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METALLOGENY AND TECTONIC DEVELOPMENT OF THE TASMAN FOLD BELT SYSTEM IN VICTORIA

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Abstract

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Current evidence suggests that most of Victoria is underlain by a relatively thick (20 km +) basement of sialic composition of assumed Proterozoic age. This basement is nowhere exposed and its structural relationship with exposed Palaeozoic rocks is conjectural. This uncertainty has resulted in both ensimatic and ensialic tectonic models being proposed for Victoria during the Cambrian.

Mineralization associated with Cambrian igneous activity shows a variety of styles from minor orthomagmatic chromite deposits, through Au and Cu deposits of syngenetic or epigenetic origin, to Fe—Mn, Ba occurrences of exhalative volcanogenic affiliation.

Cambrian volcanism and associated sedimentation was followed by the deposition of dominantly quartz-rich turbidites with interbedded shale and siliceous units. Subsequent to the epi-Ordovician Benambran Orogeny, late Silurian crustal extension caused several rifts to open along roughly orthogonal NW and NE aligned fractures. Within these fault-bounded depressions, thick acid volcanic sequences were deposited in close association with shallow-marine sediments. Mineralization in these Upper Silurian rocks comprises polymetallic base-metal sulphide lenses and minor disseminations, at least some of which are of exhalative volcanogenic affiliation.

The Silurian rifts were obliterated and their rocks strongly deformed during the Bindian (Bowning) deformation during late Silurian to early Devonian time. This in turn was followed by another episode of crustal extension and rifting, during which the formation of a broad meridional trough marks the Buchan Rift. A very thick sequence of largely subaerial bimodal volcanics is overlain by shelf limestone and mudstone. A variety of minor base metal, barite, manganese, and iron mineralization is hosted by these volcanics and shelf sediments.

The mid-Devonian Tabberabberan Orogeny was followed in the Late Devonian by bimodal volcanism and granite intrusion, and "red-bed"-type non-marine sedimentation. In Central Victoria, thick bimodal volcanics were erupted into a series of cauldron subsidences and intruded by comagmatic granites. Bimodal volcanism also occurred in the Mount Howitt Province farther east, but was followed by deposition of extensive fluviatile and lacustrine sediments (mainly mudstone, sandstone, and minor conglomerate). In the Mansfield Basin, these contain minor sedimentary copper occurrences.

There are four distinct episodes of granite emplacement in Victoria, namely Late Cambrian–Early Ordovician (Delamerian) in the Glenelg Zone; Early Silurian (Benambran) in the Highlands Zone; Early Devonian (Bindian) in the Grampians, Ararat—Bendigo, Highlands, and Mallacoota Zones; and Middle Devonian—Carboniferous (post Tabberabberan) in the Ararat–Bendigo, Melbourne, Howqua, and Highlands Zones. Data for the Delamerian granitoids are sketchy, but in the remaining groups S-type granitoids predominate with the exception of eastern Victoria, east of the Yalmy Fault (I-S line), where only I- and

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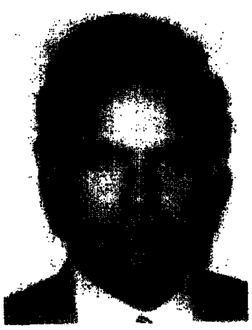
A-type granitoids occur. A variety of Sn, Mo, W deposits and prospects are associated with the Benambran and younger intrusive phases.

Victoria is a major gold province which has produced nearly 2.5×10^6 kg gold. Primary gold occurs in a number of geological settings including veins and disseminations spatially associated with mafic Cambrian volcanism, vein deposits in turbiditic sequences of central and eastern Victoria, veins associated with mafic and intermediate intrusives of Mid to Late Devonian age, and minor amounts associated with a variety of granitoids and porphyry dykes.

Kanmantoo Fