuation of the Calliope Island Arc may be represented by andesitic to basic lavas, chert, and clastic and carbonate sediments yielding Silurian fossils in the Demon Block in the northeast of the New England Province.

It is possible that early Palaeozoic shallow water marine sediments underlie the mid-Palaeozoic deposits of the Tamworth Shelf and perhaps also the volcanic arc to the west. Silurian to Middle Devonian sedimentation (including pelagic and continent margin deposition) occurred in the Woolomin Slope and Basin, an oceanic area east of the Tamworth Shelf.

The flysch sediments and basic volcanic rocks of the Woolomin Slope and Basin host stratiform ore deposits of both cupreous pyrite and siliceous manganese type. A further type, possibly related, is represented by magnetite deposition within metabasaltic sequences.

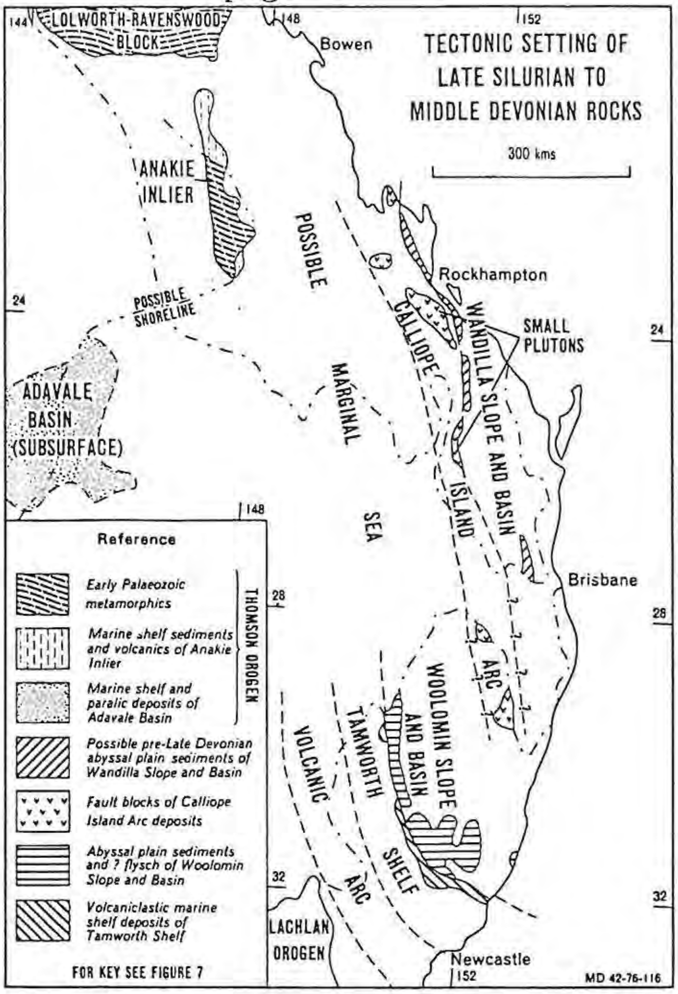

Fig. 2.44 Tectonic setting of Late Silurian to Middle Devonian rocks, New England orogen (from Day et al 1978)

Within the Woolomin - Myra Beds, over twenty Cyprus-type copper occurrences have been recorded over a strike length of about 230 km from Bingara, south to Nowendoc. These deposits are conformable, lenticular sulphide bodies associated with jasper and altered basaltic (probably tholeiitic) volcanics. The jasper and chert lenses may occur within the ore, further indicating a syngenetic exhalative origin for the mineralisation. Ore minerals in decreasing order of abundance are pyrite, chalcopyrite (with or without bornite), sphalerite and magnetite. Various other metals including silver and gold may be present in minor to trace amounts. Mineralisation is massive and banded, with banding due to compositional differences as well as later tectonism.

Numerous small concentrations of manganese occur within the Woolomin - Myra Beds. These occurrences are associated with basaltic volcanism and occur with siliceous and ferruginous (chert and jasper) horizons. They are conformable bodies, often banded, and though unrelated to igneous bodies they have been altered by later granite intrusions. They have been interpreted (Fitzpatrick 1974) as being precipitated on an ocean floor after originating from a volcanic or hot spring source.

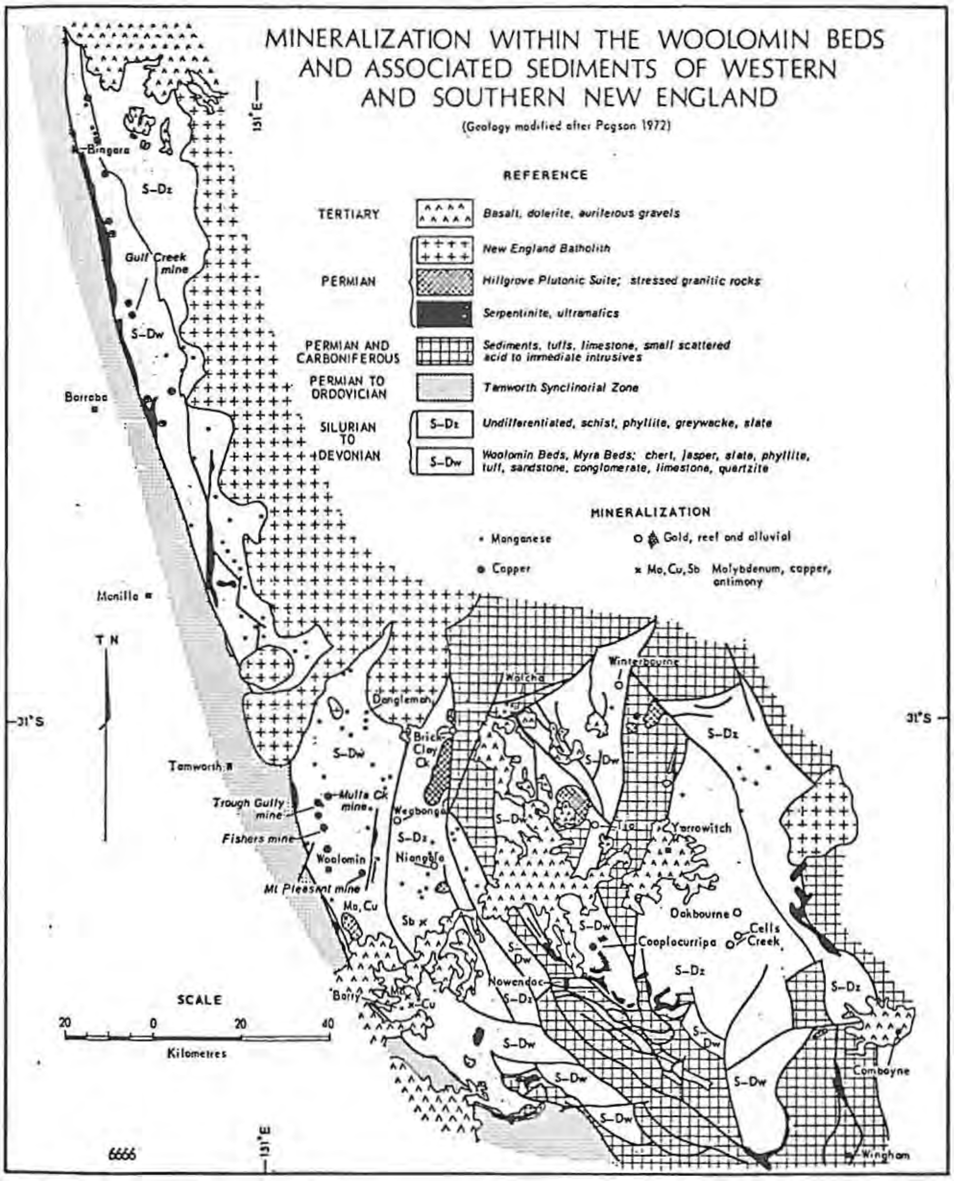

Fig. 2.45 Mineralisation within the Woolomin Beds and associated sediments of western and southern New England (from Fitzpatrick 1974)

The Devonian

As a result of the Siluro - Devonian Bowning Orogeny there was considerable modification of earlier depositional patterns in the Lachlan orogen, and new geotectonic elements appeared. A new phase of sedimentation was initiated in the New England orogen, while the north Queensland basins continued their distinctive evolution. In the Middle Devonian the extensive Tabberabberan Orogeny occurred, cratonising the Lachlan geosyncline and uplifting much of eastern Australia, which became an area of terrestrial deposition.

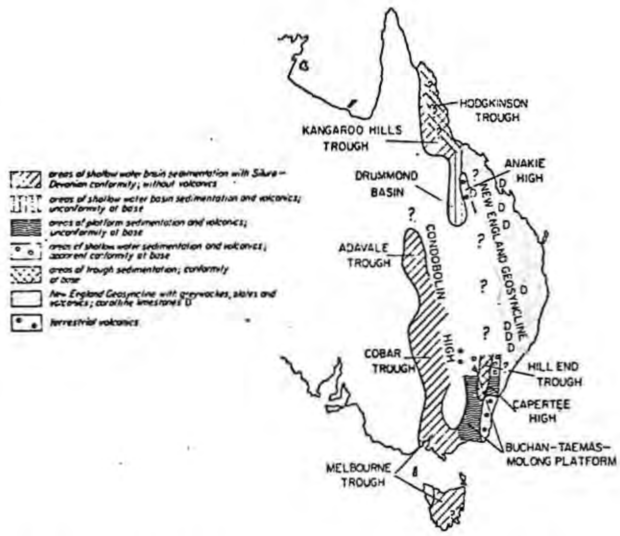

Fig. 2.46 Early and Middle Devonian palaeogeography (from Brown et al 1978)

During Silurian and Devonian times extensive granitic intrusives were emplaced in New South Wales and Victoria, and gave rise to a wide variety of gold, silver, tin, tungsten and other base metal mineralisation. The setting and regional controls of mineralisation of these deposits is briefly discussed. Of major importance in the Devonian of Tasmania is the variety of tin and tungsten deposits which are related to Devonian granitoid intrusives. Also briefly described is silver - lead (zinc) mineralisation associated with Devonian acid volcanics in Victoria, pyritic - gold occurrences in acid volcanics in a rift zone in eastern New South Wales, skarn mineralisation of possible Devonian age in the Hodgkinson - Broken River orogen of north Queensland, and minor pyrite - gold mineralisation in spilitic lavas in the New England orogen.

Both faunas and floras suggest a warm to tropical climate over the whole of the Australian region for the Devonian. The Devonian saw the first development of land plants in Australia. During the Upper Devonian the plant Leptophloeum australe was abundant throughout the continent and preserved in both terrestrial and marine sequences. Tabulate and colonial rugose corals were profuse and widely distributed in Lower and Middle Devonian times, and have proved to be very useful for correlation purposes. In general, coelenterate, brachiopod, bivalve, gastropod, ammonoid, trilobite, carpoid and conodont faunas were common and had pronounced Eurasian affinities. Vertebrate fossils are well-known from the Middle and Upper Devonian and also show Eurasian affinities.

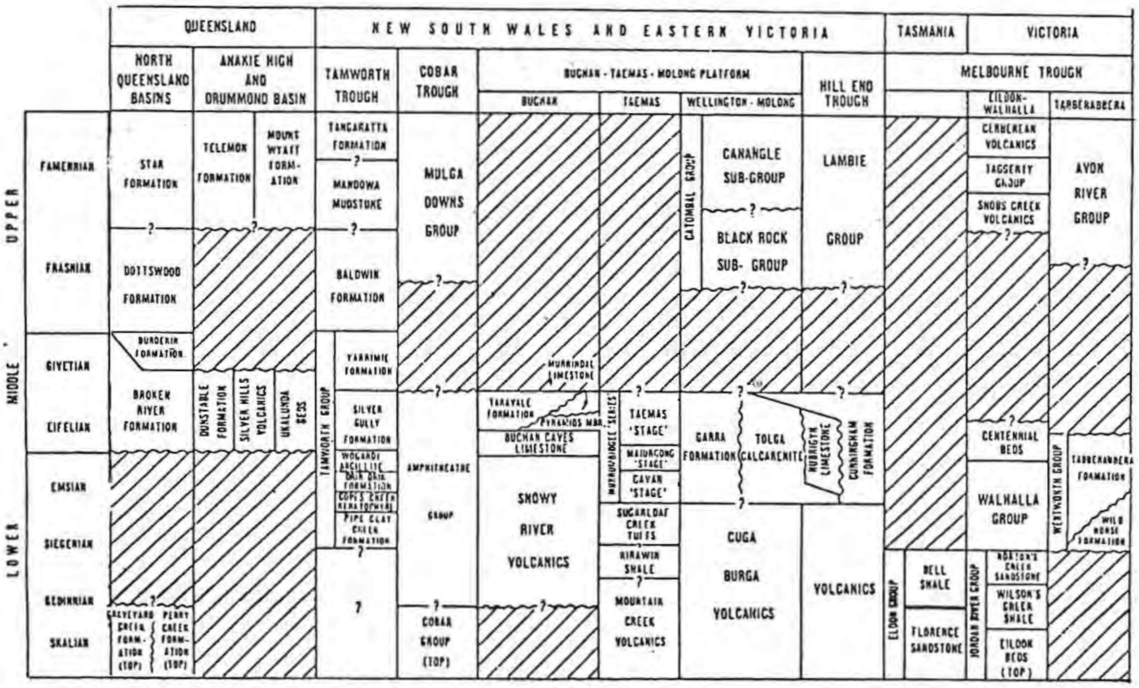

Fig. 2.47 Correlation Table for the Devonian System (after Brown et al 1968)

Much of the Lachlan orogen was uplifted in the Siluro - Devonian Bowning Orogeny. While the Melbourne and Hill End Troughs and the Capertee High were relatively unaffected, the Trundle and Cowra Troughs were completely disrupted.

An extensive north-south belt in New South Wales rose above sea level to form what Brown et al (1968) referred to as the Condobolin High (called the Wagga and Girilambone Arches and Snowy Mountain Block by Webby (1972)). To the south and east the Condobolin High was partly submerged and the shallow marine Buchan and Taemas - Molong Platforms were formed, and received extensive carbonate sedimentation. The Cobar Trough appears to have been a northward continuation of the Melbourne Trough and to have had a similar history to it.

Throughout the first part of the Early Devonian, there seems to have been a definite asymmetry in the Melbourne Trough, with deeper water to the east, and with the bulk of the sediments being derived from the west and southwest, pushing the axis of maximum sedimentation to the east. A similar asymmetry appears to have occurred in the much shallower Cobar Basin to the north and also perhaps in the deeper waters of the trough to the south in Tasmania. The western margin of the Melbourne Trough would probably have migrated eastwards parallelling the eastwards movement of the axis of deposition. However, in the late Early Devonian uplift to the east of the trough led to sediment influx from this direction and resulted in the constriction and elimination of the deeper depositional areas of the trough.

To the north and northeast of Melbourne, sedimentation was continuous from the Silurian into the Devonian. In the Heathcote area the upper parts of the McIvor and Mt Ida Formations (which exceed 2 500 m of fossiliferous shallow water sandstones and mudstones) have been referred to the Devonian. In the Central area, the Yering Group exceeds 4 000 m in thickness and consists of shallow water sandstones, mudstones and limestones with a rich Early Devonian fauna. To the east, the age of some sediments are disputed, though the sediments of the Jordan River Group contain probable Early Devonian faunas. These are overlain by sediments of the

Walhalla Group which may exceed 3 000 m in thickness and in turn are conformably overlain by the Centennial Beds in which marine shales contain land plants of Emsian to Eifelian age. Lateral equivalents of the upper Jordan River Group and basal Walhalla Group are the Tanjil Formation, the Boola Beds and the Coopers Creek Formation of the Tyers area. These formations contain limestones which together with the abundance of land plants in the Centennial Beds confirm that subsidence in the Melbourne Trough had become slow by the end of the Early Devonian and in the early Middle Devonian.

Most of Tasmania lay within the Melbourne Trough. On the west side of the island the uppermost 1 000 m of the Eldon Group extend into the Devonian. They consist of shallow water sandstones and calcareous shales with a rich brachiopod fauna. At Spero Bay on the west coast a small separate basin developed in the Early Devonian, persisting till the Middle Devonian, and contained limestones, conglomerates and sandstones. To the northeast of the island a deeper water facies occurred in the upper parts of the Mathinna Beds.

Major uplift at the beginning of the Tabberabberan Orogeny caused the final regression of the sea from the central Victorian region. The orogeny caused deformation which intensified from west to east from simple domes and basins in the west to formation of anticlinoria and synclinoria in the east. Deformation was most intense on the eastern margin of the trough, in the eastern limb of the Walhalla Synclinorium.

The Cobar Trough formed a shallow sea in Devonian times, probably linked to the Melbourne Trough to the south, and perhaps also linked at various times to the open sea to the east across the Condobolin High (or Girilambone - Wagga Arch). There is also some evidence for a short-lived Early Devonian marine connection with the Amadeus Basin to the west.

The basin appears to have had a broad, open, gently subsiding form with fault-bounded margins to the east and west. The extensive deposits it contains appear to have accumulated in a deltaic complex spreading in from the west and southwest, first into a shallow marine basin, and after the Tabberabberan uplift, into an intracratonic basin. The lack of sedimentary material from the east seems to indicate that the Girilambone Arch (or Condobolin High), though a positive feature, was not exposed to erosion.

After completion of the predominantly Silurian Cobar Group in the Lower Devonian, sedimentation in the Cobar Trough was represented by the Amphitheatre Group, consisting of at least 1 500 m of shallow water, flaggy mudstones, siltstones and sandstones with an abundant Early - Middle Devonian shelly fauna.

The Mulga Downs Group was deposited in the Upper Devonian after the Tabberabberan Orogeny, and overlies the Amphitheatre Group conformably and unconformably. The group consists of interbedded conglomerate, cross-bedded sandstones, siltstones and red shales up to a maximum thickness of over 4 000 m.

Relatively little is known of the Adavale Trough, largely because of lack of exposure due to Mesozoic sedimentary cover. The earliest rocks discovered to date are the Lower Devonian andesitic flows, tuffs and arkoses of the Gumbardo Formation, overlain by the upper Etonvale Formation, consisting of sandstones, shales and carbonates with Early Devonian shelly fossils. To the south the trough shallowed against a structure in the position now occupied by the Eulo Ridge. According to Brown et al (1968) the Adavale Trough (despite the presence of the Eulo Ridge) probably maintained a connection with the sea through the Cobar Trough to the south, rather than through the Drummond Basin to the north (which has a very incomplete sequence). Webby (1972), on the other hand, stresses the similarities between the Adavale and Drummond Basins to postulate a link between them. The Eulo Ridge contains Devonian evaporites which would suggest that it acted as a partial barrier to marine circulation.

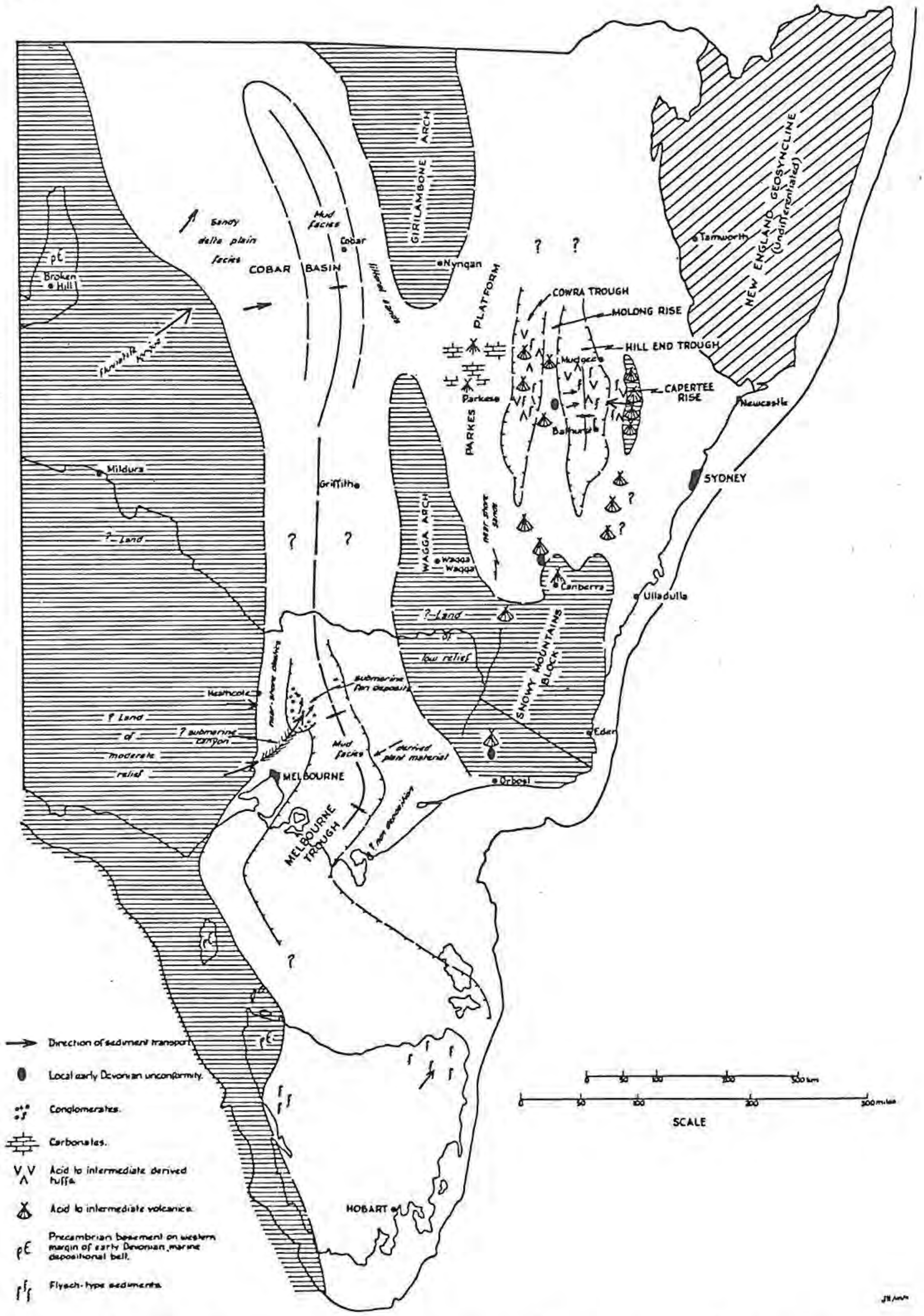

Fig. 2.48 Early Lower Devonian palaeogeographic map of the Lachlan geosyncline (from Webby 1972)

During the Early Devonian there were deep water sediments deposited in the Cowra Trough. In the eastern part a 3 000 m thick succession of Silurian and Lower Devonian rocks has been described. The Lower Devonian part of this sequence comprises three formations and consists of greywackes and (acidic) tuffaceous sandstones and other deeper water sediments passing up into increasingly shallow water lithologies, including fossiliferous limestone lenses and calcareous shales.

Elsewhere in the trough successions are similar, but to the west occurs the extensive Dulladerry Rhyolite (varying from coarse quartz porphyry to fine grained banded rhyolite and breccias) which is probably equivalent to the Hyandra Creek Volcanics further to the north. These acid volcanics are mainly Gedinnian in age and may be related to the emplacement of the Yeoval and Eugawra Granites which intrude them but not the overlying Hervey Group sediments. Similarly, west and southwest of Cowra, the Young Granite has intruded the Ilunie Rhyolite.

Along the southeast edge of the Condobolin High there developed in the Early Devonian a marine platform referred to by Brown et al (1968) as the Taemas - Molong Platform, and this feature extended to the south in Victoria as the Buchan Platform. This platform area is partly equivalent to the Snowy Mountains Block of Webby (1972), and resulted from erosion as well as the rapid accumulation of acid volcanic rocks.

The earliest Devonian rocks are sandstones and conglomerates, limited in extent and containing plant fragments. They are overlapped unconformably by extensive acid volcanics which are best known in eastern Victoria (the Snowy River Volcanics), along the Murrumbidgee and Goodradigbee Rivers (the Black Range Group), near Orange (the Bull's Camp Rhyolite) and near Wellington (the Cuga Burga Volcanics).

These volcanics probably exceed 4 000 m in thickness, and the duration of their deposition is indicated by a shale unit exceeding 500 m in thickness within the Black Range Group in the Goodradigbee area. The acid volcanics are conformably overlain by interbedded limestones and shales.

At the north end of the platform Lower and Middle Devonian rocks of the Murrumbidgee "Series" occur. These include flat, thinly bedded sedimentary units up to a total of 1 200 m thick which are persistent over wide areas and include bioclastic carbonates and limestones. Algae are present as comminuted detritus, pisolites, and as thick stromatolite-like units, while crinoidal remains also form abundant carbonate debris. Fossils are generally abundant, and the succession can readily be zoned using corals and brachiopods.

In the Wellington - Molong area the Garra Formation occurs, and is broadly equivalent to the Murrumbidgee "Series". In this area, the eastern margin of the shelf, where it joins the Hill End Trough, has been preserved. A chain of islands, formed from the underlying andesitic Cuga Burga Volcanics, mark this line, and around them accumulated a complex of calcareous shales, biostromes and small bioherms.

Lower Devonian deposits accumulated on the flanks of the Molong Rise and occasionally may have mantled it. Localised flysch sequences within the Wallace Shale, west of Orange, indicate some downwarping in the area, though this may have been of latest Silurian age. The Wallace Shale is succeeded by the rhyolites and dacites of the Bull's Camp Volcanics (up to 4 000 m thick) which may be correlated with the Dulladerry Rhyolite to the west. This in turn is overlain by the Garra Formation comprising about 1 000 m of fossiliferous shallow water sediments which exhibit rapid and complex facies changes. On the eastern flank of the Molong Rise the basal Devonian is overlain by a 600 m succession of intermediate rocks, the Cuga Burga Volcanics.

The Hill End Trough was not deformed in the Bowning Orogeny, and its Devonian succession is conformable on the Silurian. The carbonate sediments of the Molong - Wellington area grade eastwards into an 8 000 m thick succession of volcanics, greywackes and slates. The volcanics, which are predominantly dacitic, occur mainly in the lower parts of the sequence and are probably equivalent to the Cuga Burga Volcanics to the west. The volcanics are capped by slates and siltstones which make up the Cunningham Formation.

On the western side of the trough intermediate Cuga Burga-type volcanics were errupted in the north and dacitic tuffs, slates, siltstones and greywackes to the south. On the eastern side of the trough a thick complex of greywackes, shales and acid pyroclastics developed, and includes the Crudine Group. The overlying Merrions Tuff has a wide extent and is composed of pyroclastic shales and greywackes. Grading in the tuff may indicate deposition by turbidity currents or mudflows. During deposition of the Merrions Tuff the axis of sedimentation moved to the west in response to the rapid influx of material from the Capertee Rise to the east. Two major phases of volcanic activity produced graded acid tuffaceous deposits which alternated with deeper water flysch type sedimentation.

Sedimentation within the trough was more or less continuous through the Lower Devonian, and was terminated by uplift during the Tabberabberan Orogeny, at which time the foliated Davies Creek and Tamboramboro Granites were emplaced.

It is likely that in Lower Devonian times the Capertee Rise consisted of a more or less continuous elongate volcanic arc with flanking shallow and deeper water deposits, and in places mantled by shallow water facies. The volcanic arc probably supplied huge volumes of volcanic material to the Hill End Trough to the east.

Little is known of the extent of Lower and Middle Devonian sedimentation on the Capertee Rise, and it is possible that much of the sediments of this age were eroded before the Upper Devonian. However, near Mudgee, Upper Devonian sandstones lie with apparent conformity on Middle Devonian limestones. Acid volcanics are widely distributed and are best known on the southern end of the rise where they constitute the Eden Rhyolites.

The Tabberabberan Orogeny occurred from the end of the Lower Devonian to the end of the Middle Devonian, and was the main tectonic event which cratonised the various elements of the Lachlan geosyncline. As such, it profoundly altered the palaeogeography of eastern Australia, and caused the east Australian shoreline to move considerably further to the east. In the Lachlan geosyncline the old troughs were disrupted to be replaced by widespread terrestrial and paralic deposition.

The degree and nature of the Tabberabberan deformation was variable within the Lachlan orogen. In Tasmania, older structures like the Tyennan geanticline exercised an important control on the pattern of deformation (see fig. 2.49). On the west side of the island, concentric and similar folds occur, slaty cleavage is common in the mudstones, and there are numerous associated thrusts. On the other hand, folding in central Victoria is of concentric type, the folding is long and arcuate, and cleavage and large-scale faulting are generally absent. In eastern Victoria the deformation was probably more intense, but little is known about it regionally. To the north along the Taemas - Molong Platform the degree of deformation decreases until near Wellington there are areas where the Upper Devonian and Eifelian strata are almost parallel. To the west (in the Cobar Trough) and to the east (in the Hill End Trough) the deformation was stronger, and along the Capertee High the degree of deformation decreased to the north, until near Mudgee there is apparent conformity between Middle and Upper Devonian rocks.

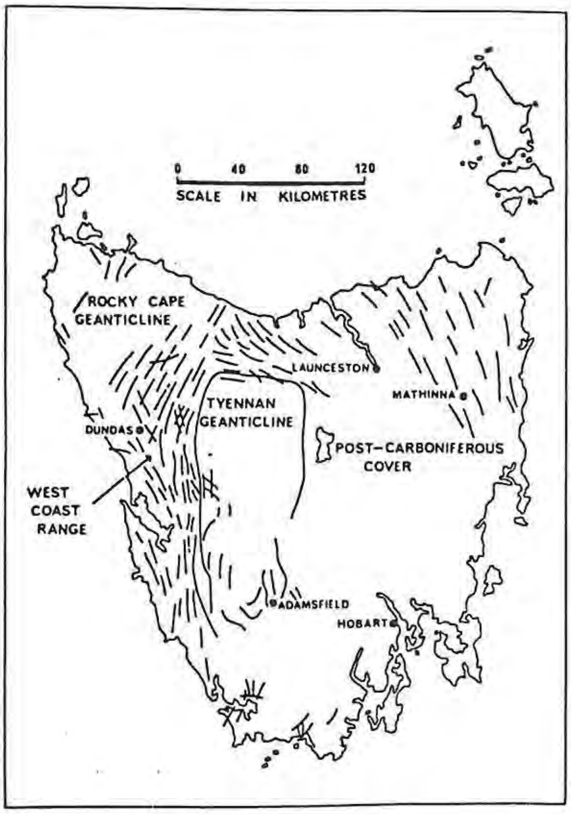

Fig. 2.49 Map showing the Tabberabberan fold trends in Tasmania (from Brown et al 1968)

Thus it would appear that the Tabberabberan Orogeny, though it resulted in extensive land areas where previously there had been sea, was not a great mountain-building event (except perhaps in Tasmania). This point is confirmed by the nature of the Tabberabberan deformation and the character and great extent of the Upper Devonian sediments.

Over the whole area previously occupied by the Lachlan geosyncline, quartzose and lithic sandstones of terrestrial (and occasionally marine) origin began to accumulate after the Tabberabberan Orogeny. These rocks occupy meridionally trending belts, which may represent their depositional basins, or may be preserved remnants of a far more extensive area of deposition. Facies relationships and current directions in New South Wales indicate a sedimentary interconnection between these now isolated belts, and the sediments are thought to have accumulated in an extensive river system (or systems) which discharged into a shallow sea in the east (see fig. 2.50). However, limited thickness data does indicate differential subsidence.

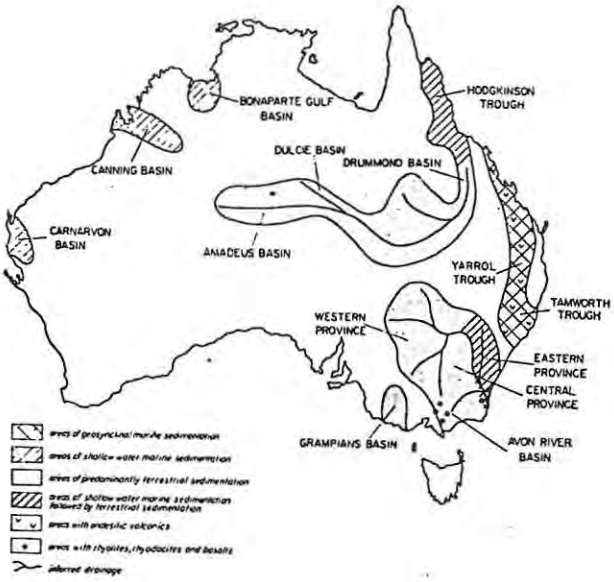

Fig. 2.50 Palaeogeographic map of Australia during the Late Devonian. The inferred drainage pattern for the areas of terrestrial deposition is indicated. It is possible that the Amadeus and Dulcie Basins at various times drained southwards through New South Wales rather than through the Drummond Basin. (from Brown et al 1968)

A marine facies in the lower part of the Lambie and Catombal Groups formed an Eastern Province, and also occurred in the Hervey Group in the Central Province. These rocks vary from volcanic lithic sandstones to proto-quartzites, and are locally cross-bedded, with occasional brachiopod shell banks. Over much of the Central Province, though, the basal beds are mostly arkosic or lithic red sandstones (containing the fish Bothriolepis and the plant Leptophloeum) while in the Western Province coarse conglomerates (probably river gravels) predominate. In all areas these rocks are succeeded by alternating red and white siltstones, lithic sandstones and proto-quartzites, which probably represent alternating lacustrine and fluvial environments. In the Catombal group, similar lithologies also contain numerous interbedded massive, red oligomictic conglomerates. In the Hervey and Mulga Downs Groups these conglomerates are replaced by red siltstones and may extend into the Early Carboniferous.

In Victoria two large basins contain rocks of this facies, the Avon River Basin to the east and the Grampians Basin to the west (see fig. 2.50). The Avon River Basin appears to have been connected to the Central Province Basin of New South Wales, and in it the Avon River Group contains, from base, terrestrial conglomerates, purple sandstones and red mudstones, followed by extensive development of acid volcanics. On the west side of the basin these volcanics exceed 1 000 m in thickness and appear to have been formed in cauldron subsidences, while elsewhere they are more thinly developed with interbedded fossiliferous sedimentary units. In the south of the basin these sequences are overlain by Upper Devonian quartzose and lithic sandstones, conglomerates and claystones, while in the north the volcanics are overlain by red sandstones and conglomerates containing Carboniferous plant and fish fossils.

In the Grampians Basin there are 7 000 m of well-bedded, coarse to fine grained quartzose sandstones and micaceous siltstones, often red-coloured and cross-bedded. The Grampians Group contains four formations and has in the past been considered to be of Carboniferous age on the basis of limited fossil evidence (which also indicates that the sequence was partly marine).

Late in the Middle Devonian adamellites (and some quartz - mica - diorites and granodiorites) were intruded into the Taemas - Molong Platform, the Condobolin High, the Melbourne and Cobar Troughs and the southern part of the Capertee High. At this time there was an abundance of hypabyssal intrusives, especially in eastern Victoria. At Tabberabbera several sets of dykes (some probably post-Givetian in age) may have acted as feeders for the overlying Upper Devonian volcanics. However, the main dyke swarm, of Tabberabberan age, consisted of quartz diorite, hornblende porphyrite and quartz - felspar - porphyrite, and intruded roughly parallel to the strike of the Wentworth Group. In Late Devonian - Early Carboniferous times, igneous intrusions occur in central Victoria in association with the extensive acid volcanics. Calcalkaline volcanic piles are preserved in cauldron subsidences up to 40 km in diameter, whose boundary faults are filled with ring dykes of porphyritic granodiorite, diorite and quartz porphyry. In the Dandenong and Strathbogie Ranges granodiorite plutons (regarded as the final phase of evolution of a granodiorite magma differentiating at shallow crustal depths), are intruded into the Upper Devonian volcanic piles.

Granitoid intrusions occur in Tasmania, and were especially common in the northeast where several distinctive plutons were composed mainly of garnet - cordierite - biotite granodiorites. They range in age from 370 to 400 m.y., slightly older than the granitoid plutons of Western Tasmania (which range in age from 340 to 375 m.y.). The western granitoids are smaller in number and composed mainly of biotite granites and hornblende biotite granodiorites. The Tasmanian plutons are of contact aureole type and include both S and I types. They appear to have been emplaced at relatively shallow levels, largely by diapiric intrusion and roof lifting, with minimal assimilation. There is no evidence of related felsic volcanism and cauldron development as found in Victoria. The granitoids of western Tasmania occur mainly in the Dundas and Dial Range Troughs, and a tendency has been noted for them to lie within first phase large-scale Tabberabberan anticlinoria (Solomon 1981).

Emplacement of Siluro - Devonian granites in the southern part of the Wagga Anticlinorial zone has given rise to a wide variety of mineralisation, including deposits of tin, tungsten, gold, silver, lead, fluorite, molybdenum, bismuth and uranium.

These granite-related deposits occur within what Scheibner (1974) has referred to as the "orogenic granite metallogenic unit" and Degeling (1974) has subdivided these into two subunits - an acidic granite metallogenic subunit and a post-batholithic metallogenic subunit.

The acidic granite metallogenic subunit covers most of the Wagga Anticlinorial Zone. It is characterised by deposits of tin and tungsten, with relatively minor gold deposits and lesser molybdenum, bismuth and fluorite. The molybdenum, bismuth and fluorite mineralisation appears to be more strongly associated with the older Corryong Batholith, where minor but significant lead - silver - fluorite mineralisation also occurs.

Gold mineralisation associated with quartz veins occurs mostly marginal to, or remote from granites, with relatively few deposits found well within the granites. To the north of the Corryong Batholith, gold occurrences (e.g. the Yarrara and Billabong reefs) are located along structural lineaments, some of which are continuous with major shear zones which have influenced the shape of the Corryong Batholith.

The post-batholithic metallogenic subunit is represented by a series of rich pyrite - gold deposits with associated intermediate to basic intrusions occurring between Wyalong and Batlow on the east side of the Wagga Anticlinorial Zone. The genesis of these intermediate and basic intrusives is not yet understood, as they appear to be both post- and pre-batholithic.

Silurian and Devonian granitoids were emplaced in the southern part of the Molong - South Coast Anticlinorial Zone (the present structural zone which broadly equates to the lower Palaeozoic Molong Rise and Snowy Mountains Block). These granites were emplaced along a north-south belt stretching for over 400 km from near Bathurst in New South Wales into eastern Victoria in the south. Mineralisation of predominantly vein and replacement hydrothermal type shows a close spatial and genetic relationship to these granites, and includes metals such as gold, copper, lead, zinc, silver, tin, tungsten, bismuth and molybdenum. The mineralisation in each of the more important granites will be discussed briefly.

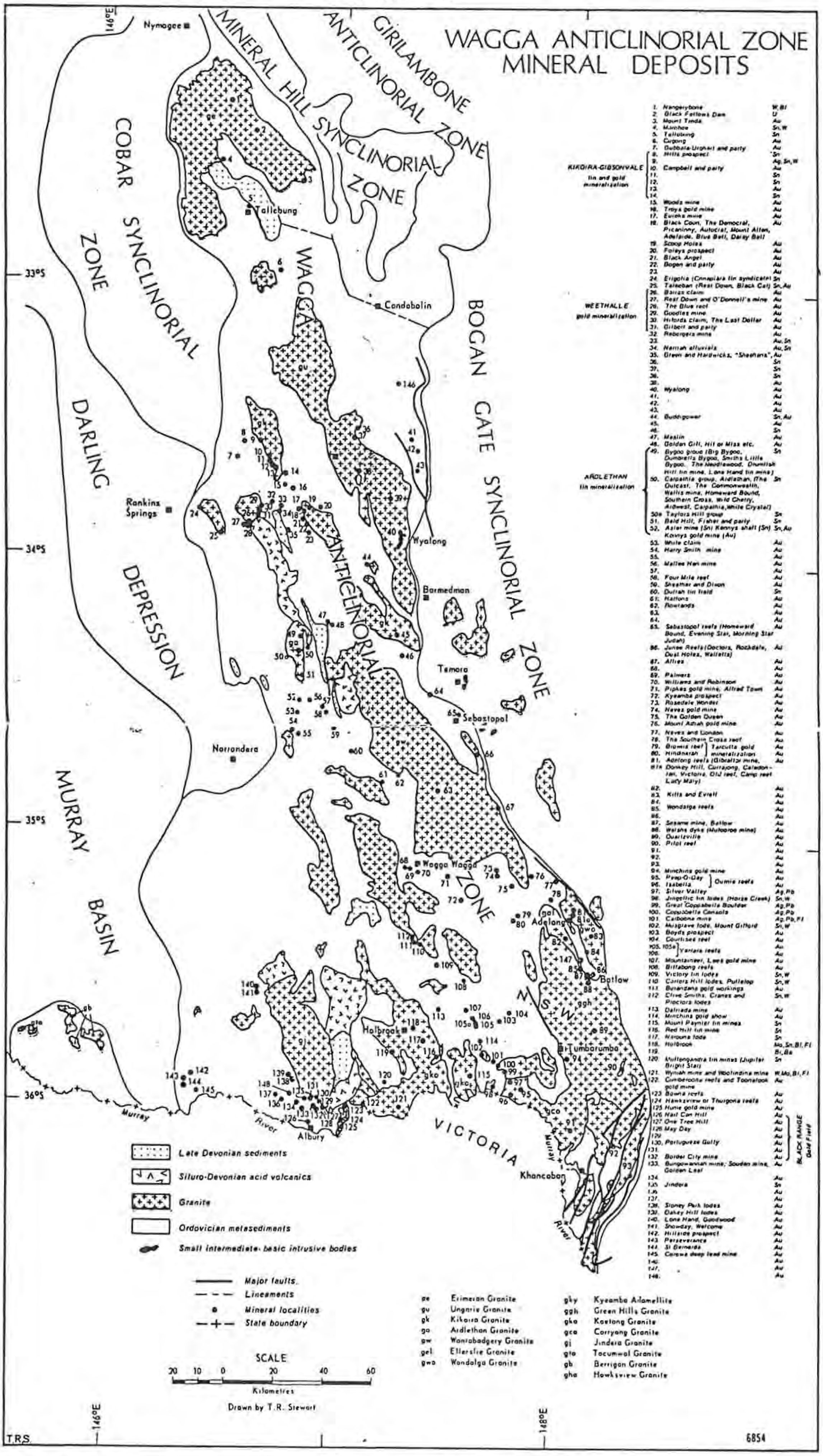

Fig. 2.51 Mineral deposits of the Wagga Anticlinorial Zone (from Degeling 1974)

The extensive Bega Batholith is the most abundantly and diversely mineralised intrusion, and is both massive and foliated in character. In the Braidwood Granite the gold - silver - copper - lead mineralisation is developed along prominent joint planes, while silver - copper - lead mineralisation occur in a shear system in the Boro Granite. A similar silver - copper - lead assemblage occurs at the southern end of the Bega Batholith in an extensive shear system. These deposits were probably formed by hydrothermal activity.

Within the Berridale Batholith the Buckleys Lake Adamellite contains tungsten - tin - copper - gold mineralisation, while the Clarkeville Adamellite is host to a number of copper occurrences. Shearing is important for ore localisation at all these deposits, as well as in the copper - gold mineralisation south of the batholith. Silver, lead and zinc mineralisation is notably absent, while tin occurs in a narrow greisenous lode.

Rich gold - silver - arsenopyrite mineralisation occurs in and near the late-stage acid phases of the Moruya Batholith. The grade of the deposits decreases away from the batholith. A similar relationship may be seen at the Sutton Granite, where the Bywong - Gundaroo Gold Fields form a halo of vein quartz mineralisation around the granite. The Wologorong - Tumboramboro Granite is considered to be the source of minor silver - gold and base metal mineralisation.

The late-stage acidic phases of the Wyangala Batholith appear to be the hosts to tin - tungsten mineralisation, and occur mainly in the western part of the batholith. Vein gold - silver - arsenopyrite mineralisation is associated with the earlier, more foliated phases of the intrusion. Closely resembling this batholith is the Barry Granite, which has minor vein gold and vein copper deposits associated with it.

The highly foliated Davies Creek Granite contains a number of small vein copper deposits, most of which occupy shear zones (though unlike the Berridale Batholith they contain minor sphalerite and pyrrhotite).

The Kosciusko Batholith is large and of variable composition, though mineralisation appears to be sparse. Its only mineralisation appears to be gold and copper in narrow quartz veins and tin in a siliceous aplitic muscovite-tourmaline rock. As in the Wyangala Batholith, tin mineralisation occurs in the later, more acid phases of the intrusion.

The more massive intrusions (like the Bega and Moruya Batholiths) contain abundant galena, barite, molybdenum and bismuth occurrences. The abundance of molybdenum decreases with increasing foliation in the granite body. Tin and tungsten occurrences occupy well-defined zones which are probably related to particular types of intrusion, while the more prolific gold and copper occurrences are more generally distributed. Silver and arsenopyrite are variable in occurrence and are often associated with the lead and gold mineralisation. Gross mineral zoning may be observed around some of the smaller bodies, such as the Sutton Granite and Moruya Batholith.

Porphyry-type disseminated copper mineralisation occurs in eastern Victoria. At Sunday Creek, 30 km east of Buchan, two ages of granodiorite (the younger of which, the Ellery stock, is known to be of Upper Ordovician age) intrude folded Ordovician sediments. The Double Bull Creek mineralisation occurs in the same intrusive as Sunday Creek, and has fracture-controlled copper - molybdenum mineralisation located on the intrusive-sediment contact.

In eastern Victoria the Devonian Snowy River and Mitta Mitta Volcanics host a number of barite - lead - silver (zinc) deposits (see fig. 2.52). Mineralisation at Mount Tara and Gelantipy comprises veins and disseminations of silver and lead (with lesser gold) within the volcanics. Other types of deposit include Mt Deddick where quartz - galena lodes occur within a granodiorite which cuts epi-Middle Devonian lamprophyre dykes, and parallel a major arcuate fracture zone. At Campbells Nob, 16 km to the south, small subvertical quartz galena - sphalerite fissure veins occur within a granodiorite stock. A number of stratiform and disseminated lead - zinc occurrences are hosted in the Middle Devonian Buchan Caves Limestone.

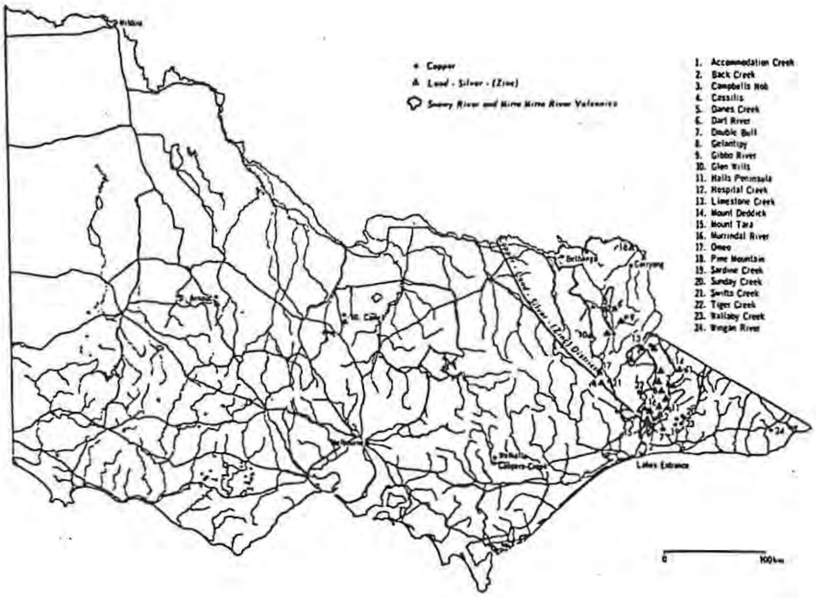

Fig. 2.52 Mineral location map for Victoria - copper - lead - zinc - silver (after Hill 1975)

In northeast Victoria tin mineralisation occurs in association with Siluro-Devonian granites and forms the southern end of the belt of granite derived mineralisation on the Wagga Anticlinorial Zone of New South Wales.

Fig. 2.53 Mineral location map for Victoria - iron - manganese - molybdenum - tungsten - tin - uranium (after Hill 1975)

The Eden - Comerong - Yalwal rift zone is a discontinuous graben structure located within Ordovician flysch sediments in the Molong - South Coast Anticlinorial Zone. Within this rifted structure Devonian acid volcanics host gold - pyrite mineralisation, localised in silicified and altered rhyolitic lavas and pyroclastics. The mineralisation at Yalwal and Pambula occurs as both narrow veins and wide disseminated zones, and appears to have formed as a result of near-surface hot spring activity.

The rift zone structure is bounded by normal faults and varies between 5 and 20 km wide. It extends for 320 km from Cape Howe in the south to near Nowra in the north, where its northward continuation is covered by younger rocks. The rift occurs within a north-south elongate cratonised block of Ordovician flysch sediments. Large composite batholiths (of probable Late Silurian to Middle Devonian age) intrude the southeastern part of the basement block.

Deposition in the rift zone commenced in the late Middle Devonian with up to 1 000 m of subaerial acid and basic volcanics, with associated coarse talus slope and alluvial fan sediments. Various names for this sequence include the Comerong Volcanics and Yalwal Volcanics, while in the Eden area they are divided into a basal Eden Rhyolite and the overlying (basic volcanic) Lochiel Formation.

The volcanic sequence is overlain by the Merrimbula Group, a succession of arkosic red-beds which reach 2 000 m in thickness and were deposited in an intramontane setting in the graben by braided and meandering rivers. Within this sequence a brief but widespread Late Devonian marine incursion is represented by paralic to littoral sediments containing a shelly fauna.

Disseminated gold - pyrite deposits occur in the Panbula, Sugarloaf Mountain, Yalwal, and Grassy Gully Gold Fields. They occur with small pyrophyllite deposits within the acid volcanics, and may be regarded as resulting from late stage hydrothermal activity in the cooling volcanics (McIlveen 1974).

A number of minor occurrences of disseminated native copper (with associated secondary copper minerals) have been reported in both the basic volcanics and the Merrimbula Group sediments.

Several important tin and tungsten deposits occur in Tasmania and are related to the emplacement of various Devonian granitoids. Scheelite deposits in skarns and minor molybdenite occurrences are associated with granodiorite (e.g. on King Island and at Kara), and a number of cassiterite - wolframite - fluorite deposits occur near or within biotite granites and alkaline granitoids (e.g. Renison, Mt Bischoff, Aberfoyle, Storys Creek, Moina and Anchor, and probably Cleveland, Razorback and Queen Hill at Zeehan).

Solomon (1981) has subdivided the Tasmanian tin and tungsten deposits into four major types:

(a) Cassiterite - stannite - pyrrhotite lenses mainly derived from replacement of carbonate beds and associated with small and large fissure lodes. Examples include Renison, Mt Bischoff, Cleveland, and Queen Hill at Zeehan, Razorback, St Dizier and Stanley River.

(b) Quartz - wolframite veins ($\pm$ cassiterite) mainly lying within country rocks immediately overlying granitoid cupolas. Examples of this type include Aberfoyle, Storys Creek, Lutwych, Shepherd and Murphy (with other nearby deposits at Moina), Mt Oakleigh and Interview River.

(c) Disseminated cassiterite in altered, gneisenised granite intruded as sills, dykes, and plutons, or derived by in situ alteration - examples include the Anchor mine and the Federation mine in the Heemskirk Granite.

(d) Scheelite in skarns, without cassiterite - examples include King Island and Kara.

Fig. 2.54 illustrates the setting and mode of occurrence of tin and tungsten deposits in Tasmania.

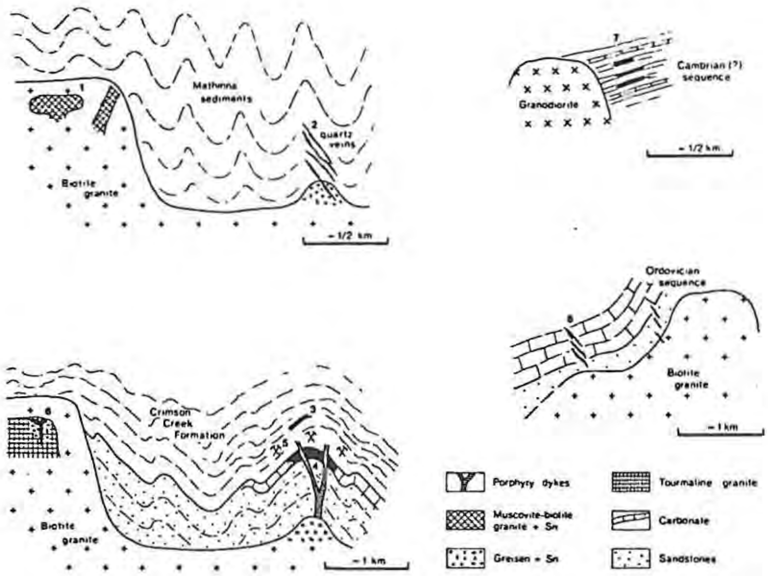

Fig. 2.54 Sketches illustrating the variation among the tin and tungsten deposits of Tasmania. 1, Anchor mine (closed at January 1980), producer of cassiterite; 2, Aberfoyle and Storys Creek mines, cassiterite, wolframite; 3, Cleveland mine, cassiterite, stannite, chalcopyrite; 4, Mt Bischoff (closed) and Renison mines, cassiterite; 5, Magnet mine (closed), sphalerite, galena; 6, Federation mine, Heemskirk (closed), cassiterite; 7, King Island mine, scheelite; and 8, Shepherd and Murphy mines, Moina (closed), cassiterite, wolframite, bismuthinite. (from Solomon 1981)

Tasmania appears to have occurred within an Ordovician to Devonian continental margin, with tin-bearing granitoids being emplaced close to the continental foreland (as has occurred in the New South Wales, New England and northern Queensland tin provinces of eastern Australia). Another feature noted elsewhere is the westward younging of the granitoid plutonism.

The tin - tungsten deposits (a) to (c) are associated on a large scale with biotite granites (having tin contents of a few p.p.m.) and on a more local scale with silica-rich intrusives (some of which carry high tin contents). These intrusives include two-mica granites, orthoclose-quartz porphyries, and highly altered and greisenised boron- and fluorine-rich varieties. There appears to be a link between scheelite-bearing skarn deposits and I-type hornblende granodiorites, though this is not always well defined.

The distribution of tin tungsten deposits probably reflects a subsurface granitoid structure. For example, a granite mass (or masses) probably extends east of the Heemskirk Granite, with probable cupolas beneath Queen Hill and Razorback, to link up with granitoid outcropping near Renison (see fig. 2.55). A zone subparallel to this occurs north of the Meredith Granite and appears to be marked by the line of small lead - zinc deposits between Cleveland and Mt Bischoff. These subparallel zones have an east-northeast trend (the same trend as the main folding at Mt Bischoff) implying that the granitoid emplacement followed early structural trends. On the west end of this Bischoff - Cleveland zone are the wolframite veins of the Interview granite, while the Kara deposit lies on the eastern end.

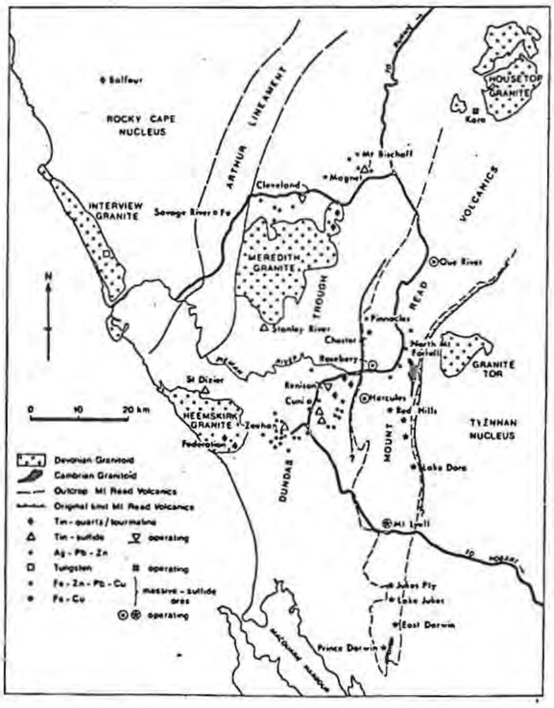

Fig. 2.55 The central western part of Tasmania showing tin - tungsten and massive sulphide deposits (from Solomon 1981)

Silurian depositional patterns in the Hodgkinson - Broken River orogen continued to the Middle Devonian. Clastic and carbonate deposits continued to be laid down on the Chillagoe Shelf on the western margin of the Hodgkinson Province and on the Broken River and Burdekin River Shelves in the south and southwest of the Broken River Province (fig 2.56). The Broken River shelf occurs on the western end of the earlier Kangaroo Hills Trough and received nearly 6 000 m of shallow water sediments (mainly sandstones and siltstones) during the Emsian and Middle Devonian. The carbonate succession on the Burdekin River Shelf reached 2 500 m in thickness and contained true reefs with abundant fossil faunas. West of the Chillagoe Shelf the sediments become deeper water greywackes, shales and basic volcanics with thin limestone horizons. To the east these rocks were progressively more highly metamorphosed and are known (with earlier formations) as the Barron River and Barnard Metamorphics. In the Middle Devonian, the sea transgressed the Lolworth - Ravenswood Block to the south across the Broken River Shelf and deposition began in the Burdekin Basin.

Deformation and uplift began during the Devonian in the Camel Creek Sub-Province and restricted terrestrial and shallow marine sedimentation occurred in the Late Devonian and Early Carboniferous in the Broken River Province and Burdekin Basin.

The Mt Garnet copper - zinc lode occurs on the Chillagoe Shelf in the Hodgkinson Province. The Mt Garnet Formation consists of deltaic shelf facies typical of the western margin of the Hodgkinson Basin. The absence of biohermal reefs has been attributed to prevailing high relief causing rapid erosion and sedimentation. Mineralisation is of skarn-type and comprises magnetite, sphalerite, chalcopyrite, with some pyrrhotite and galena, hosted in an argillite horizon now metamorphosed to a garnet-diopside - wollastonite assemblage. Lenses of granite and granite porphyry are shown occurring to the east, but little information on these rocks is available.

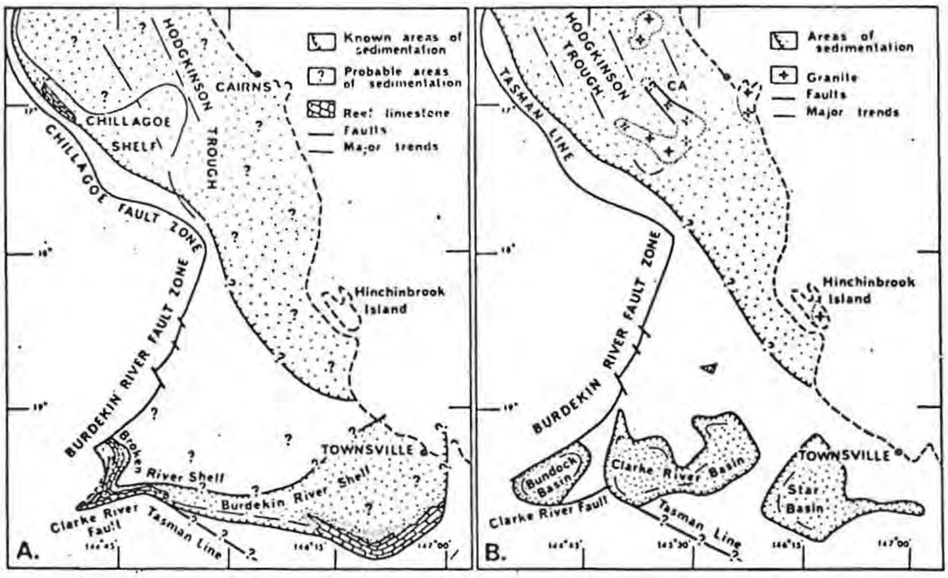

Fig. 2.56 Depositional pattern in the North Queensland Basins during A, the Middle Devonian; B, the Late Devonian to Early Carboniferous (Modified after White, 1961, from Brown et al 1968)

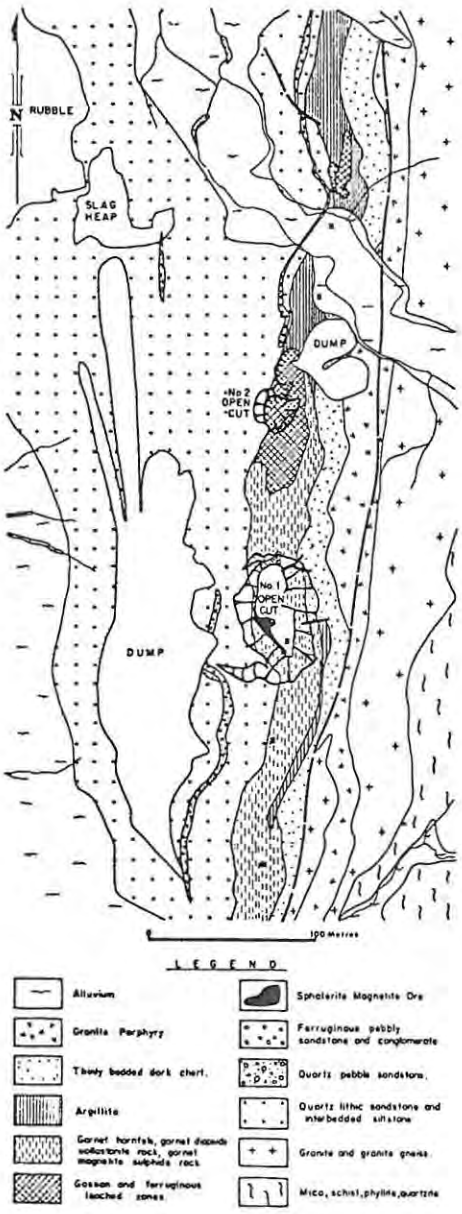

Fig. 2.57 Surface geology of Mt Garnet mine area.

In Early and Middle Devonian times the sea transgressed over the Thomson orogen. The transgression reached its maximum westward extension in the early Middle Devonian when the shoreline was located to the east of the Anakie Inlier and continued to the southwest close to the northern margin of the Adavale Basin. Eruptions of andesitic volcanics accompanied deposition of clastic sediments and limestone along a northeast trending continental margin. In the deeper water southeast of the Adavale Basin some of the fine grained clastics of the "Timbury Hills Formation" may have been laid down at this time. North of the Anakie High was the slightly emergent Lolworth - Ravenswood Block, on whose northern flank was the Burdekin Basin which first received sedimentation in the late Middle Devonian, when there was a southward marine transgression from the Broken River Province.

The Early to Middle Devonian rocks of the Anakie Inlier, and perhaps also the "Timbury Hills Formation" were folded in the late Middle Devonian. This folding has been correlated with the Tabberabberan Orogeny of the Lachlan geosyncline, and resulted in north-trending fold axes (with the Anakie Inlier probably being formed as a north-northwest trending structural unit at this time). No folding occurred in the Adavale or Burdekin Basins, but uplift caused the withdrawal of the sea at the beginning of the Late Devonian. Post-tectonic granites were emplaced in the southern part of the Anakie Inlier, the Roma Shelf, and the Eulo Ridge.

Late Devonian red-beds and other continental deposits accumulated over much of the Thomson orogen. The thickest sedimentation occurred in the Drummond Basin, and was interlayered with sporadic volcanism until the Early Carboniferous. Fluctuating continental to marine conditions (as well as occasional volcanics) occurred in the Burdekin Basin from Late Devonian to Early Carboniferous time. Part of the "Timbury Hills Formation" may be of Late Devonian age, while a thick red-bed sequence was deposited in the Adavale Basin in the Late Devonian and also perhaps the Early Carboniferous.

On the western edge of the Anakie High the basal Devonian formation is the Silver Hills Formation, consisting of rhyolitic and andesitic pyroclastics and flows and interbedded slates, lying unconformably on a metamorphic basement. Southwards the volcanics probably merge in part into volcaniclastic marine sediments (the Dunstable Formation) which exceed 1 000 m in thickness containing Eifelian coral faunas in thin limestone lenses. To the east the volcanics transgress the strongly deformed Anakie Metamorphics where stratigraphic relationships are difficult to determine. Small outcrops of Eifelian coralline limestones occur, associated with slates, on the Anakie High itself.

At the northern end of the Drummond Basin the Ukalunda Beds occur, comprising shallow water marine sandstones, siltstones, shales and limestones. They contain thin interbedded volcanics and their relationships with underlying lithologies is unknown. Their abundant faunas indicate ages from late Lower Devonian to Middle Devonian.

After the Tabberabberan Orogeny the Drummond Basin became an area of largely terrestrial deposition (see fig. 2.58). The Upper Devonian Telemon Formation lies unconformably and disconformably on the underlying Middle Devonian rocks, and is terrestrial and estuarine in nature. Against the Anakie High it has an increasing volcaniclastic component, and includes tuffs, thin andesite, basalt and rhyolite flows and volcanic lithic sandstones, while to the west the volcanic content decreases and gives way to flaggy and ashy sandstones and limestones composed of fresh water algae.

The Devonian in the New England geosyncline saw a continuation of some Silurian patterns of sedimentation and volcanism. In the southwest of the New England Province Early and Middle Devonian volcaniclastic greywacke, cherty siltstone and minor limestone, keratophyre and spilite were deposited on the Tamworth Shelf, an unstable shelf or fore-arc basin to the east of an active andesitic volcanic arc. The site of this arc is obscured by Permo-Triassic sediments in the Sydney

Basin and the relationship of the arc with the Lachlan orogen is unclear. Scheibner (1973) has suggested that a marginal basin (which he named the Murruin Basin) may have existed to the west of this arc, so its setting may have been similar to that of the Calliope Island Arc in the Yarrol Province.

The rocks of the Calliope Island Arc were strongly deformed in the late Middle Devonian and small granodiorite plutons were emplaced. Folding was dominantly along north-northwest axes, with cleavage being developed locally. East-trending cross faults were probably initiated at this time, and strongly influenced the pattern of later sedimentation. This deformational event may be correlated with the Tabberabberan Orogeny of the Lachlan orogen, and it also folded Early and Middle Devonian rocks around the Anakie Inlier. It would appear that the marginal sea west of the Calliope Island Arc became cratonised after this orogeny, since the Drummond Basin experienced a change from marine to terrestrial conditions at this time. Although major changes occurred at about this time in the Tamworth Shelf, no significant deformation may be seen there.

In the Late Devonian and Early Carboniferous Andean-type calcalkaline volcanics were abundant in the New England orogen, and appear to have occurred along the entire western margin of the geosyncline. In the Yarrol Province, thick terrestrial volcanics formed the Connors - Auburn Volcanic Arc. In the northern part of the arc between Bowen and Rockhampton (the present Connors Arch) the main volcanic rox are massive andesite flows, with subordinate dacitic and rhyolitic lavas and pyroclastics, and locally abundant basalt flows. Further south (the present Auburn Arch) dacitic and rhyolitic flows are dominant with localised andesitic volcanics. These volcanics extend well into the Carboniferous and are intruded by Late Carboniferous granites.

The Yarrol and Tamworth Shelves were unstable shallow marine shelves and occurred east of the volcanic arcs. The southern part of the Yarrol Shelf developed unconformably over the deformed rocks of the Calliope Island Arc, which may have been emergent in places, while the rocks of the Tamworth Shelf were deposited unconformably on lower Palaeozoic basement. Both these shelves were sites of Late Devonian to Early Carboniferous deposition of volcaniclastic sediments derived from the arcs to the west and contained varying amounts of primary volcanics.

East of the Yarrol and Tamworth Shelves, thick volcaniclastic flysch-type sediment occurred in the Wandilla Slope and Basin and the Woolomin Slope and Basin. Major fault zones (probably thrusts) indicated by serpentinite belts mark the present boundaries of these shelves and the slope and basins to the east (i.e. between the Yarrol Shelf and the Wandilla Slope and Basin and between the Tamworth Shelf and Woolomin Slope and Basin) thus disrupting any transition zones that might have existed between them. The flysch sediments of the slopes overlie and locally interdigitate with abyssal plain sediments (argillite, siltstone, greywacke, and manganiferous radiolarian jasper) and spilitic basic volcanics in the deeper parts of the basins.

Much of the flysch of the Wandilla Slope and Basin appears to be Early Carboniferous in age, based on palaeogeographic and sparse palaeontological considerations (Day et al 1978; Murray 1974). The underlying abyssal-plain deposits may be diachronous, and include rocks as old as Silurian.

In the Woolomin Slope and Basin coral and conodont faunas from limestone lenses have indicated a maximum age of Ordovician to Silurian. However, some doubts remain over these ages as almost all of these limestone lenses occur in fault blocks either to the west of, or within the Peel fault system, separating the Woolomin Slope and Basin from the

Tamworth Shelf (and the lenses are associated with different rock types from those of the Woolomin and Myra Beds).

The Woolomin and Myra Beds include both abyssal plain sediments and some terrigenous flysch material derived from the west. Younger sequences of thick volcaniclastic flysch to the east and northeast (the Texas and Sandon beds) have yielded Early Carboniferous fossils. Based on the available data, it would appear that the sediments of the Woolomin Slope and Basin have a similar age and sequence of deposition to those of the Wandilla Slope and Basin. This comprises a diachronous abyssal plain sequence containing rocks as old as Silurian age, overlain by a terrigenous, volcaniclastic flysch wedge of Devonian to Carboniferous age.

In the south of the Demon Block volcaniclastic turbidites are generally considered to be of Devonian to Carboniferous age. They may be correlatives of Carboniferous sediments in the southern part of the Wandilla Slope and Basin, with which it may be continuous under the Mesozoic cover of the Moreton - Clarence Basin.

The early stage of development of the Tamworth Trough was characterised by deep water sedimentation, and, locally, spilitic volcanism. In the Nundle region, spilitic lavas of probable Early Devonian age host minor vein and disseminated gold -pyrite mineralisation which appears to be related to hydrothermal activity associated with the extrusion and alteration of the lavas.

The Mount Morgan copper - gold deposit occurs 36 km south-southwest of Rockhampton in Central Queensland, within the Rockhampton Block, which separates the intracratonic Bowen Basin in the west from the marine eugeosynclinal Yarrol Basin in the east.

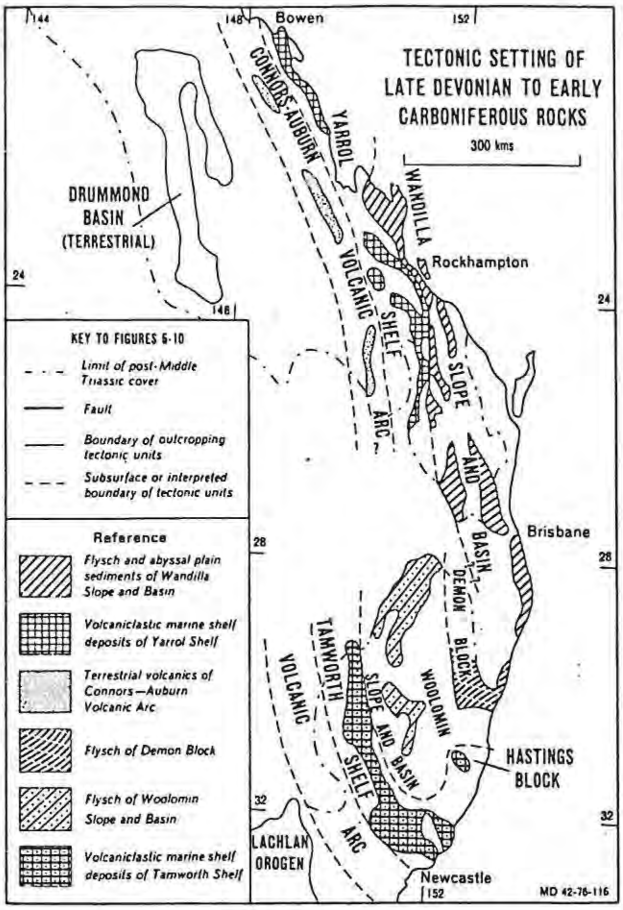

Fig. 2.58 Tectonic setting of Late Devonian to Early Carboniferous rocks, New England orogen (from Day et al 1978)

Mineralisation occurs within a north-northwest trending belt of Middle Palaeozoic volcanic rocks (the "mine corridor complex") which has been assigned a Middle Devonian age (Frets and Balde 1975) and is overlain by Upper Devonian volcanics (the Dee Volcanics). These volcanic successions are intruded by the Mount Morgan Tonalite, a Devonian intrusive complex which includes gabbro, diorite, quartz diorite, granite and alaskite. Pyrite, chalcopyrite, pyrrhotite, magnetite, sphalerite and important gold and gold tellurides (as well as a large variety of accessory trace minerals) occur in brecciated and disseminated form in the quartz porphyry.

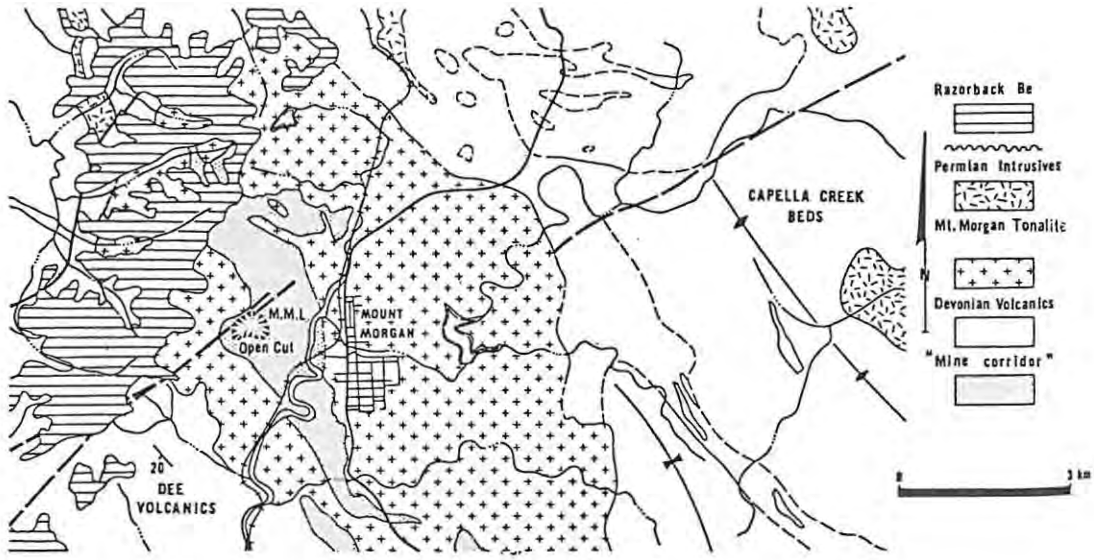

Fig. 2.59 Geological map of the Mount Morgan area (from Frets and Balde 1975)

The Carboniferous

Prior to the Carboniferous, both the Lachlan and Thomson orogens had been cratonised. The Early Carboniferous saw a continuation of the terrestrial (red-bed) sedimentation which was widespread in the Devonian. During the Carboniferous both these orogens were again deformed, this time by the Kanimblan Orogeny, whose movements resulted in relatively gentle deformation of the continental sediments. After the Kanimblan Orogeny emplacement of post-kinematic granites was widespread in both the Lachlan and Thomson orogens (with comagmatic subaerial acid volcanics) and these intrusives are associated with a wide variety of granite-derived, vein type mineralisation.

The Hodgkinson - Broken River orogen received some marine sedimentation during the Carboniferous and suffered major deformational events which had begun in the Devonian.

This deformation resulted in steep to isoclinal folding, pervasive slaty cleavage, and was primarily responsible for the present structural trends in this fold belt (i.e. north to north-northwest in the Hodgkinson Province and northeast in the Broken River Province). As in the Thomson and Lachlan orogens, post-kinematic plutonism and acid volcanism was extensive (and continued into the Permian), resulting in widespread (though mostly relatively minor) granite-derived mineralisation.

The New England geosyncline or orogen is considerably younger than the Lachlan and Thomson orogens, and although it was mildly affected by Early Carboniferous deformation, it was not until the latest Carboniferous that the major folding occurred. This deformation, which affected the eugeosynclinal slopes and basins to the east but not the more stable shelves to the west, persisted into the Permian (when it is known as the Hunter-Bowen Orogeny), and was associated with syntectonic granodiorite plutons. Calcalkaline volcanism occurred throughout the Carboniferous on the Tamworth Shelf and further to the west, becoming progressively more acidic with time.

Fig. 2.60 Early Carboniferous palaeogeography (from Brown et al 1968)

Based on the widespread invertebrate faunas and the extensive development of chemically deposited limestones it would appear that the Australian climate continued to be warm, at least until the Namurian. Probably as a result of a relatively sudden change in the position of the pole relative to the Australian continent at this time, much of the southern part of the Tasman Geosyncline underwent conditions of glaciation for the remainder of the Carboniferous (and this glaciation may have almost totally covered the continent by the end of the Stephanian). Some evidence exists for a periodic nature of this glaciation, at least in New South Wales where interglacial deposits have been identified (Brown et al 1968).

The most striking feature of the Lower Carboniferous biotas of Australia is their large cosmopolitan element. Invertebrates included corals, brachiopods, polyzoans, bivalves, gastropods, ammonoids, conodonts and ostracods, to mention only a few genera. Although several endemic genera occurred (as well as others with provincial relationships with east and southeast Asia and America), generally migration routes to Europe, Asia and America were open for the whole of the Dinantian and at least part of the Namurian Epoch.

Lower Carboniferous vertebrate fossils have been reported sporadically from eastern Australia, and form comparable though less varied faunas than those of Europe and North America.

In Westphalian times new and markedly provincial faunas developed in eastern Australia, lacking compound fossils, fusulinids, ammonoids and other groups common in the northern hemisphere at the time. The range of genera is small, and relationships are with Argentina, where almost identical assemblages occur.

The Dinantian is characterised by plant assemblages such as species of Lepidodendron, Stigmaria and Pitys, while some genera common in the northern hemisphere were absent in Australia. Spores are known from the Australian Carboniferous, some of which indicate relationships with North America and the U.S.S.R.

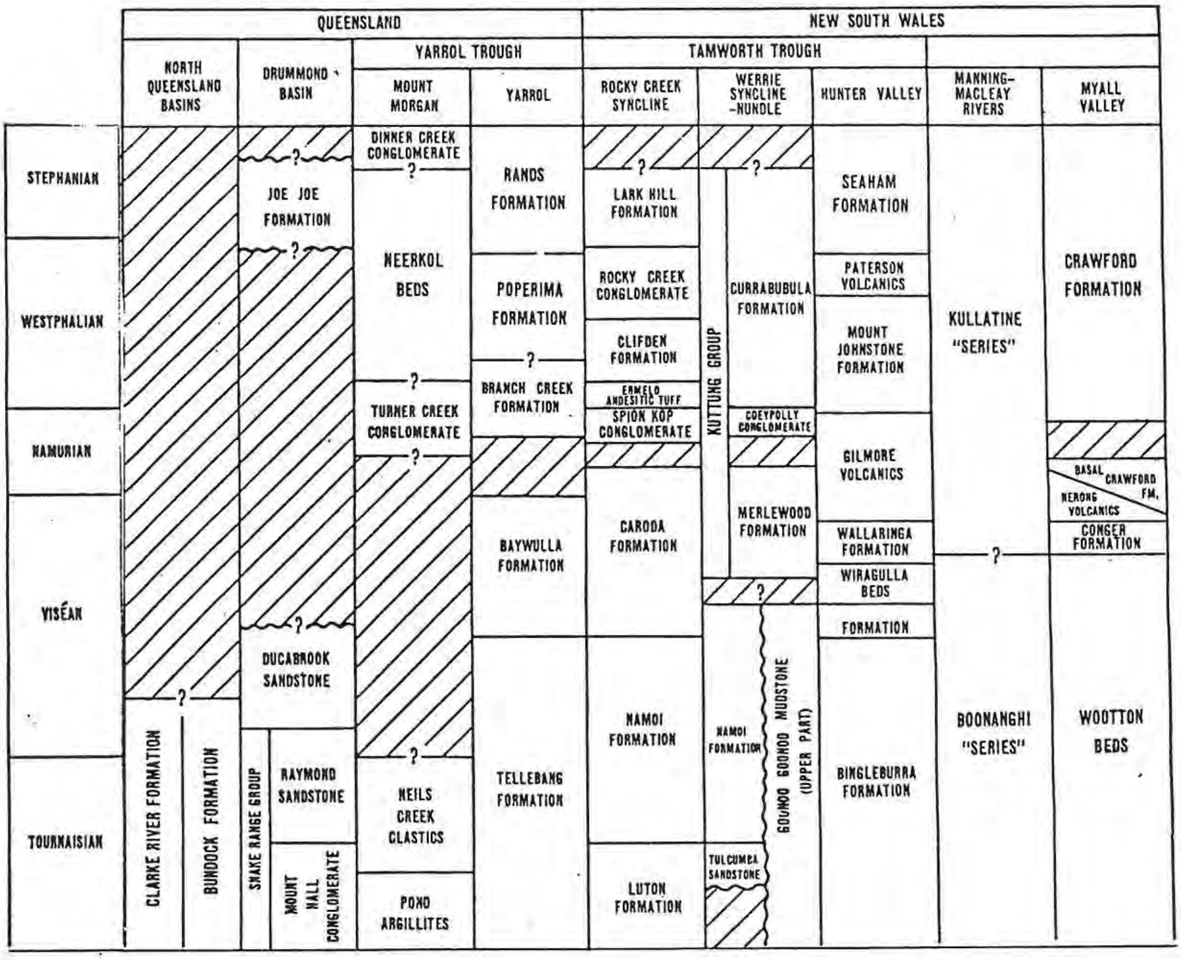

Fig. 2.61 Correlation Table for Carboniferous System (after Brown et al 1968)

In the area of the Lachlan orogen the only sedimentary activity in the Carboniferous was a continuation of the terrestrial (and paralic) deposition in the Lambian Basins. Although the upper parts of the successions in the Grampians and Avon River Basins are referred to the Lower Carboniferous, detailed correlations are hampered by insufficient palaeontoligal data (Brown et at 1968).

It is possible that the Lambian Basins were becoming disrupted by faulting and folding as early as the latest Devonian. This occurred in the Avon River Basin and in the deformed Melbourne Trough, where the development of downfaulted basins was accompanied by extensive volcanism.

Deformation in the Lambian Basins proceeded in the Early Carboniferous so that deposition in them had effectively ceased by the Namurian. The results of the deformation were north-south trending synclines and anticlines, with flank dips usually less than 45°. Volcanism (which was generally absent over the Lambian Basins) did occur to the east towards the Tamworth - Yarrol Trough of the New England geosyncline. Granodiorite stocks were intruded in the Grampians Group, while batholiths (predominantly of granodiorite) intruded Tabberabberan structures in the Melbourne Trough.

After the end of the Kanimblan Orogeny in the Late Carboniferous, many post-kinematic granitoids (often referred to as "Kanimblan Granites") were emplaced in a north-northwesterly trending belt whose western boundary stretches between Wellington and Goulburn. This belt runs across several structural zones in the Lachlan orogen (being more similar in trend to structural elements in the New England orogen) and may be partially obscured by younger sediments of the Great Australian and Sydney Basins.

East and southeast of Mudgee there are extensive areas of acid volcanics (the Rylstone Tuff), which are intruded by the Kanimblan Granites with which they appear to be comagmatic. The volcanics, which are composed of rhyolitic and dacitic crystal and vitric tuffs, breccia, and lava flows, are similar in age and lithology to extensive acid volcanics in the Hunter Valley.

Within the granite belt, individual granitic bodies were emplaced under tensional or dilational conditions, and show a strong preference for zones of crustal weakness such as pre-existing fracture zones. For example, the Bathurst Granite and several other bodies appear to have been emplaced along crosscutting fracture zones, since they are elongate across the strike of the enclosing rocks.

It would seem likely that the Carboniferous volcanics of the Hunter Valley, the Rylstone Volcanics and the Carboniferous granites were directly or indirectly derived from melting along a north-northwesterly trending subduction zone, with its trench in the New England area and the western limit of activity below the Wellington - Goulburn line (Stevens 1974).

A large number of vein-type deposits of molybdenum, bismuth, tungsten and tin are spatially and genetically related to the Kanimblan granites, occurring either within or adjacent to the intrusives. Silver, lead, zinc and copper often occur with these deposits, while gold-quartz vein and magnetite-rich contact metasomatic deposits also occur.

In the Thomson orogen the pre-cratonic (orogenic) development of the fold belt had ended before the beginning of the Carboniferous. However, major deformation occurred in the Thomson orogen during the Carboniferous, and post-tectonic Late Carboniferous granites and associated continental calcalkaline volcanics were emplaced in the northeastern part of the orogen.

Late Devonian red-beds and similar continental sediments, widespread in the Thomson orogen, were most thickly developed in the Drummond Basin, where with interlayered sporadic volcanics they continued into the Early Carboniferous. The Burdekin Basin underwent fluctuating marine to continental conditions from Late Devonian to Early Carboniferous, and also contained volcanics. Similarly, red-bed sequences in the Adavale Basin may extend into Carboniferous time.

The mid-Carboniferous deformation was widespread in the Thomson orogen, and was of similar style and age to the Kanimblan Orogeny of the Lachlan geosyncline. In most areas, open folds and faults retained the predominantly northeast strike imposed by the mid-Ordovician orogeny, while the north-south orientation of structures in the Drummond Basin has been attributed to the influence of the north-northwest trending Anakie Inlier (Murray and Kirkegaard 1978). Variable trends within the Burdekin Basin were controlled by faults and basement topography. This mid-Carboniferous folding ended the transitional tectonic regime of the Thomson orogen, which has subsequently behaved as a stable cratonic region.

In the Hodgkinson - Broken River orogen the Carboniferous was a time of major deformation, as well as post-orogenic acid volcanism and plutonism.

In the Broken River Province the major deformation occurred at the end of the Early Carboniferous, and produced tight, southwest plunging folds in all units. This event produced a pervasive slaty cleavage of constant orientation, and strongly influenced the present structural trends and overall shape of the Broken River Province.

In the Hodgkinson Province, deformation (which began at the end of the Devonian and probably continued into the Carboniferous) resulted in four generations of folding with predominant north to northwest striking axes and steep axial planes. The major folding phase produced steeply plunging, tight to isoclinal folds and a strongly developed axial plane slaty cleavage, which locally transposed the bedding into a new lamination. Most faults dip steeply and parallel the north to northwest orientation of the axial plane cleavage. There is a progressive increase in the intensity of deformation from west to east, reaching low pressure - high temperature metamorphism of greenschist and amphibolite facies in the eastern areas.

In the Late Carboniferous and Early Permian post orogenic acid volcanism, plutonism and block faulting occurred in the fold belt. The volcanics are mainly ash flow tuffs and lavas preserved in cauldron subsidence depressions and ring complexes. Comagmatic plutonic rocks consist mainly of adamellite, with lesser granite and granodiorite.

The Chillagoe Mineral Field occurs about 230 km west of Cairns, on the western side of the Hodgkinson Province. In it skarn and vein type mineralisation occurs where lower Palaeozoic carbonate successions have been intruded by the Permo - Carboniferous Almaden Granite.

The Precambrian basement crops out in the western part of the district and consists of schists, gneisses, granulites, migmatites and amphibolites, which make up the Dargalong Metamorphics. These rocks are separated by the Palmerville Fault from the Silurian - Lower Devonian Chillagoe and Mt Garnet Formations to the east. The Chillagoe Formation consists of chert and fossiliferous limestone with subordinate greywacke, conglomerate and basic volcanics, while the Mt Garnet Formation (considered to be a time equivalent of the Chillagoe Formation) consists mainly of siltstone and greywacke. To the east both these formations are intruded by the Permo - Carboniferous Almaden Granite and are overlain by pyroclastics and welded tuffs of the Featherbed Volcanics.

In these deposits mineralisation occurs in the calcareous facies of the Chillagoe Formation within skarns at the contact of the granodiorite with marble (e.g. Shannon-Zillmanton), in extensive faults within marble and other sediments (e.g. Mungana and Hensey-Consols) and at the contact of basic volcanics with marble (e.g. Dorothy and Aruba).

At Shannon - Zillmanton skarn formation and introduction of mineralisation is thought to have occurred in three stages (Verwoerd and Harvey 1975). The skarns themselves were formed by contact metamorphism during the intrusion of the Almaden Granite into limestones of the Chillagoe Formation. This was followed by intrusion of granite porphyry stocks into the Almaden Granite and partial brecciation of the skarn. Finally the sulphide mineralisation was introduced via the granite porphyry stocks into the most intensely brecciated parts of the skarn.

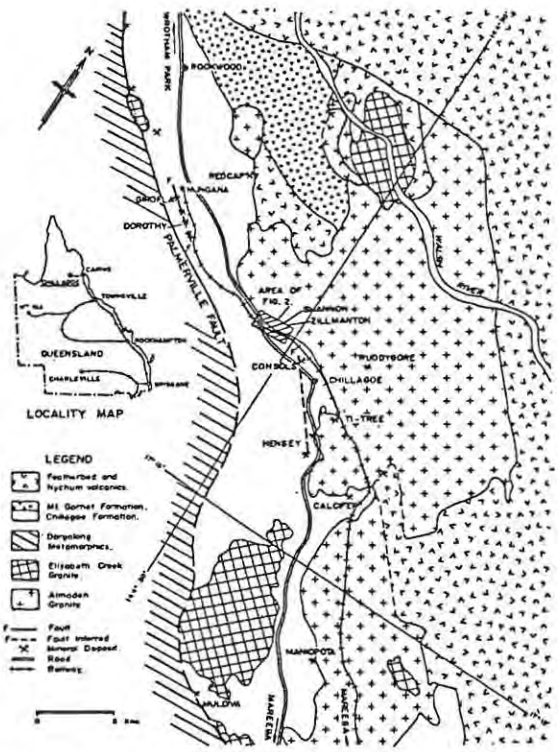

Fig. 2.62 Regional geology - Chillagoe District (from Verwoerd and Harvey 1975)

At Wolfram Camp, 50 km west-southwest of Cairns, wolframite - molybdenite - bismuth - quartz pipes occur in the Permo - Carboniferous Elizabeth Creek Granite within the Hodgkinson Province. This granite (actually a slightly deformed adamellite) has intruded the Devonian pelitic flysch-type sediments of the Hodgkinson Formation and the overlying Featherbed Volcanics. Plimer (1975) indicates a genetic association between the Elizabeth Creek Granite with the concomitant chemically similar Featherbed Volcanics, with a shallow depth of adamellite emplacement inferred by the presence of cauldron subsidence and ring dykes. Two episodes of hydrothermal deformation and alteration are indicated, with ore minerals forming at the earliest stage from a late, volatile-enriched aqueous phase within the granite.

At Mount Carbine, 36 km west-southwest from Port Douglas, wolframite and scheelite mineralisation occurs in a swarm of parallel, nearly vertical quartz reefs. The deposit occurs within the tightly folded Lower Palaeozoic Hodgkinson Formation (composed mainly of argillaceous sediments and minor basic volcanics) which has been intruded by bodies of the Carboniferous Mareeba Granite. The deposit occurs in the centre of a concentration of stress and pneumatolytic effects with the tungsten occurring along quartz veins which fill regular joints. The mineralisation is thought to have originated from the Mareeba Granite (Plumbridge 1975).

The Maureen Prospect occurs about 35 km north-northwest of Georgetown, and comprises uranium - fluorine and molybdenum mineralisation within the basal sedimentary portion of a Palaeozoic acid volcanic sequence. The mineralisation occurs as lenticular stratiform bodies, conformable within a conglomerate - sandstone - shale - siltstone sequence with some later remobilisation of ore. The deposit is spatially related to the Precambrian - Palaeozoic unconformity and is thought to be metasomatic, with the mineralisation perhaps ultimately originating from a non-outcropping intrusion of the Elizabeth Creek Granite (O'Rourke 1975). Several features of the mineralisation are typical of sedimentary uranium deposits, while some features typical of hydrothermal mineralisation include mineralisation crosscutting sedimentary structures and reconcentrated into faults and joints, and indication of replacement textures and bleaching effects.

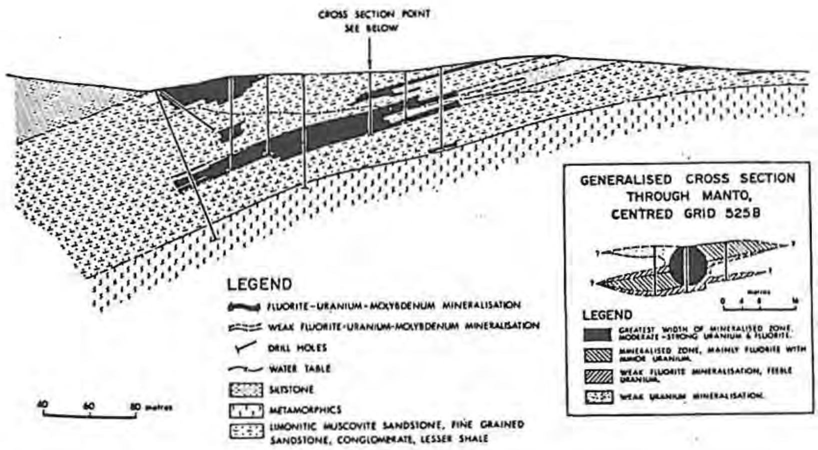

Fig. 2.63 Maureen Prospect - Long section through manto at 525 B (from O'Rourke 1975)

Tectonic events which deformed the Drummond Basin and Hodgkinson - Broken River orogen at the end of the Early Carboniferous caused changes to the Late Devonian to Early Carboniferous tectonic pattern in the New England orogen. Although these changes began in mid-Carboniferous time (and may be seen particularly in the Yarrol Province) no significant deformation occurred at this time in the New England orogen.

At the end of the Early Carboniferous, volcanism waned in the Connors - Auburn Volcanic Arc, suggesting a change in the pattern of subduction to the east. The emplacement of granitic batholiths in the Late Carboniferous may have coincided with uplift which restricted mid- and Late Carboniferous sedimentation on the Yarrol Shelf.

There was a marine regression from the Yarrol Shelf at the end of the Early Carboniferous. There is no record of Late Carboniferous sedimentation in the north part of the Yarrol Shelf, but Westphalian and Stephanian (Late Carboniferous) deposition did occur further to the south. These sediments contain detritus from acid and intermediate volcanics (though evidence for contemporary volcanism is lacking), granite-derived clasts, are more quartz-rich than Late Devonian to Early Carboniferous sediments, and lack ooliths.

The Wandilla Slope and Basin sequence has a quartz-rich upper part which appears to have been deposited (in mid-Carboniferous times) when the Yarrol Shelf was emergent, since there appear to be no sedimentary equivalents to it in the shelf sediments. In the Beenleigh Block the Wandilla Slope and Basin sequence includes conglomerates which contain granite boulders with a mid-Carboniferous age.

On the Tamworth Shelf, and to the west of it, calcalkaline volcanism continued throughout the Carboniferous, becoming more acid with time. Terrestrial conditions prevailed after the mid-Carboniferous regression, particularly in the north of the shelf. Mid- to Late Carboniferous shallow marine and fluvial deposits of the present Hastings Block are related to those of the southeastern end of the Tamworth Shelf.

Within the Woolomin Slope and Basin, flysch-type sedimentation appears to have continued conformably from the Silurian into the earliest Permian. An uplift in the latest Carboniferous to earliest Permian times in the western part of the Woolomin Slope and Basin resulted in the main area of sedimentation being moved to the east. Thus at this time extremely thick dimictite and conglomerate units were associated with flysch sediments on the Nambucca Slope and Basin. Late Carboniferous and Early Permian marine shelf sediments in southern Queensland and in the northeast of the Demon Block may be correlatives of the restricted deposition occurring on the Yarrol Shelf at this time. The relationship between these areas and the Tamworth Shelf is obscure.

Recent data suggests that the age of the main period of folding and metamorphism in the Wandilla Slope and Basin, Woolomin Slope and Basin, and possibly also the Nambucca Slope and Basin is latest Carbnoiferous to earliest Permian. In the Wandilla Slope and Basin, the earliest deformation produced mesoscopic isoclinal folds, with a generally steeply dipping axial planar cleavage which obscures recognition of original bedding and larger scale structures. Up to four phases of mesoscopic folding have been recognised and were accompanied by widespread metamorphism to lower greenschist facies. North of Brisbane (up to about 26° S latitude), metamorphic grades were higher, with rocks up to amphibolite and transitional blueschist facies occurring. Small syntectonic granodiorite plutons are associated with the amphibolite facies metamorphics. These plutons include the Hillgrove Suite, and they were associated with the highest grades of metamorphism. The emplacement of ultramafic rocks west of the Gympie Province, and the first movements of the Yarrol fault system, may have also occurred in Late Carboniferous time.

A large, north-south trending belt of anatectic granitic rocks (the "Bundarra Suite") was intruded into the western part of the Woolomin Slope and Basin (see fig. 2.64). These rocks have been radiometrically dated as latest Carboniferous or earliest Permian in age and their emplacement was associated with uplift resulting in the New England Arch, and was probably related to the development of the Peel fault system to the west.

The similarity of overall style of deformation and nature and distribution of metamorphic assemblages between the Woolomin, Nambucca and Wandilla Slopes and Basins suggest a similar orogenic history for each.

In contrast to these eastern flysch basins, there is little evidence for a latest Carboniferous deformation in the relatively stable shelf areas of the New England orogen. In the eastern, deeper water parts of the Yarrol Shelf, deposition was continuous from Late Carboniferous to Early Permian, while on the western edge of the shelf Permian sediments were laid down disconformably on Early Carboniferous rocks. Carboniferous and Permian sequences are conformable in most areas on the Tamworth Shelf with only localised disconformities, while a faunal break may represent a discontinuity in the Carboniferous and Permian sediments of the Demon Block.

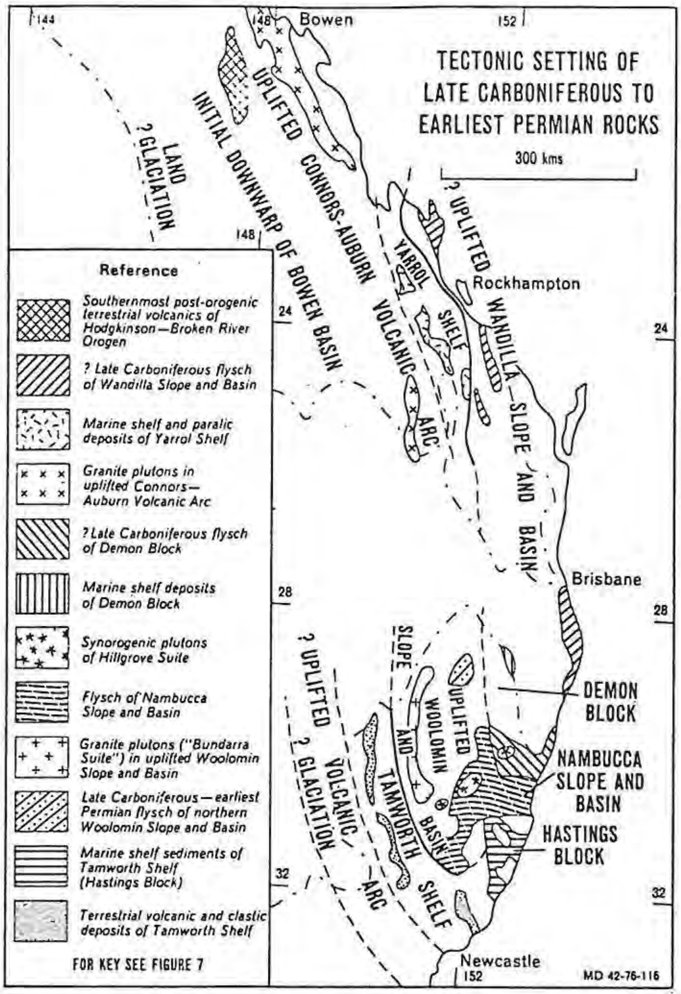

Fig. 2.64 Tectonic setting of Late Carboniferous to earliest Permian rocks, New England orogen (from Day et al 1978)

Minor alunite mineralisation, probably of sub-volcanic type, occurs in Late Carboniferous terrestrial acid volcanics near Bulahdelah in the far southern portion of the Tamworth Shelf. The alunite occurs as joint fillings, vein-lets and small disseminated bodies in hydrothermally altered rhyolite and trachyte.

The Permian

During the Permian, activity in the Tasman Geosyncline was concentrated in the New England orogen, the youngest and most easterly of the Tasman Geosyncline's subsidiary fold belts. West of the New England orogen earlier Tasman fold belts had become cratonised and their deformed geosynclinal sequences were being increasingly covered by sediments of predominantly terrestrial nature.

Major changes took place within the New England orogen (especially in the Yarrol Province to the north) leading up to the Hunter - Bowen Orogeny, the protracted tectonic event which cratonised most of the orogen. However, the Gympie Province (the most easterly in the geosyncline) escaped deformation in the Hunter - Bowen Orogeny and continued its development into Triassic time.

From mid-Permian to Early Triassic times syn-, late-, and post-kinematic granites were emplaced throughout the New England orogen, and gave rise to varied "granite type" mineralisation. Other types of mineralisation include subvolcanic hydrothermal type (as in the Drake mineral field), Captains Flat type stratabound massive sulphides in rift-controlled acid volcanics (e.g. Halls Peak) and varied minor mineralisation associated with westward-thrust ultramafic rocks (the most important of which is chrysotile asbestos, as at Woodsreef).

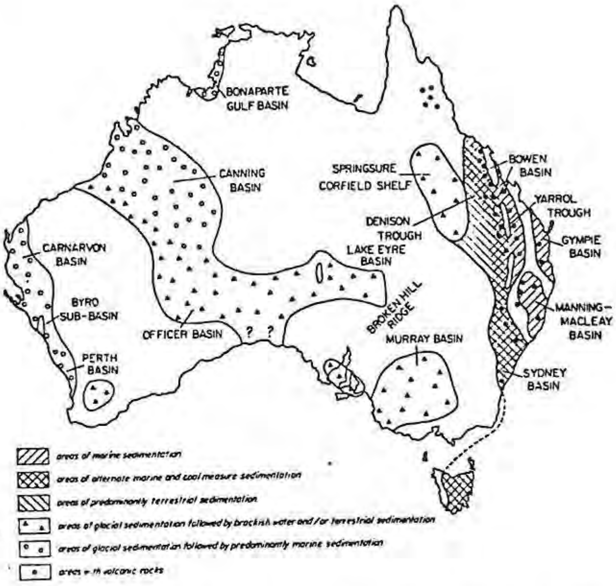

Fig. 2.65 Permian palaeogeography (from Brown et al 1968)

Climatically the Permain time in Australia was characterised by alternating periods of glaciation and warmer climatic conditions. Sakmarian tillites and varves indicate widespread glaciation for that time over the southern two-thirds of the continent, with the eastern areas less affected than the west. During the Artinskian the climate became generally warmer and the formation of coal-measures in eastern Australia indicates a sub-glacial or warmer climate. However, in late Artinskian and Kungurian times widespread glaciation is again indicated by abundant dropped boulders as far north as north Queensland, and by marine glacials and terrestrial varves and tillites. Warmer conditions returned in the Kazanian and Tatarian with extensive coal-measure conditions.

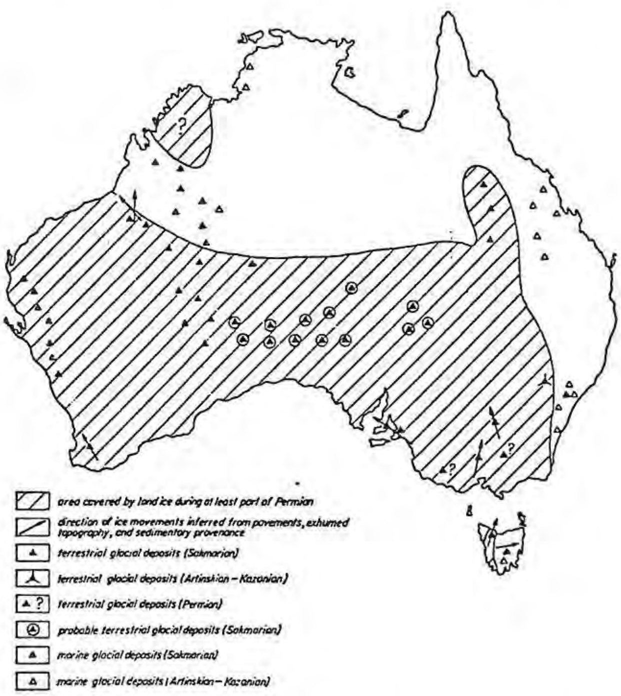

Fig. 2.66 Distribution of glacial deposits of Permian age in Australia. The area is considered to have been covered by ice during at least part of the period, and the inferred directions of ice movement, are also shown. (from Brown et al 1968)

Although Australian Permian faunas were of general "Gondwana type" (with characteristic bivalve, gastropod and brachiopod faunas), important faunal provinces and sub-provinces were present in eastern and western Australia. A striking feature is the complete absence in the Australian Permian of warm water fusulinid forams, compound rugose corals and some brachiopod types. The more or less indigenous fauna of eastern Australia included the solitary coral Euryphyllum, and distinctive species of brachiopod, bivalve, gastropod and polyzoan. Ammonoids were less abundant, many smaller forams were found throughout the continent, and insects were locally abundant in the Newcastle Coal Measures. Floral distribution was not differentiated, with the Glossopteris - Gangamopteris flora and the Striatites Microflora being widespread and ubiquitous.

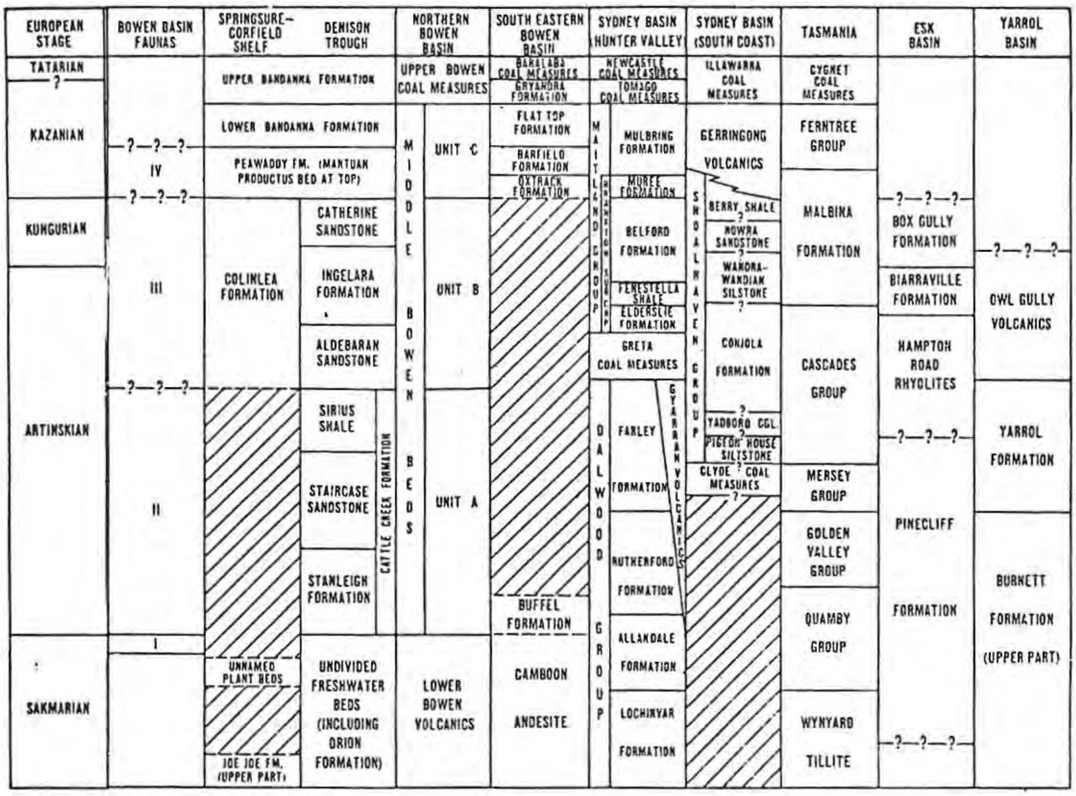

Fig. 2.67 Correlation Table for the Permian System in Australia (after Brown et al 1963)

In the New England orogen, major changes occurred in the Yarrol Province in the Early Permian. A calcalkaline volcanic chain, the Camboon Volcanic Arc.(called the Eungella-Gogango High by Brown et al 1968), developed largely on the site of the earlier Connors - Auburn Volcanic Arc. Although relatively short-lived, the Camboon Volcanic Arc was of major proportions (see fig. 2.68).

West of the Camboon Volcanic Arc, broad downwarping initiated marine and freshwater sedimentation in a large foreland basin, the Bowen Basin. To the east of the arc occurs the Grantleigh Trough, an elongate, deep depression that may have resulted from rifting, and was filled with flysch type sediments and spilitic basalts.

Calcalkaline volcanism and shallow marine sedimentation occurred extensively over much of the Yarrol Shelf and possibly parts of the deformed and uplifted Wandilla Slope and Basin to the east. The volcanics vary from andesitic and basaltic in the south to predominantly acid with subordinate andesite in the north.

The Permian succession in the Gympie Province is best known near Gympie, where it comprises basic to intermediate volcanics overlain by shallow water marine clastics with a prominent limestone horizon. Elsewhere the sequence, despite overall similarities, cannot be precisely correlated with that at Gympie. Outcropping to the west of the Permian succession are abyssal plain deposits (including spilitic pillow basalt, manganiferous radiolarian jasper and chert with thin shale interbeds, mudstone and minor arenite), which may represent basement to the shallow water clastics or fault slices of the older Wandilla Slope and Basin sequence.

Within the New England Province, changes were not so marked. On the Tamworth Shelf the pattern of Late Carboniferous sedimentation and volcanism continued unchanged into the Early Permian, with calcalkaline volcanism and freshwater and restricted marine sedimentation. To the west, the Sydney Basin occupied a position comparable to the Bowen Basin in the north (in fact attempts have been made to prove that they interconnect beneath the later cover). In the northern part of the Demon Block, sedimentation was probably continuous from Late Carboniferous to Early Permian time. Marine deposition also took place in the northern area of the uplifted Woolomin Slope and Basin. Sedimentation ceased in the Nambucca Slope and Basin in the Early Permian.

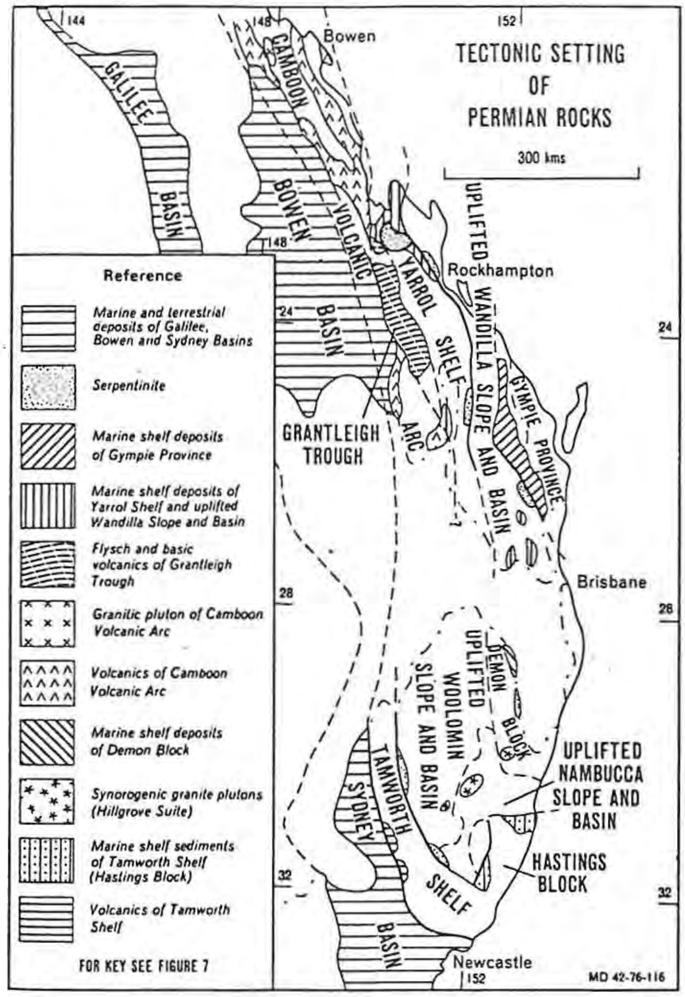

Fig. 2.68 Tectonic setting of Permian rocks, New England orogen (from Day et al 1978)

As mentioned above, recent information has put the earliest deformation of the Wandilla, Woolomin and Nambucca Slopes and Basins as old as latest Carboniferous to earliest Permian (Day et al 1978). Previously this deformation was considered to be of mid-Permian age, along with the other tectonic episodes that make up the Hunter - Bowen Orogeny. Folding in shelf areas like the Yarrol and Tamworth Shelves and the Demon Block was apparently of mid- to Late Permian age. Thus it would appear that the Hunter - Bowen Orogeny was essentially continuous from Permo-Carboniferous to mid- to Late Permian time, and that its effects were experienced earliest in the flysch sequences of the east, and latest in the shelf deposits of the west.

On the Yarrol Shelf deformation was characterised by open folding along north-northwest axes increasing in intensity to the east, and high-angle reverse and minor transcurrent faulting. In the Rockhampton area the folding was of Late Permian age, though it may have begun earlier in other areas. A large thrust sheet of ultramafic rocks (whose root zone lies to the east within an extension of the Yarrol Fault System) overlies the central part of the Yarrol Shelf and the Permian sediments of the Grantleigh Trough, and may have been emplaced at this time.

On the Tamworth Shelf the style of deformation is essentially similar to that of the Yarrol Shelf, with isoclinal folding and deformation increasing in intensity to the east. The folded sequence of the Tamworth Shelf is separated from the less deformed rocks of the Sydney Basin to the west by the Hunter - Mooki thrust system. This thrust system influenced sedimentation in the adjacent parts of the Sydney Basin and appears to have been active in Late Permian and Early Triassic time. Later movements occurred on the Goondiwindi Thrust (a northern continuation of the Hunter - Mooki thrust system) and are associated with deformation on the eastern part of the Bowen Basin.

Deformation of the Yarrol and Tamworth Shelves was probably accompanied by renewed thrusting and remobilisation of serpentinite along the Yarrol and Peel fault zones, which now separate these shelves from the Wandilla and Woolomin Slopes and Basins to the east.

To the west of these major fault systems the area of greatest deformation is the Gogango Overfolded Zone, which includes the deformed sediments of the Grantleigh Trough. In the mid- to Late Permian, rocks of this overfolded zone were thrust westwards, probably over the central section of the former Connors - Auburn and Camboon Volcanic Arcs. Tightly to isoclinally folded argillaceous sediments show either slaty or fracture cleavage dipping steeply to the east, indicating that the folds are overturned to the west. Small thrust faults are common, and local folding of the cleavage indicates a second less intense generation of deformation. Within the overfolded zone, deformation decreases to the west, where open, upright folds are present.

In the Gympie Province, although local disconformities do occur between Permian marine sediments and overlying Early Triassic strata, there is little definite indication of the mid- to Late Permian orogeny.

From mid-Permian to Early Triassic a number of syn-, late- and post-kinematic granites were emplaced throughout the New England orogen, being most prominently developed in the northern and central portions of the Woolomin - Texas Block. They include a generally older series of foliated, synkinematic intrusives of the Hillgrove Plutonic Suite and a younger group of late- and post-kinematic intrusives of the New England Batholith and Bundarra Plutonic Suite. These granites have given rise to a diverse suite of mineral deposits which constitute the most characteristic, widespread and economically most important mineralisation of the New England orogen. In some cases it is possible to classify individual intrusives into categories such as pre-batholithic, batholithic, acidic granite and post-kinematic, but due to insufficient geochemical and radiometric data, this is not possible for the region as a whole.

Granitoids of the Hillgrove Plutonic Suite are of wide distribution but are most prominently developed in the western part of the Nambucca Block. They appear to belong to both pre-batholithic and batholithic stages of orogenic granite intrusion. Within the Nambucca Block deposits spatially associated with Hillgrove-type intrusives are often fault or shear controlled and are typically enriched in gold, antimony, and tungsten with minor copper, lead, zinc and silver. In contrast, mineralisation associated with intrusives of the New England Batholith may contain tin and molybdenum in addition to the above. Despite their spatial association, the extent to which these Hillgrove-type intrusives are genetically responsible for mineralisation is not known.

Elsewhere, mineralisation associated with New England Batholith type intrusives comprises tin, tungsten, molybdenum, bismuth, gold, copper, lead, zinc, silver, arsenic and antimony. The majority of deposits of the Woolomin - Texas Block are of granitic hydrothermal type, and occur as veins, pipes, "bungs", stockworks and disseminations within both granitic intrusives and intruded sediments and acid volcanics. The major tin deposits of the Woolomin - Texas Block show a close spatial (and an assumed genetic) relationship to three "tin" granites of the region, the Ruby Creek Granite in the Wilsons Downfall area, the Mole Granite north of Emmaville, and an un-named granite at Tingha. A brief account of tin - tungsten and base-metal mineralisation in the Mole Granite is given.

The Emmaville - Torrington area is located in the Woolomin - Texas Block in New South Wales. It contains tin - tungsten and base-metal mineralisation associated with the epi-Permian Mole Granite, which has intruded older Permian sediments and rhyolitic volcanics. The granite hosts mineralisation which occurred in an unusually wide range of magmatic to hydrothermal conditions. A further point of interest is that base-metal sulphides and tin - tungsten ores developed contemporaneously in the late-magmatic stage but then formed two divergent hydrothermal systems, one lithophile and the other chalcophile.

Two differentiates of the granite developed in the late- to epi-magmatic phase. The first, a quartzose hydromagmatic differentiate, was intrusive into the granite and the sedimentary roof pendant centrally located within the granite. It was fluxed with fluorine, carried abundant wolframite, occasional molybdenite, and tungsten ore as irregular bunches or "bungs". The second differentiate formed complex pegmatites which, as irregular and pipe-like masses, were intrusive into granite and roof pendant. It contains chalcophile and lithophile minerals, with ore-grade wolframite, bismuth and cassiterite, and a variety of other minerals including base metal sulphides. Highly acidic conditions in this relatively high temperature phase of mineralisation are indicated by abundant topaz and fluorite.

The pegmatitic stage was succeeded by a high temperature hydrothermal stage which was characterised by fractionation of the lithophile and chalcophile components. The cassiterite mineralisation occupies an earlier set of fractures in the granite while the base metals occupy a later set in the sedimentary country rock around the granite. Two dominant trends of fracture systems occur in the Mole Granite - a northeast set (which hosts nearly all the cassiterite mineralisation) and a complimentary northwest set.

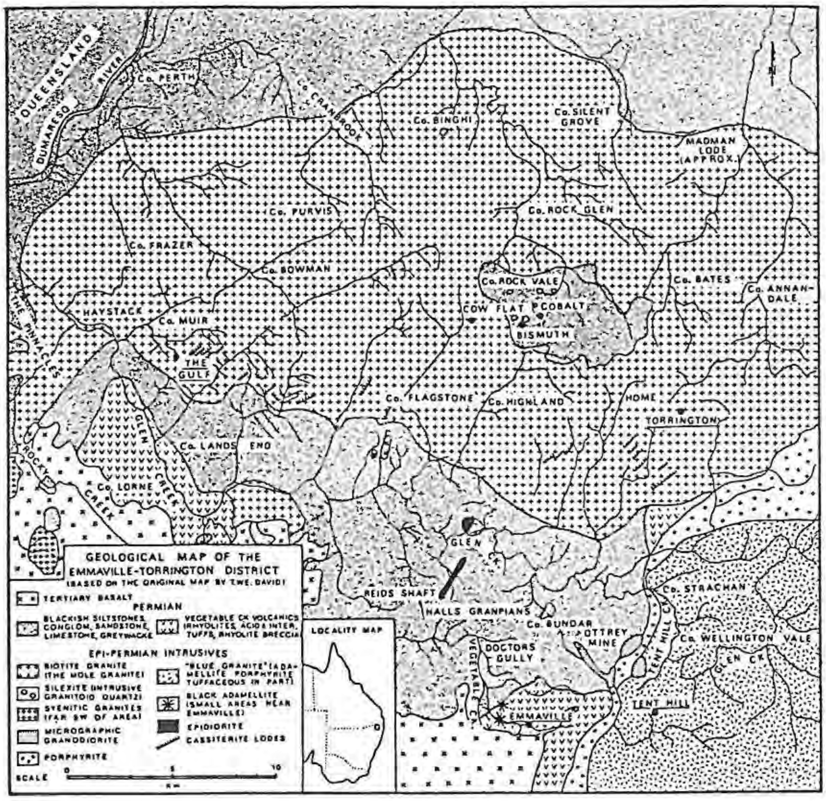

Fig. 2.69 Geological map of the Emmaville - Torrington District (from Lawrence 1975)

In the Drake mineral field, situated about 560 km north-northeast of Sydney in the northern part of the Demon Block, a large number of small gold and base-metal deposits are hosted in Permian acid to intermediate volcanics. They appear to be of characteristic subvolcanic hydrothermal type.

The regional geology around the Drake mineral field comprises shallow marine sediments and terrestrial acid to intermediate volcanics of Late Carboniferous to Late Permian age, that have been intruded by Upper Permian to Triassic acid and lesser basic rocks. The Drake Volcanics, of probable Middle to Upper Permian age, total about 1 000 m in thickness and consist of a lower and an upper sequence. The lower sequence (containing most of the gold and base metal mineralisation) consists of fine to coarse lapilli tuffs with lesser tuff breccia and trachyandesitic flows, while the upper sequence comprises andesitic and dacitic tuffs and flows. Most of these units are well stratified and consistent along strike, despite local rapid facies variations.

Most of the mineralisation is located within the earlier fragmental volcanic sequence and occurs mainly in fissure lodes, with stockwork and disseminated deposits being of lesser importance. Mineral associations include gold - copper - zinc, gold - silver, copper - zinc, silver - lead - zinc, gold - zinc or solely copper.

It is possible that siliceous mineralising fluids may have permeated the cooling volcanics at a late stage when contraction fissures were developing. Alternately, the fluids may have been introduced much later, perhaps from a granite source, and found favourable lithologies and structures for replacement and filling within the volcanics.

Stratabound pyritic zinc - lead mineralisation has been recorded from Halls Peak in the western portion of the Nambucca Block. The mineralisation occurs within a sequence of acid tuffs, pyroclastics and interbedded marine sediments, and appears to be of "Captains Flat type". The age of these volcanics and their relationship to the surrounding sediments of the western Nambucca Block are not precisely known, and although presently regarded as of Permian age they could be as old as Late Carboniferous. It would appear that these volcanics were extruded in a relatively long, narrow, fault-bounded block, probably similar in setting to the volcanic rift zones so well-developed in the Silurian in the eastern part of the Lachlan geosyncline.

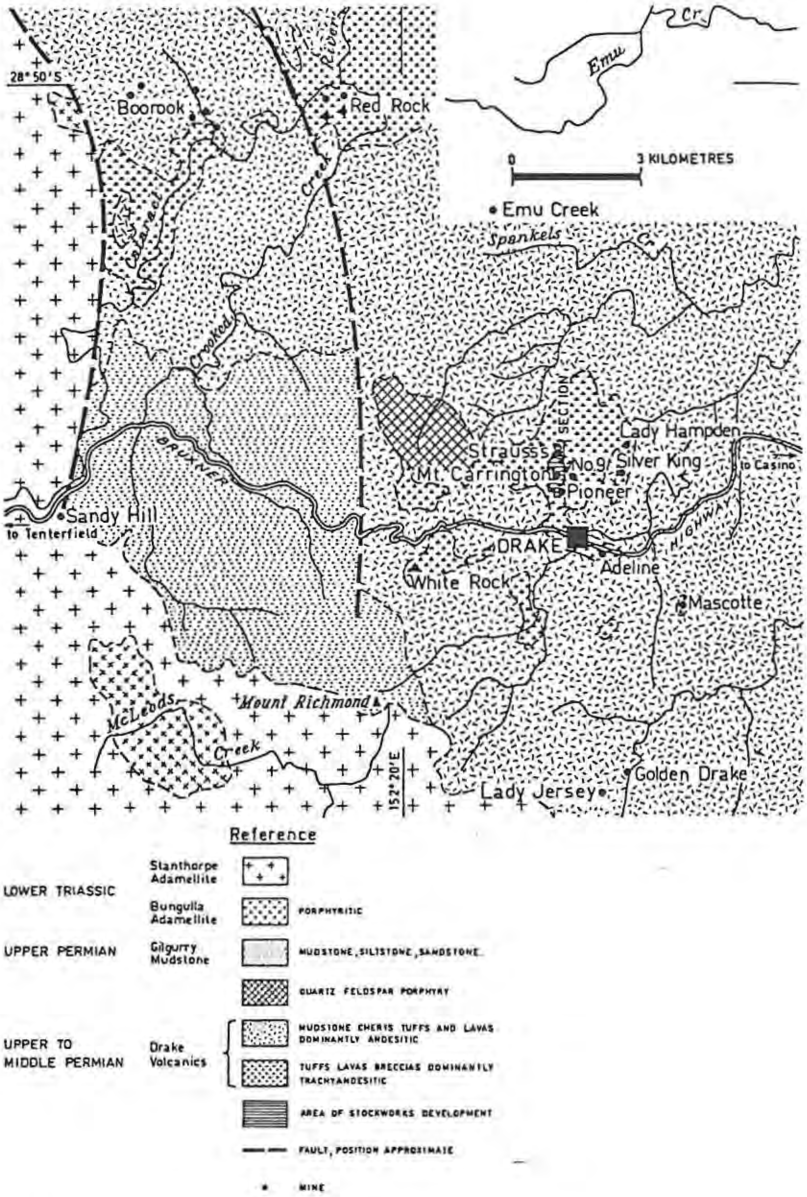

Fig. 2.70 Geological map of Drake Mineral field (from Offenberg and Cochrane 1975)

Varied but generally minor mineralisation is associated with the ultramafic and related igneous rocks that make up the Great Serpentinite and Gordonbrook Serpentinite Belts. These rocks have been tectonically emplaced along major crustal fractures, and may be regarded as upthrust fragments of oceanic lithosphere. The most important deposits have been those of asbestos at Woodsreef and Baryulgil. Of the mineralisation occurring within or adjacent to the serpentinite, chromite appears to be a magmatic crystallisation product of the parent ultramafic, while the asbestos, talc, copper - nickel, magnesite, opal and nephrite deposits represent either the products of serpentinisation or of late-stage alteration by silica or carbonate-bearing solutions. Numerous gold and mercury deposits occur adjacent to the serpentinite belts but appear unlikely to have a genetic relationship with them.

The Triassic

The orogenic evolution of the Tasman Geosyncline was concluded in the Triassic, with deformation in the Gympie Province and the eastern parts of the New England and Yarrol Provinces of the New England orogen. Granite plutonism and comagmatic acid volcanism continued from the Permian, but have been described in the previous section, along with their associated mineralisation. No other mineral deposits of importance are associated with the Triassic rocks of the Tasman Geosyncline.

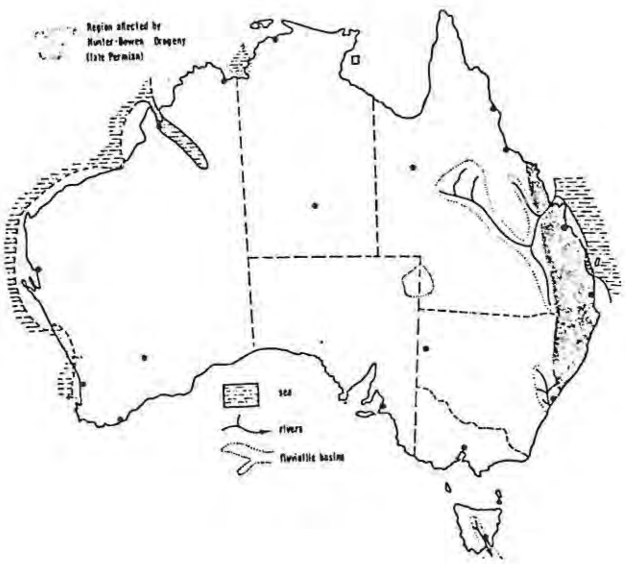

Fig. 2.71 Early Triassic palaeogeography (from Brown et al 1968)

Despite the high palaeolatitude of Australia during the Triassic (when Tasmania, for example, extended as far south as 75° S), neither the flora and fauna nor the sediments show evidence of cold conditions. The accumulation of continental red-beds in eastern Australia are suggestive of warm climatic conditions.

In place of the Permian Glossopteris flora, the Triassic flora is dominated by Dicroidium, with major changes also occurring in the microflora. Marine sequences were of very limited extent in the Australian Triassic, but contain invertebrate fossils such as ammonites and bivalves. Labyrinthodont amphibians, freshwater fish and insects are also found in the Triassic fossil record.

In the New England orogen, the Permian to Early Triassic sequence of the Gympie Province was folded shortly after deposition. The youngest rocks, furthest to the east, were strongly deformed, metamorphosed to greenschist facies, and the fine grained sediments developed a dominant slaty cleavage.

During the Triassic, the eastern part of the Yarrol Province (and probably also the New England Province) was extensively affected by normal faulting, with volcanic fault troughs or rift zones developing from Rockhampton to at least as far south as Brisbane. Thick sequences of intermediate to acid terrestrial volcanics and volcaniclastic sediments accumulated in these troughs. During this time continental sediments were accumulating at the southwestern margin of the Moreton - Clarence Basin and in the Lorne Basin. Minor granitic intrusives of Middle and Late Triassic age (some of which are comagmatic with the volcanics) occur largely to the east of the troughs. The trough sediments were moderately to severely folded parallel to the trough margins during the Triassic. In the Esk Trough overturning of strata to the west occurred in folds associated with major faults along the trough axis.

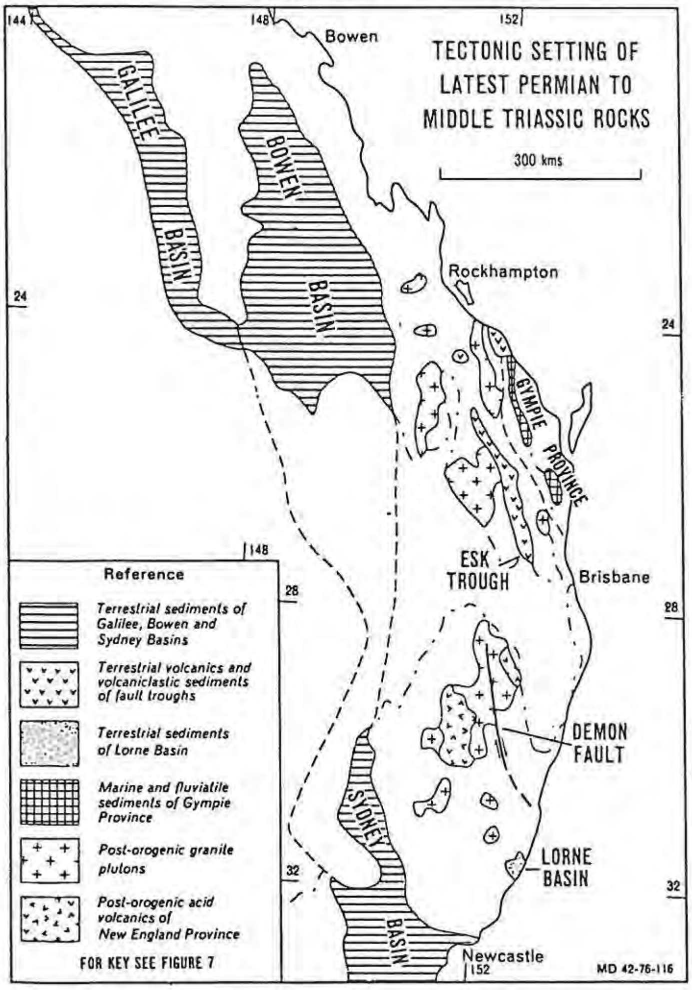

Fig. 2.72 Tectonic setting of latest Permian to Middle Triassic rocks, New England orogen (from Day et al 1978)

The Demon Fault is a major dextral strike fault in the northeast of the New England Province. It defines the western margin of the Demon Block and was probably active at this time, with an indicated minimum displacement of 20 km.

Deformation of the Triassic trough sequences marked the end of the transitional tectonic regime of the New England orogen, and completed the development of the present structural blocks. During the remainder of the Mesozoic, the area received continental sediments and rare volcanics which filled comparatively shallow downwarps. With the exception of the Late Triassic to Early Cretaceous sediments of the Maryborough Basin (see fig. 2.73), which were folded during the Cretaceous, these sequences have remained virtually undeformed, apart from normal faulting.

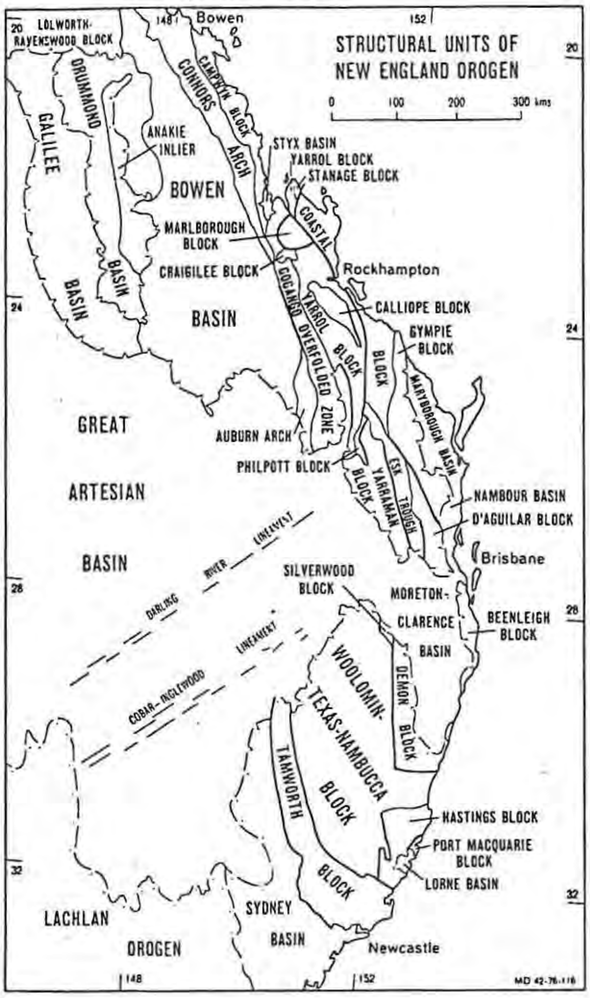

Fig. 2.73 Present structural units of the New England orogen (from Day et al 1978)

Tasman Metallogeny

In this section a more detailed examination is made of ore deposits within the Tasman Geosyncline, with a view to pinpointing smaller scale controls on ore deposition. Due to space considerations it was decided to select one example (usually the best known example) of each of the major categories of mineral deposits within the Geosyncline, and these are treated in age order, from older to younger.

Cyprus-type (or Besshi-type) cupreous pyrite deposits were characteristically developed in many of the Tasman Geosyncline's subsiding, faulted troughs, where flysch-type sedimentation sometimes alternated with minor basaltic volcanism. The numerous examples include the Girrilambone and Tottenham deposits of the Lachlan fold belt, as well as many such occurrences within the Woolomin Slope and Basin of the New England orogen. The Kanmantoo Copper deposit of South Australia has been described. It occurs in the Cambrian Kanmantoo fold belt and provides an interesting example of the type, showing the effects of later metamorphism and remobilisation of ore into structural and lithological traps.

Volcanogenic massive base metal sulphide deposits are well represented in the Tasman Geosyncline, and are especially abundant in the Cambrian Mt Read Volcanics of Tasmania and in rift-controlled Silurian acid volcanic sequences within the Lachlan orogen of New South Wales. Although the Captains Flat and Woodlawn deposits of New South Wales are very well known, they are overshadowed in importance by the deposits of the Mt Read Volcanics, which include some of the largest orebodies of this type in the world. Although the Mt Lyell deposits are the largest within the Mt Read Volcanics, they are predominantly of disseminated nature, and may represent incomplete development of exhalative massive sulphides (perhaps in a predominantly subaerial setting), or alternatively the overlying, more massive types of mineralisation may have been removed by later erosion. For this reason Rosebery has been selected from the Tasmanian deposits as it constitutes a large, well-preserved, stratabound exhalative massive sulphide deposit.

Vein-type gold mineralisation in Victoria (typified by the Ballarat and Bendigo gold fields) has in the past been presumed to be associated with the emplacement of Devonian granitoids. However, more recently opinions have begun to favour the Lower Palaeozoic geosynclinal sediments as the source of the gold in many cases, with remobilisation into concordant and discordant veins occurring during later deformation. A further category of gold veins are related to basic and intermediate intrusives. The vein gold deposits of Victoria are briefly discussed below, as they are of major economic importance and appear to be quite distinct from the granite-derived mineralisation which is generally widespread within the Geosyncline.

The Silurian Cobar deposits of the Lachlan orogen of New South Wales comprise copper (and other) sulphide mineralisation within a sedimentary sequence which appears to have a volcaniclastic component. In this respect, and in that they represent copper deposition on a horizon marking a transition from a high energy to a lower energy environment, the Cobar deposits show similarities to some African sedimentary copper deposits (although the Cobar deposits have been extensively reconstituted by later deformation). This type of deposit does not appear to be well represented in the Tasman Geosyncline as a whole, and for this reason, together with their undoubted economic importance, they merit a detailed description in this section.

Gold, silver and base metal mineralisation associated with Devonian to Permian granite intrusions is particularly widespread in the Tasman Geosyncline, although individual deposits are for the most part of minor importance. A marked exception to this rule are the tin - tungsten deposits of Tasmania, which are genetically associated with Devonian granitoids, and include some of the largest primary tin deposits in the world. In this section the four subdivisions of Solomon (1981) of Tasmanian tin/tungsten deposits (briefly mentioned in Section 2) are elaborated on, and the mineralisation at Renison Bell, Tasmania's largest primary tin deposit, is described.

The <u>Kanmantoo Copper deposit</u> occurs within the Brukunga Formation of the Kanmantoo Trough in South Australia (see fig. 3.1). It comprises syngenetic, stratiform sulphides, which were deposited in argillaceous and arenaceous sediments and were later metamorphosed. Later deformation in the Cambro-Ordovician Delamerian Orogeny has remobilised sulphides into structural and lithological traps. The regional geological setting of the deposit is described in the previous section.

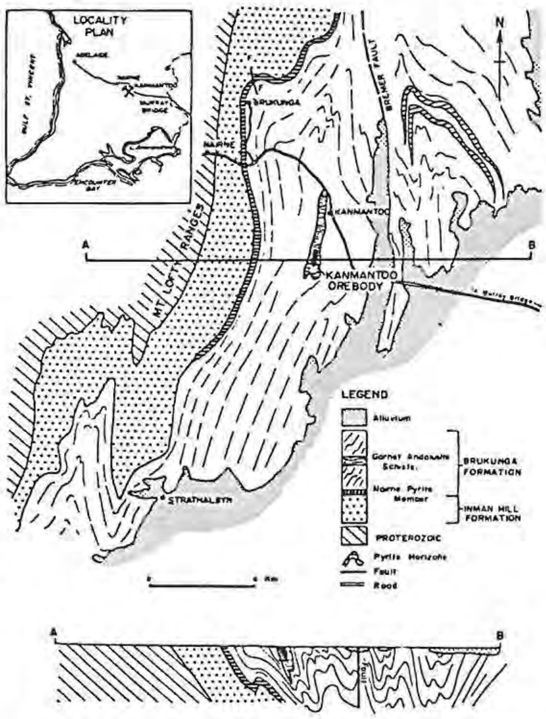

Fig. 3.1 Regional geology of the Kanmantoo district (modified from Thompson and Horwitz, 1972) (from Verwoerd and Cleghorn 1975)

Three main rock types occur in the mine area, namely garnet - andalusite schists, quartz - felspar schists, and quartz - mica schists.

The garnet - andalusite schists contain large porphyroblastic andalusite crystals, set in a schistose matrix of biotite, quartz, garnet and chlorite. Common accessory minerals include staurolite and muscovite. Although metamorphism appears to have obscured many original sedimentary features, the lithological banding present is thought to represent original bedding (Verwoerd and Cleghorn 1975).

The quartz - felspar schists are composed of quartz, felspar and minor biotite, and contain a weak schistosity caused by the alignment of the biotite flakes. Many original sedimentary features are present, for example, bedding, ripple marks and cut and fill compound structures.

The quartz - mica schists are grey and fine grained, and contain biotite, quartz, muscovite, felspar and chlorite. Accessory andalusite and almandine are concentrated into distinct bands, especially near the contact of the garnet - andalusite schists. Cross-bedding is locally developed.

During the Delamerian Orogeny the garnet - andalusite schists (and less obviously the other lithologies) were folded into a series of tight anticlines and synclines, plunging from 10° to 60° to the south. The associated axial-plane schistosity dips to the east at about 75°. No major faulting is apparent in the vicinity of the mine, but later less important deformation has caused mineral banding parallel to the schistosity, crenulations, kinking of schistosity planes and pervasive jointing.

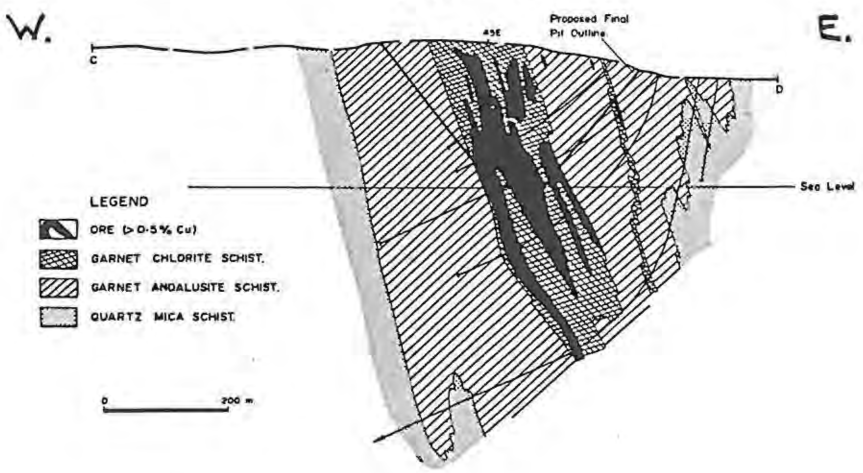

Fig. 3.2 East-west cross section of Kanmantoo Copper deposit (after Verwoerd and Cleghorn 1975)

The ore body consists of several lenses of mineralisation, flattened parallel to the axial-plane schistosity, striking at 010°, dipping 75° E and plunging 80° to the north. The maximum horizontal dimensions of the orebody are 120 m by 180 m, while the vertical extent is at least 450 m.

Within individual ore lenses, the mineralisation occurs mostly as veinlets parallel to the axial-plane schistosity, but also as veinlets cross-cutting bedding and foliation, as massive pockets and bands, and as fine grained disseminations parallelling the bedding. The ore contains approximately equal proportions of chalcopyrite, pyrrhotite and magnetite. The chalcopyrite is commonly intergrown with pyrrhotite and contains minor inclusions of cubanite and sphalerite. Other accessory minerals include pentlandite, cobaltite, bismuth, bismuthinite, galena, pyrite, molybdenite, wolframite, gold and silver. Alteration accompanies mineralisation and has affected the garnet - andalusite schist, with chloritisation of biotite and garnet, increase of stanrolite and garnet contents, and decrease of andalusite content towards the mineralisation.

A likely sequence of events in the formation of the Kanmantoo Copper deposit is suggested by Verwoerd and Cleghorn (1975). In this sequence, sulphides were deposited syngenetically in Cambrian argillaceous sediments (now andalusite schists) or arenaceous sediments (now quartz - mica or quartz - felspar schists). These sulphides, in particular the more ductile chalcopyrite, were remobilised in the Delamerian Orogeny into favourable structural or stratigraphic sites within the folded and schistose argillaceous sediments. Further minor remobilisation and metamorphic crystal growth occurred during ensuing tectonic events.

The regional geological setting of the massive sulphide deposits of the Mt Read Volcanics of Tasmania has been outlined in the previous section. There follows a brief description of the Rosebery ore deposit.

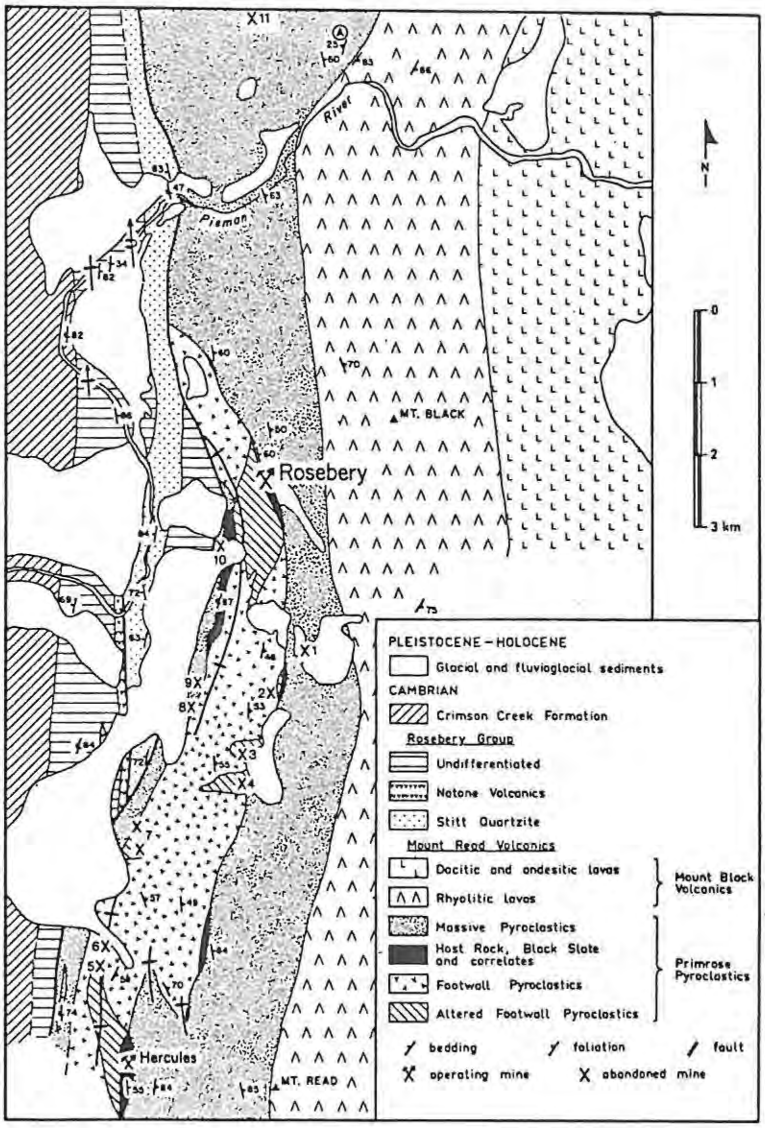

Fig. 3.3 Geologic map of the Rosebery area. Abandoned mines: 1. Dalmeny, 2. Rosebery Lodes, 3. Koonya, 4. Grand Centre, 5. King P.A., 6. Williamsford, 7. Jupiter, 8. Chamberlain, 9. Salisbury, 10. Black P.A., 11. Chester. (from Green et al 1981)

Fig. 3.3 is a geologic map of the Rosebery area, and shows the distribution of the various sulphide deposits occurring between the Rosebery and Hercules mines. In this area the Mt Read Volcanics are represented by the Primrose Pyroclastics (containing the mine sequence) and the overlying Mt Black Volcanics. This sequence is faulted against a volcanic/sedimentary succession to the west, the Rosebery Group.

The "mine sequence" at Rosebery comprises, from base, the footwall pyroclastics (exceeding 1 000 m in thickness), the host rock (up to 35 m) overlain by a black slate (up to 30 m thick), followed by massive pyroclastics (about 400 m thick). These lithologies will be briefly described.

The footwall pyroclastics form a uniform assemblage of vitric-crystal lapilli tuffs, which occur as a north-south orientated zone, 11 km in length, open to the south, and truncated to the north by faulting. They consist of felspar phenocrysts set in a fine grained groundmass of quartz, albite and K-felspar. Sericite, which is almost ubiquitous, increases in abundance towards the mineralisation, where the rock grades into quartz - sericite schist (these zones are interpreted as areas of hydrothermal alteration associated with massive sulphide mineralisation). Green et al (1981) have interpreted the footwall pyroclastics as resulting from hot ash flows in a subaerial environment.

The host rock at Rosebery consists predominantly of pale grey siltstone and slate, with lenses of quartz - albite crystal tuff and lithic tuff. Bedding has usually been obliterated by the development of a strong axial surface slaty cleavage. The siltstones are composed of quartz, sericite and chlorite, with minor pyrite, carbonate and plagioclase. The host rock can be traced intermittently south of the mine to Hercules mine, varying in proportions of siltstone, shale, tuff, and reworked tuff.

The host rock is overlain, with a sharp contact, by a finely banded pyritic black slate. A single graded bed of sandstone, up to 1 m thick, occurs near the top of the black slate. This bed appears to be a marine turbidite deposit composed of angular rock fragments derived from the nearby Tyennan geanticline to the east.

In contrast to the footwall pyroclastics, the massive pyroclastics overlying the black slate are diverse in nature, both along and across strike. In this area the massive pyroclastics comprise two main facies. The lower facies is about 450 m thick and is composed of aphyric rhyolite breccia, quartz - felspar crystal tuff, and banded fine grained crystal tuff. The breccia contains fragments of black shale, chert, quartz porphyry and probable footwall welded tuff, up to 30 cm diameter. There are a few lenses of siltstone and shale, one of which contains minor massive sulphides (the Dalmeny mine). Breccias and crystal tuffs may contain rafts of black shale up to several metres long. These shale rafts, along with other angular shale fragments and occasional size grading in pyroclastic debris suggest that the unit was deposited by submarine density flows or slides. The upper facies of massive pyroclastics is about 120 m thick and is composed of green pumice tuff and agglomerate.

A dramatic subsidence is indicated in the Rosebery area by the transition from a thick sequence of (probable) terrestrial ash-flow tuffs to a much thinner sequence of marine sediments and sulphides. The massive pyroclastics above the ore zone contain undoubted submarine flows up to 700 m thick - thus if the footwall pyroclastics were entirely of subaerial setting, subsidence exceeding 1 700 m prior to deposition of the host rock may be indicated (Green et al 1981). The black slate immediately overlying the orebody has a limited distribution, roughly equal to that of the orebody, implying the presence of a local topographic low within a marine basin at that time.

The ore at Rosebery occurs as more or less tabular sheets dipping 45°E, striking north-south for about 1 500 m, and extending to at least 800 m below surface. In the southern zone a lower horizon of massive sulphide ore is separated from an upper series of massive barite - sulphide lenses by weakly mineralised sericitic schist. In longitudinal section, an area of barren host rock divides the orebody into a northern and a southern zone. The lower massive sulphide horizon is generally continuous in the central part of the mine, but to the north and south tends to split into a number of lenses separated by carbonate- or sericite-rich host rock. The A and B lenses comprise the northern section of the orebody, while the southern zone consists, from north to south, of C, D, E and F lenses, with G lens representing a major parasitic fold (see fig. 3.5). H lens is the upper barite-rich ore horizon.

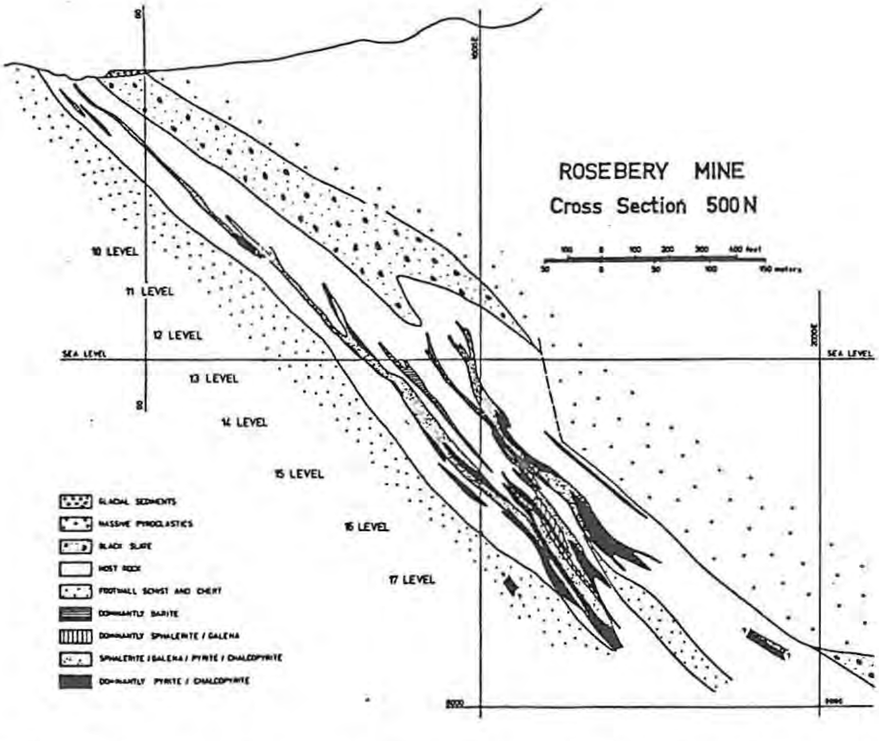

Fig. 3.4 East-west cross section of the Rosebery ore zone at 500N. Note that mine coordinates, drill hole footages, and altitude are all in feet. The altitude zero = 10,000 ft for altitudes below zero. Drawn from mine plans prepared by mine staff. (from Green et al 1981)

The complex ore distribution is partly the result of Tabberabberan (Devonian) deformation, when the more ductile sulphide ores suffered greater deformation than the more competent surrounding rocks, and partly due to synsedimentary slumping. A major anticlinal parasitic fold within the orebody (see fig. 3.4) pitches north in the plane of the ore zone at between 65° and 80°. It is the most important structural element in the mine, and has been interpreted as resulting from synsedimentary gravitational slumping.

The sulphide ore consists mainly of pyrite, sphalerite, galena and chalcopyrite, with lesser tetrahedrite, tennantite, arsenopyrite, magnetite, electrum and gold. Most of the ore shows fine compositional banding (typical of exhalative deposits), conformable both within the ore zone and within the enclosing rocks. Small scale folding is common and may be of synsedimentary origin. Subsequent deformation has caused differential recrystallisation of the ore.

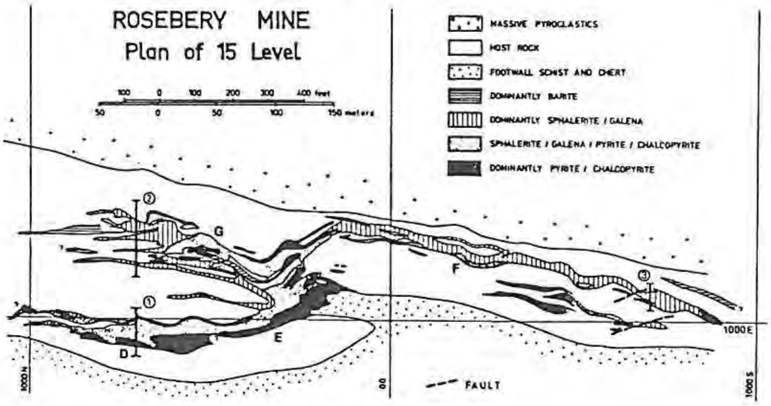

Fig. 3.5 Geologic plan, 15 level, Rosebery mine, showing lenses and locations of the three sampled sections (projected). Letters refer to ore lenses. (from Green et al 1981)

Overall, the Rosebery ore lenses show metal zoning typical of volcanogenic massive sulphide deposits, with pyrite - chalcopyrite enrichment in a lower and central zone, surrounded and overlain by zinc - lead - silver-rich ore (see fig. 3.6). Barite - sulphide ore occurs as separate lenses higher in the sequence, separated from the sulphide orebody by barren, cleaved siltstone. The orebody is underlain by an extensive alteration zone which is marked by a depletion of sodium and strontium, and an enrichment in rubidium, potassium, magnesium and manganese. A feeder zone is inferred beneath the central, copper and iron rich part of the ore zone, where pyrite and chalcopyrite contents in the altered footwall tuff and cobalt content of the pyrite reach a peak.

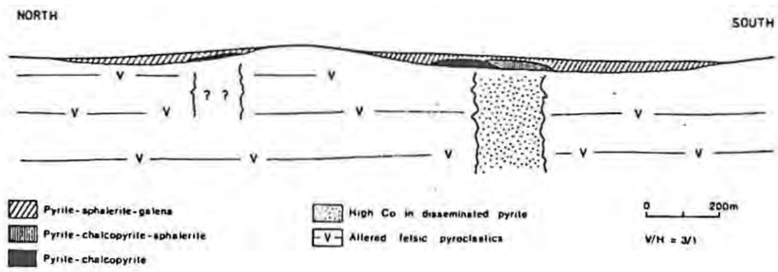

Fig. 3.6 Reconstruction of the Rosebery massive sulfide orebody prior to the deposition of the H lens, based on the data of Figures 9 to 13. (from Green et al 1981)

Victoria is well established as an area of gold mining, with a total of 2,4 million kg of gold having been produced up to 1972 (Bowen and Whiting 1975). Initial gold mining interest in the 1850's was focused on the shallow alluvial deposits, which were soon worked out and were followed by development on the "deep leads". The deep leads are buried placer deposits occurring in the lower reaches of former drainage courses. Neither of these two types of secondary deposits, shallow alluvials or deep leads, will be considered further here.

Most of the primary gold deposits of Victoria occur as quartz veins, with less important disseminated deposits. The regional setting of these deposits and their likely mode of origin are dealt with briefly in the previous section (see also fig. 2.21).

The primary gold deposits of Victoria occur mainly as quartz veins or "reefs" in sediments of Cambrian to Lower Devonian age, and in igneous rocks intruding these sediments in the Ballarat and Melbourne Troughs of the Lachlan Geosyncline. The vein deposits are highly variable in geometry and up to a point each gold field is characterised by a particular reef shape. The structure developed probably relates to the degree of deformation and the relative amounts of different lithologies present in the sequence.

Veins developed in igneous rocks are of major importance and are characteristically developed in the Walhalla - Woods Point area, where they are associated with intermediate to basic dykes. The reefs usually occur either along or subparallel to the dyke walls (as in the Long Tunnel mine near Walhalla) or in shears or fractures cutting across dyke bulges (as in the Morning Star, A.I. and Loch Fyne mines). Cohen's reef, Walhalla was one of the two most important ore shoots in Victoria and was largely associated with a diorite dyke up to 2 m in width, although there also appears to have been an association with a belt of slates (Bowen and Whiting 1975).

In the larger dykes the reefs occur along generally flat dipping reverse faults, which probably represent the conjugate shear directions resulting from lateral compression of the dykes. In the Morning Star Mine most reefs dip east, while in the A.I. mine the reefs form a zig zag pattern down to a point of union of two dykes, below which the reefs are generally east dipping.

Most dyke-associated reefs are known for their relatively high grade. The mines of this belt have produced some 3 million tonnes grading 30 gm per tonne.

Vein deposits in sedimentary rocks are the most important and well known category of gold mineralisation.

They are usually associated with faults and may be broadly divided according to whether they are concordant or discordant with the enclosing sediments.

The most important concordant veins are the saddle reefs (probably best known at Bendigo) which occur where two strike faults intersect at the crest of an anticline. Usually one of the faults is more strongly developed than the other, and the quartz reef extends up this fault plane forming a "neck" where the fault cuts the bedding above the crest of the anticline (see fig. 3.7). The faults may displace the crest of the anticline, usually by about a metre, but occasionally by up to 30 m. In the former case the fault would not extend down into the adjacent syncline, though it may do in the latter instance. Small spurs or veins may taper from the neck and flanks of the saddle reef into the underlying sediments.

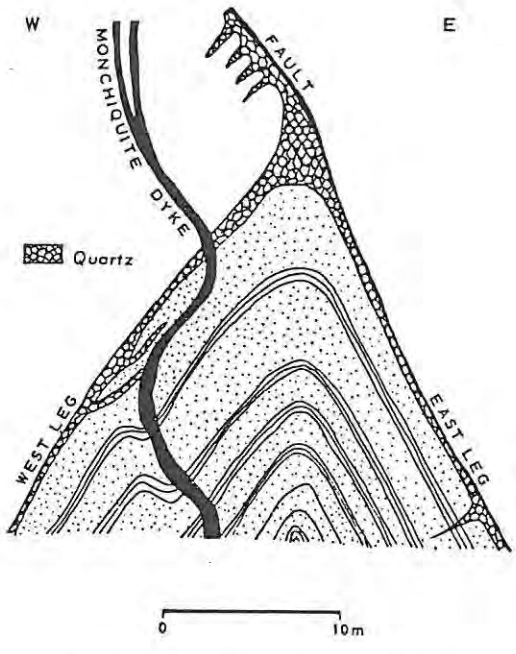

Fig. 3.7 Cross section, looking north, of a saddle reef on the Sheepshead anticline, Bendigo. (from Bowen and Whiting 1975)

The saddle reefs at Bendigo occur in 13 adjacent, parallel anticlines, in a tightly folded sequence of Lower

Ordovician slates and greywackes, along strike for 19 km and across strike for 4 km. However, only three saddle reefs were extensively mined. The deepest mine on the Bendigo goldfield was the Victoria Quartz mine, where saddle reefs recurred at irregular intervals to depths of over 1 400 m. In the Great Extended Hustlers mine 24 reefs were intersected on one anticline over a depth of over 600 m. Within these quartz reefs gold occurs in definite shoots, though no obvious structural control of the ore shoots has been established (Thomas 1953 b).

On the Ballarat West gold field concordant gold reefs are confined to a horizon 20 to 30 m thick, containing several zones of black slate which may be traced across three anticlines (see fig. 3.8). Within these slate horizons laminated quartz reefs with graphic inclusions occur along planes of slippage. Although the quartz reefs occur on either limbs of the anticlines, the ore shoots were restricted to the west dipping limbs.

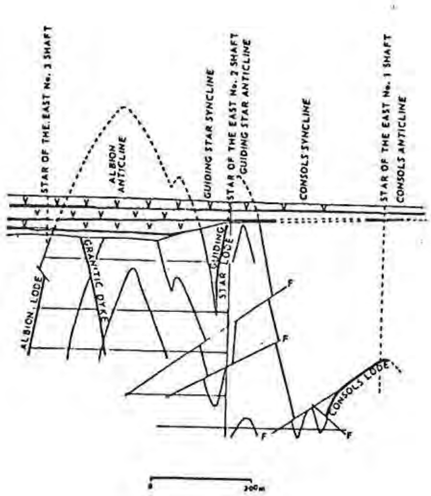

Fig. 3.8 Cross section through the Star of the East Mine, Ballarat West (from Bowen and Whiting 1975)

One of the commonest types of discordant vein development is along reverse faults which approximately parallel the strike of the sediments. These faults are usually steeply dipping and parallel to the bedding, but where they cross the anticlinal axis the dip flattens and they cut across the bedding towards the next synclinal axis.

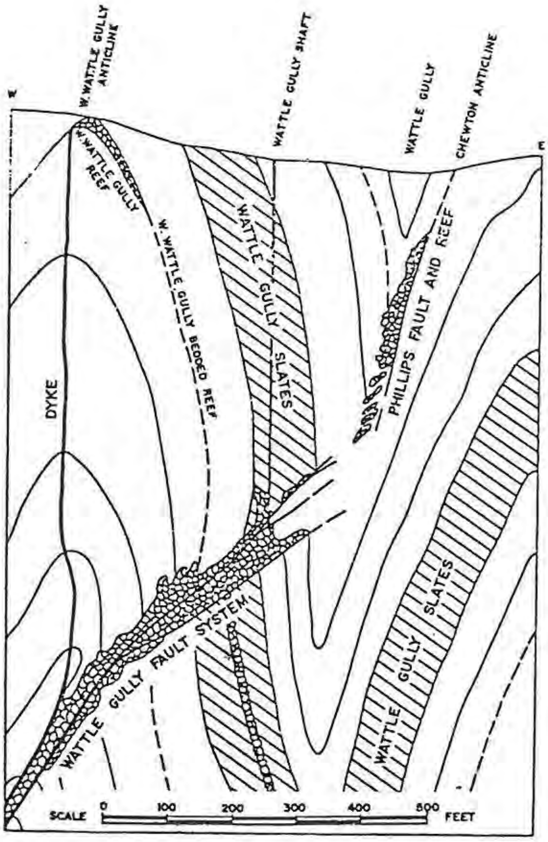

Fig. 3.9 Cross section, looking north, through Wattle Gully mine, Chewton (from McAndrew 1965)

The main ore development is in the flatter cross-cutting section, where there is frequently extensive development of spurs or tapering veins parallel to the tension gash direction. Reefs of this sort have been worked at the Wattle Gully mine (Chewton), Daylesford, and Ballarat East. At Ballarat East faults with associated reefs and spurs occur repeatedly at depth intervals of 80 to 100 m. Although both east and west dipping faults may be present, often the west dipping set is better developed and more extensive mineralisation occurs where the west dipping faults intersect east dipping beds, or (in the case of Wattle Gully), intersects overturned beds on the east limb of an anticline.

On the Ballarat East gold field the reefs frequently contained localised enrichment in very coarse gold where they intersected thin laminated quartz veins or thin beds of pyritic or carbonaceous slate locally known as "indicators".

The regional geological setting of the Cobar mineralisation has been described in section 2, with Fig. 2.35 showing the regional geology and distribution of the mines in the vicinity of Cobar. A more detailed examination of the nature of the geology and mineralisation at Cobar follows.

The Silurian Cobar Group consists of three conformable formations, which comprise, from the base, the Chesney Greywacke, the Great Cobar Slate, and the C.S.A. Siltstone. Fossils occur, but none are diagnostic, while facies changes along strike are common, and indicate the probable diachronous nature of the formation boundaries. As might be expected, sedimentary features are well preserved with the lower greenschist facies metamorphism, though some disruption occurs in areas of shearing.

The Chesney Greywacke consists of well graded, felspathic greywackes and siltstones, sandstones and conglomerates. Conglomerates are well developed between Bee Mountain and Mt Narri (near the Queen Bee mine, see fig. 2.35) where they are reputedly basal, though they also occur at other horizons within the formation. North of Chesney mine the sequence becomes more silty, while to the south, poorly graded sandstones predominate. This unit has been described as a "tuffaceous sandstone" by many workers (Brooke 1975) and contains tuff fragments north of Queen Bee mine and flow-banded rhyolites further south near Nymagee (see fig. 2.36), as well as several small quartz - felspar porphyry intrusives south of Queen Bee mine.

The Great Cobar Slate conformably overlies the Chesney Greywacke, though in places apparently discordant relationships have been caused by shearing. This contact represents a marked decrease in the coarser sediment fraction, and it is significant that much of the copper mineralisation occurs along this contact. The Great Cobar Slate is composed of quartz - sericite or quartz - sericite - chlorite. Bedding is only apparent when marked by thin, silty interbeds or accentuated by weathering. Strong slate development is especially marked in the Great Cobar - Occidental area (where most of the mines occur), while to the south and north of this area the unit becomes coarser and more sandy.

The Great Cobar Slate is conformably overlain by the C.S.A. Siltstone, which consists of slate and siltstone. This contact is gradational north of Cobar, but sharper to the south where the formation becomes markedly sandier. In the C.S.A. mine area, the formation consists of typical geosynclinal flysch-type sediments, overlain by coarser greywackes and quartzites indicative of increasingly shallower conditions with time.

In the Cobar area, the Cobar Group forms the west limb of an anticline plunging 45°S. Bedding generally strikes 345° and dips 50° - 80° W. Despite some localised overturning, for example, in the Chesney Greywacke near the Peak, facings are generally to the west. However, isoclinal folding observed in the softer rocks of the overlying Amphitheatre Group indicate that the competent (apparently gently folded) quartzites of the Cobar Group give a false impression of the degree of deformation which has occurred (Brooke 1975). A strong regional cleavage is developed in the Cobar Group, striking approximately 355° and dipping 75° - 85° E. It is parallel to the axial surface of folding, and has been warped by shearing or later folding. Movement has occurred to varying degrees along the pre-existing cleavage, culminating in shears.

All the mineralisation in the Cobar area is located in quartz-filled shear zones sub-parallel to the regional cleavage. Elongate lenses of higher grade material occur within a lower grade envelope, and in the larger deposits a number of sulphide shoots may lie within a zone of intense deformation and shearing up to 300 m wide.

The ore shoots generally strike slightly west of north, dip 70° - 85° E and pitch 75° to the north. They average 60 - 120 m in length, though several ore shoots may form a semi-continuous zone of mineralisation up to nearly 400 m in length. While disseminated ore shoots may reach 125 m wide, the more massive ones (no true massive sulphide ore occurs at Cobar) average about 12 m width reaching up to 30 m. The greatest dimension of the shoots is down-plunge. Drill intersections have indicated shoot lengths of over 900 m, while outcropping shoots have been mined to about 600 m in the Occidental mine (see fig. 3.11). Individual sub-parallel ore lenses may form a semi-continuous ore zone down plunge, as well as along and across strike. The disseminated or vein-like nature of many of the ore shoots and their peripheries makes exact structural relationships unclear, and results in assay cutoffs being used more than geological boundaries in mining operations.

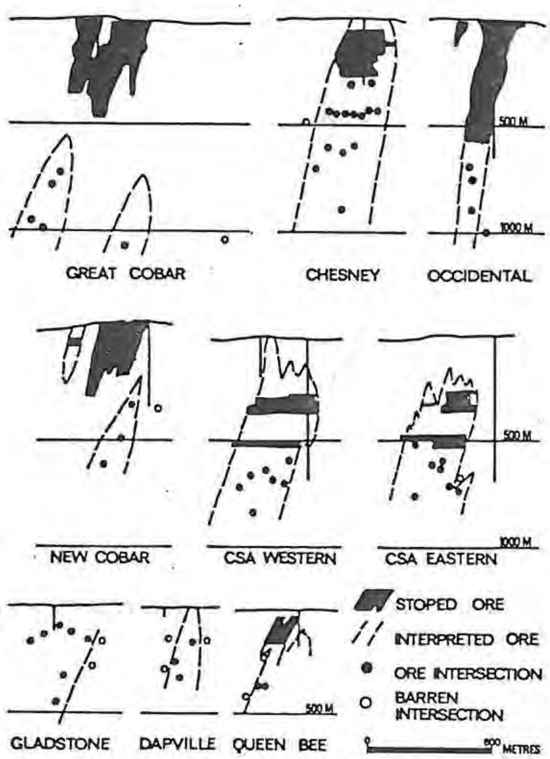

Fig. 3.11 Longitudinal projections of Cobar orebodies, looking east (from Brooke 1975)

Although the zones containing the ore shoots are roughly tabular and continuous, in detail the bodies show considerable variations in all directions. The quartz and sulphide veins mostly follow the cleavage, but also any other line of weakness, like sub-parallel fractures and sometimes the bedding. Occasional larger transverse veins, up to 1 m wide, have been reported.

Although the orebodies are obviously discordant and have been localised by structural controls, there is an apparent stratigraphic control which has been commented on above. Thus three major orebodies (New Cobar, Chesney and Occidental), several smaller ones, and minor sulphide showings occur in the Great Cobar Slate adjacent to the Chesney Greywacke. However, this lithological contact may also be regarded as a structural feature, as it represents a strong contrast in rock competency and shearing has occurred along it. Elsewhere mineralisation does seem to be associated with shearing preferentially located on competency contrasts. At New Cobar, dip changes with corresponding preferential ore deposition are related to competency, and at Chesney, cleavage (traced by quartz - sulphide veins) can be seen refracting through sandy beds. Throughout the field mineralisation also shows a marked preference for finer grained sediments. At Chesney and New Cobar ore veins crossing the contact weaken rapidly in the greywacke, while at Queen Bee the orebodies occur in a slaty zone within the Chesney Greywacke.

A further structural control is that several orebodies occur in buckles in the bedding, New Cobar being the best documented example. The Occidental, C.S.A. and Gladstone, and possibly Great Cobar and Chesney mines, all have bedding flexures near the ends of the orebodies. In contrast, the Spotted Leopard mine contains a strong fold in competent quartzites where only weak mineralisation has been located.

A variety of theories have been put forward to explain the relationship of the structure to the ore distribution (Brooke 1975). Conolly (1946) regarded the shears as stretch thrusts caused by a competency contrast during folding, with maximum expression along the regional cleavage in the less competent beds. He invoked a second set of stretch thrusts (striking at 330°) which, when they intersected the major shears (trending at about 355°), formed north-pitching columns of fractured rock, with severe attenuation occurring in the slates. This at least explains the pitching of the ore shoots, though the existence of the 330° stretch thrusts has yet to be adequately proved. Mulholland and Rayner (1953) modified this theory by supposing a wide area of shattering due to the intersection of 340° northeast-dipping fractures on a number of complex thrust faults approximately parallel to the cleavage (such fractures were observed at New Cobar and Chesney). In conclusion, Russell and Lewis (1965) advocated an overall stratigraphic control (with mineralisation occurring in fine grained sediments overlying coarser grained possibly volcaniclastic lithologies) with ore remobilised into zones of shearing and deformation.

In the previous section the regional geological setting of the Devonian granite-related tin and tungsten mineralisation of Tasmania was outlined. Below, a more detailed account is given of the four subdivisions of these deposits proposed by Solomon (1982), after which the cassiterite sulphide mineralisation at Renison Bell is described. Solomon's (1981) four categories are as follows.

(a) Cassiterite - stannite - pyrrhotite lenses mainly derived from replacement of carbonate beds and associated with small and large fissure lodes. Examples include Renison, Mt Bischoff, Cleveland, and Queen Hill at Zeehan, Razorback, St Dizier and Stanley River.

The deposits of type (a) include the largest tin resources in Tasmania, while Renison probably ranks as one of the world's largest primary deposits. All members of this type involve replacement of carbonate host rocks. The Mt Bischoff, Renison, Queen Hill and Stanley River carbonates are contained in sandstone - siltstone successions immediately underlying Cambrian rocks, while at Cleveland the relatively minor carbonate is in a Cambrian siltstone - basalt - greywacke succession. At Razorback the carbonate is thought to be related to a serpentinised ultramafic complex. At Mt Bischoff the related granitoids are orthoclase quartz porphyry dykes and at Renison are biotite granites and altered granites with tourmaline and muscovite.

If granitoids were the source of mineralising fluids, then the tin has been transported in solution over distances up to 1 km. Fluid inclusion data indicate temperatures varying from 350°C (at Renison) to 580°C (at Mt Bischoff), while the sodium - potassium - calcium solutions show a wide range of salinities and were fluorine bearing. It has been suggested (Patterson et al 1981) that these ore-forming fluids had a relatively low pH and FO_2 and that deposition was brought about by pH changes and / or a decrease in temperature. Both Renison and Mt Bischoff show evidence of magmatic and non-magmatic fluids during mineralisation. A feature of these deposits is their variable copper content.

(b) Quartz - wolframite veins ($\pm$ cassiterite) mainly lying within country rocks immediately overlying granitoid cupolas. Examples of this type include Aberfoyle, Storys Creek, Lutwych, Shepherd and Murphy (with other nearby deposits at Moina), Mt Oakleigh and Interview River.

These deposits are related to dilational quartz vein systems which show relatively little reaction with the country rock, and carry minor sulphides. They are relatively small deposits (Aberfoyle, the largest, probably contained less than 20 000 tonnes of tin). Temperature data and sulphides/

silicate mineralogy indicate that solutions were similar to those of type (a) deposits, but ore deposition probably occurred due to cooling and mixing with meteoric water. Mineral zoning observed in vein systems (from "proximal" to "distal", granitoid to wolframite to cassiterite to bismuthinite) may be a function of solubility.

(c) Disseminated cassiterite in altered, gneisenised granite intruded as sills, dykes, and plutons, or derived by in situ alteration - examples include the Anchor mine and the Feredation mine in the Heemskirk Granite.

These deposits are the only intramagmatic examples and tend to be relatively low grade (less than 0,2% Sn). They occur in late-stage volatile-enriched granitoids. For example, in the area of the complex Blue Tier batholith, there are several biotite - muscovite bodies occurring as dykes, sills and flat-topped plutons. Near their roofs there has been gneisenisation and enrichment in lithium, fluorine, rubidium and tin, with crystallisation of topaz, tourmaline and cassiterite.

In Western Tasmania the Heemskirk Granite comprises an upper zone of layered biotite granite (the "red" granite) apparently intruded by a flat-topped body of muscovite - biotite granite (the "white" granite) and contains pipes and irregular zones of cassiterite - tourmaline mineralisation. The highest grade mineralisation occurs near the top of the white granite (e.g. the Federation Mine).

(d) Scheelite in skarns, without cassiterite. Examples include King Island and Kara.

The King Island deposit occurs on the flank of an I-type hornblende - biotite - granodiorite (the Grassy Granodiorite), while the smaller nearby Dold Head skarn orebody is adjacent to a biotite adamellite. The King Island scheelite deposit occurs mainly in andradite skarn, and contains molybdenite, pyrite and pyrrhotite, which with the lack of hydrothermal alteration appears to indicate conditions of relatively high pH and FO_2 in comparison to tin-bearing solutions (Solomon 1981). At the Kara deposit (20 km south of Burnie) both hornblende granodiorites and biotite granites occur in the vicinity. The scheelite-bearing skarn is rich in magnetite and, as at King Island, the granite is more or less unaltered.

The cassiterite - sulphide mineralisation at Renison Bell in western Tasmania represents one of the largest primary tin deposits in the world (with production to 1978 totalling about 42 000 tonnes of tin, and reserves of about 24 million tonnes grading about 1% Sn). The mineralisation is associated with the Upper Devonian Pine Hill Granite and occurs in dolomites and associated sediments of probable Cambrian age within the Dundas Trough.

Fig. 3.12 shows the geology of the area around the Renison Bell deposits. The sedimentary succession consists of an older, siliceous, clastic and carbonate sequence (the Success Creek Group), overlain by, and in faulted contact with, a predominantly volcaniclastic sequence (the Crimson Creek Formation). The Success Creek Group comprises thinly bedded quartzites, siltstones, shales and dolomite of probable shallow marine origin, while the Crimson Creek Formation consists of siltstones and volcaniclastic greywackes of basaltic composition. The Success Creek and Crimson Creek successions are separated by the Red Rock sequence, consisting of conglomerates, tuffs, cherts and carbonate rocks.

The oldest unit of the Success Creek Group is the Dalcoath Quartzite, an 800 m thick succession of thickly bedded quartz sandstone, with interbedded sequences of micaceous sandstone, siltstone, and shale. Dolomitic shales and thin dolostone beds occur throughout the sequence, increasing in abundance toward the base of the No. 3 dolomite.

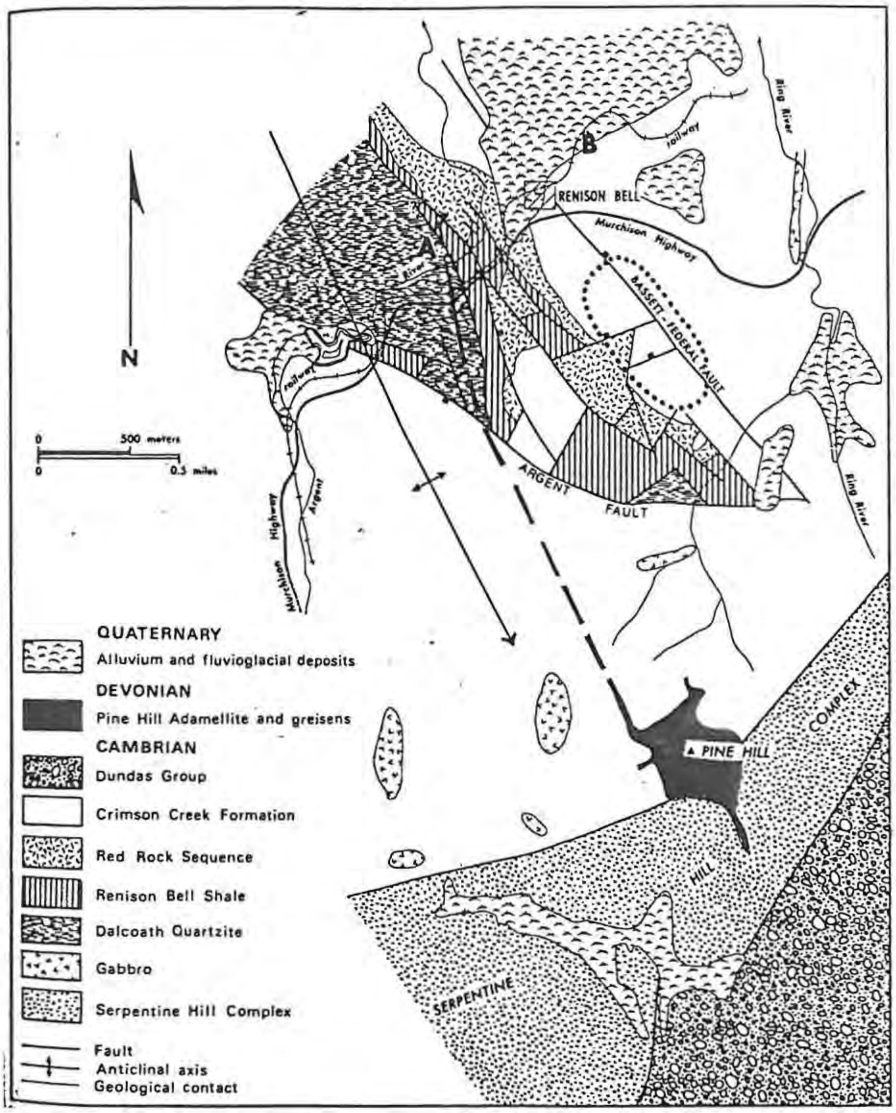

Fig. 3.12 Geologic sketch map of the Renison Bell district, compiled from mapping by Renison Limited, Groves (1968), Collins (1972), Rubenach (1974), and the senior author; from Patterson (1976), with minor modifications. Dotted ellipse indicates approximate limit of the Renison mine workings. A - B indicates the section given in Fig. 3.13 (from Patterson et al 1981)

The No. 3 dolomite is about 5 m thick at the northern end of the mine (where it comprises fine grained, massive to laminated dolostone with quartz - muscovite shale interbeds), but thins to the south where it passes into a calcite-bearing shale. It is overlain (with probable local disconformity) by the Renison Bell Shale, approximately 60 m thick, which consists of interbedded quartzites, quartz sandstone and shale, with a 10 m thick pyritic black shale toward the top. The Renison Bell Shale becomes markedly more dolomitic toward the top, where it passes (apparently conformably) into the No. 2 dolomite. The No. 2 dolomite consists of about 15 m of massive to thinly bedded dolostone with shaley partings and dolomitic shale interbeds.

The No. 2 dolomite is overlain by a sequence of cherts, conglomerates and quartz sandstones, all variably dolomitic, locally referred to as the Red Rock or Red Rock sequence. The Red Rock is about 20 m thick at the mine, but this, like its internal composition, is widely variable. Although structurally continuous with the underlying No. 2 dolomite, a disconformable relationship is indicated by the presence of dolostone fragments at the base of the Red Rock.

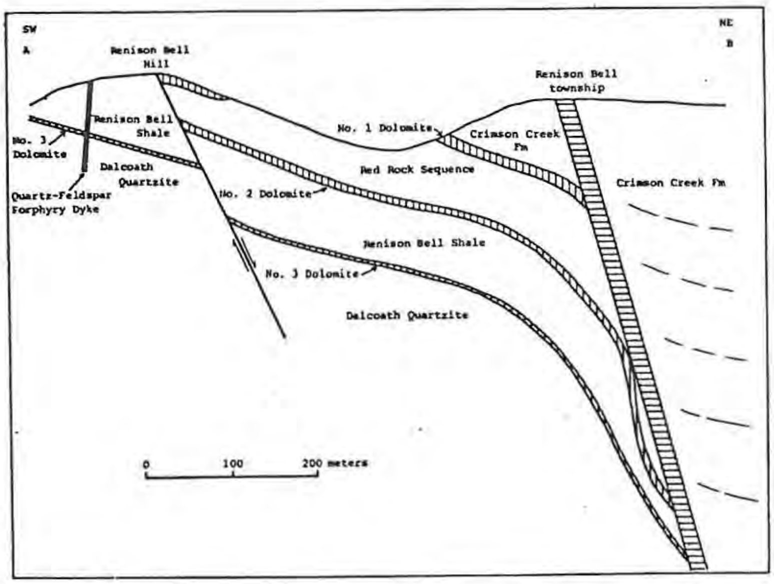

Fig. 3.13 Idealized cross section through the northern part of the Renison mine, (from Patterson et al 1981)

The Red Rock is overlain, apparently conformably, by the No. 1 dolomite, consisting of about 20 m of massive dolostone and siliceous and dolomitic shale. This sequence is in turn overlain by the Crimson Creek Formation, which exceeds 1 000 m in thickness in the Renison Bell area. The Crimson Creek Formation consists of siltstones and volcaniclastic greywackes of basaltic composition, and to the south and southwest of Renison Bell is faulted against the Serpentine Hill Complex.

Granitic rocks are exposed at Pine Hill 2 km southeast of the Renison mine, and in a number of quartz prophyry dykes radiating from this centre (see fig. 3.12). The Pine Hill Granite is a porphyritic biotite granite which has been locally altered to greisen and muscovitic assemblages carrying minor cassiterite and fluorite. Adjacent rocks have been thermally metamorphosed to hornblende - hornfels facies assemblages.

The mine lies on the northeastern flank of the Renison Bell anticline, a regional structure of probable Tabberabberan age, whose axis strikes approximately northwest and plunges shallowly south. The northeastern limb of this fold is approximately monoclinal, with minor subsidiary folds parallel to the main fold axis, as well as a second generation of minor folds striking at right angles to the major fold trend. Age relationships between the two fold sets are unknown, but both may be Devonian.

The northeastern limb of the anticline is extensively faulted between Renison Bell township and Pine Hill. The faults are all normal, with dips between 55° and 80°, and fall into two groups. The first group are a well developed set of faults striking northwest, parallel to the main fold axis, and include the Bassett-Federal and Argent faults which bound the central uplifted block. The Bassett-Federal fault has a vertical component of at least 1 000 m at Renison Mine, while the Argent fault probably had vertical movements of several hundred meters. Parallel faults within the horst block have much smaller movements, generally much less than 100 m. The second group of faults includes two sets of shorter transverse faults occurring between the main longitudinal faults. One set strikes east-northeast and lies adjacent to the Bassett-Federal Fault, while the second set strikes north-northeast and occurs near the Argent fault. This group, whose vertical movements average 50 to 100 m, includes shears L and P, the major transverse faults in the Renison mine.

In addition to these two major fault sets, swarms of minor faults occur in the Renison mine. These broadly parallel the L and P shears, with generally normal movements up to a maximum of 10 m. While the major longitudinal faulting has been shown to be active both before and during mineralisation, the minor faults and major transverse faults indicate movements after mineralisation, as well before and during (Patterson et al 1981).

Tin mineralisation at Renison is most intensely developed in the central block bounded by the Argent and Bassett-Federal faults, and may be divided into two major deposit types, namely stratabound and fault-controlled deposits.

Stratabound deposits (also called conformable lodes or sill orebodies) occur within dolostone horizons in the Success Creek Group and the Red Rock sequence adjacent to their intersections with relatively major faults, and are considered to have formed by replacement of these dolomites. They consist principally of massive pyrrhotite, with minor cassiterite, arsenopyrite and other sulphides, as well as variable amounts of quartz, tourmaline, talc, tremolite, siderite and fluorite. This type of deposit accounts for the bulk of the cassiterite mineralisation in the Renison mine, as well as the majority of the outlying orebodies.

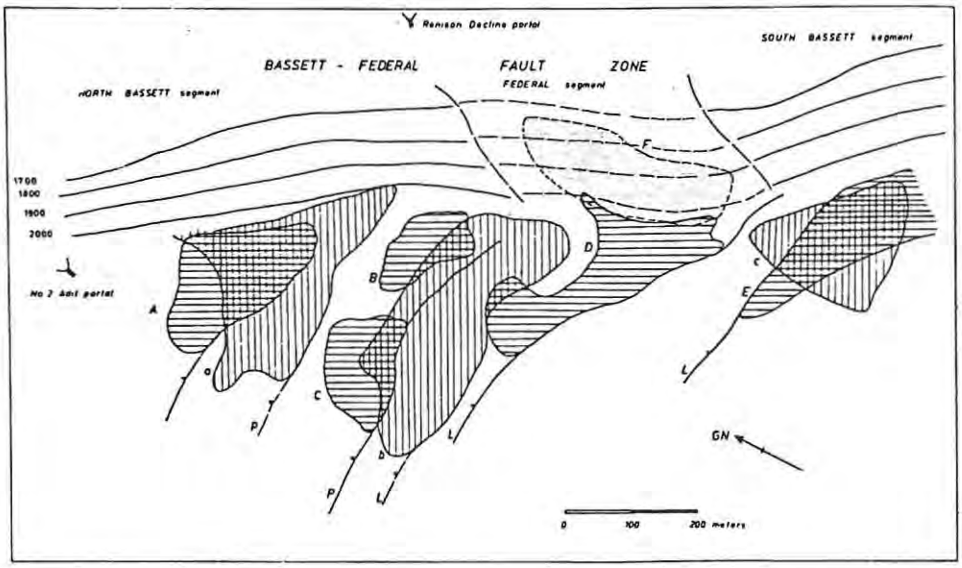

Fig. 3.14 Composite plan projection of stratabound replacement orebodies in the Renison mine. Horizontal shading =

stratabound replacement orebodies in the No. 2 dolomite horizon: A, Murchison; B, Lower Dreadnought; C, Upper Dreadnought; D, North Stebbins; and E, South Stebbins. Stippled (F) = Central Basset. Vertical shading = stratabound replacement orebodies in the No. 3 dolomite horizon: a, Penzance; b, Colebrook; and c, Howard. Faults shown as solid lines are indicated shears at the No. 2 dolomite horizon; dashed faults are indicated shears at the No. 3 dolomite horizon. Contours on the Bassett-Federal fault zone are shown in meters above Renison Limited mine grid base level. (from Patterson et al 1981)

In the Renison mine stratabound mineralisation is extensively developed in the No. 2 and No. 3 dolomites in the area of the intersection of the Bassett-Federal fault zone and major transverse normal faults (shears L and P, see fig. 3.14). However, although the No. 1 dolomite is extensively altered, it contains only minor mineralisation of economic grade. Replacement commonly extends over the complete stratigraphic thickness of the dolostone unit, and the orebodies may terminate abruptly at their outer margins or taper to a feather edge anywhere within the unit.

The stratabound orebodies are mineralogically and chemically zoned. Small orebodies show a simple, more or less concentric distribution of sulphur (effectively due to pyrrhotite), tin, arsenic and copper, with assay valves decreasing fairly smoothly from some point on the bounding fault (see fig. 3.15). Larger orebodies such as the Colebrook show more complex zoning patterns, probably resulting from an overlap of several simple concentric patterns of the type described above, developed about several points on the bounding faults. Stratabound orebodies in the Renison mine are rimmed by a continuous zone of coarsely crystalline magnesian siderite. This zone varies in width from about 10 cm to over 100 m, and observed textures (in hand specimens and thin sections) indicate that it formed by replacement of thermally metamorphosed (but otherwise unaltered) dolostone and was in turn replaced by ore assemblages, usually massive pyrrhotite. Contacts between the siderite zone and the unreplaced dolomite, and between the siderite zone and the massive sulphides, are commonly knife-sharp. On the outer edges of the siderite zone, veinlets of magnesian siderite extend for up to several hundreds of metres into the dolostones and dolomitic shales, developed along transverse and bedding plane fractures.

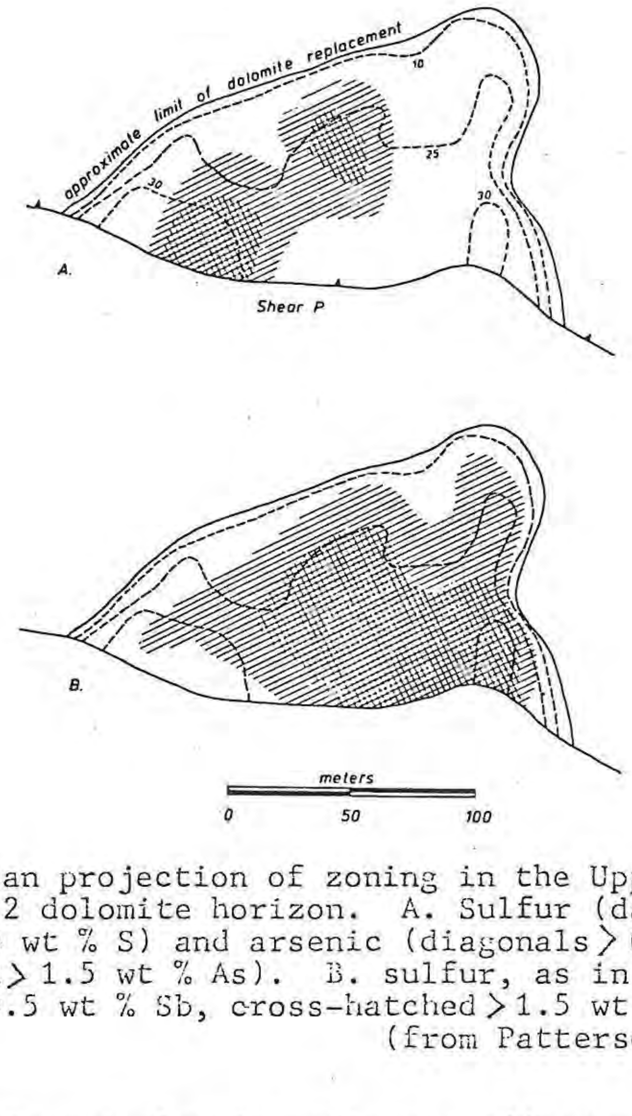

Fig. 3.15 Plan projection of zoning in the Upper Dreadnought orebody, No. 2 dolomite horizon. A. Sulfur (dashed lines at 10, 25 and 30 wt % S) and arsenic (diagonals > 0.5 wt % As and cross-hatched > 1.5 wt % As). B. sulfur, as in A, and tin (diagonals > 0.5 wt % Sb, cross-hatched > 1.5 wt % Sn).
(from Patterson et al 1981)

Siliceous clastic sediments adjacent to the stratabound orebodies are locally recrystallised and veined by quartz, with minor pyrrhotite, arsenopyrite, cassiterite, and blue-green tourmaline, and carry minor to abundant disseminated tourmaline, muscovite and sulphides. Bands of pyrrhotite parallel to the bedding may represent original carbonate-rich layers in siliceous sediments.

Fault-controlled deposits (also called fissure replacement lodes) have a similar mineralogy to the stratabound orebodies, and consist of fault-bounded vein systems with variable wall-rock replacement. Mineralisation of this type occurs throughout the central block often adjacent to the stratabound deposits. The best development of this type of mineralisation in the Renison mine is in the Federal segment of the Bassett-Federal fault zone (see fig. 3.14), but this type also occurs in the North Bassett and South Bassett segments. The ore is made up of massive replacements, disseminations, and veinlets of pyrrhotite, with lesser cassiterite, arsenopyrite and other sulphides, with a gangue of quartz, tourmaline, phlogopite and minor muscovite. Localisation of the orebodies is largely structurally controlled, and element distribution patterns are much less regular than in the stratabound deposits.

In addition to the stratabound and fault controlled ore types, two other types of cassiterite mineralisation of lesser importance are developed in the Renison mine. One type consists of a set of steeply dipping, anastomosing, arsenopyrite-rich veins developed mainly in the Bassett-Federal fault zone, where they cut and contain inclusions of replacement mineralisation. The veins consist of quartz, arsenopyrite, and minor cassiterite, pyrrhotite, chalcopyrite and rarely other sulphides, and are up to 1 m in width. The other type consists of minor cassiterite with trace arsenopyrite and pyrrhotite, disseminated in areas of recrystallised and tourmalinised quartzite within the Renison Bell Shale between shears L and P (2.5 ore zone).

The generalised paragenetic sequence in the Renison mine is:

Stage 1: cassiterite + silicates - probably an early stage of replacement ore formation;

Stage 2: cassiterite + pyrrhotite + arsenopyrite + silicates + minor sulphides + iron oxides - this was the main stage of mineralisation, associated with sideritic alteration of dolomites and tourmalinisation of clastic sediments;

Stage 3: cassiterite + pyrrhotite + arsenopyrite + silicates + minor sulphides - forming veins in major fault zones;

Stage 4: minor veining by sphalerite + galena + silicates + carbonates + fluorite;

Stage 5: a vug-filling sequence of carbonates, quartz, fluorite and sulphides.

From fluid inclusion, mineralogical, and stable isotope data, temperatures of about 350°C are inferred for stages 1 to 3, 300°C for stage 4, and 200° to 150°C for stage 5. Bulk fluid inclusion analyses indicate that for stages 1 to 4 the fluids were sodium - potassium - chlorine brines with a total salt concentration of about 2 molal and a sodium/potassium ratio of about 7. Stage 5 fluids were more saline, with salt concentrations of about 5 molal and sodium/potassium ratios of about 20. Formation of cassiterite-bearing stages took place at about 350°C, at low FO_2, low FS_2 and low pH in the reduced sulphur field. The major control on ore deposition was probably an increase in pH due to dolomite replacement (Patterson et al 1981).

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APPENDIX

Mineral Deposits of the Tasman Geosyncline (see map)

Key

▲	Cupreous Pyrite deposits
o	Volcanic associated deposits
□	Sedimentary copper deposits
+	Granite-derived deposits
x	Vein-type deposits, not granite-derived

Kanmantoo orogen

	1.	Kanmantoo Cu
	2.	Nairn Py

Lachlan orogen

o	3.	Mt Lyell Cu-Au
o	4.	Mt Farrell Pb-Ag(Zn)
o	5.	Rosebery Zn-Pb-Cu
o	6.	Hercules Pb-Ag
o	7.	Que River Zn-Pb-Cu
+	8.	Mt Bischoff Sn
+	9.	Mt Magnet Ag-Pb-Zn
+	10.	Cleveland Sn
+	11.	Renison Bell Sn
+	12.	Anchor Sn
x	13.	Bendigo Au
x	14.	Ballarat Au
x	15.	Maldon Au
x	16.	Castlemaine Au
x	17.	Heathcote Au
x	18.	Stawell Au
x	19.	Warrendyte Au
x	20.	Woods Point Au
x	21.	Costerfield Sb
x	22.	Coimadai Sb
o	23.	Gelantipy Pb-Ag(Zn)
+	24.	Yambula Au
+	25.	Browns Camp Au
+	26.	Majors Creek Au
+	27.	Black Range Au
+	28.	Bongongalong-Burra Gold field Au
+	29.	Ardlethan Sn
+	30.	Weethalle Au
+	31.	Kaikora-Gibsonvale Au-Sn
□	32.	Mt Hope Cu
□	33.	Shuttleton Cu
□	34.	Cobar Cu
▲	35.	Girilambone Cu
▲	36.	Tottenham Cu
o	37.	Bobodah Zn-Pb-Cu
o	38.	Mineral Hill Zn-Pb-Cu
x	39.	Stuart Town Au
x	40.	Hargraves Au
x	41.	Hill End Au
x	42.	Ophir Au

o 43. Copper Hill Cu-Au
o 44. Cargo Cu
o 45. Junction Reefs Cu-Au
o 46. Cadia Cu-Au
o 47. Mt Bulga Cu-Pb-Zn-Ag-Au
o 48. Lewis Ponds Cu-Pb-Zn-Ag-Au
o 49. Sunny Corner Cn-Pb-Zn-Ag-Au
o 50. Cow Flat Cu-Zn-Ag-Au
o 51. Wisemans Creek Cu-Pb-Zn-Ag
o 52. Burraga Cu-Ag-Au
\+ 53. Trunkey-Tuena Au
o 54. Peelwood Cu-Zn-Pb-Ag-Au
o 55. Kangiara Cu-Pb-Zn
o 56. Woodlawn Cu-Pb-Zn
o 57. Captains Flat Cu-Pb-Zn
o 58. Michelago Cu-Pb-Zn
o 59. Yalwal Au

Thomson orogen

▲ 60. Peak Downs Cu
\+ 61. Charters Towers Au

Hodgkinson - Broken River orogen

\+ 62. Mt Garnet Cu-Zn
\+ 63. Herberton Sn
\+ 64. Wolfram Camp W
\+ 65. Chillagoe Cu-Pb-Zn
\+ 66. Mt Carbine W

New England orogen

\+ 67. Mt Chalmers Cu-Au
\+ 68. Mt Morgan Cu-Au
o 69. Drake Mineral Field Au-Cu-Pb-Zn
\+ 70. Torrington) Sn-Cu-Pb-Zn
\+ 71. Emmaville)
72. Gulf Creek Cu
73. Trough Gully Cu

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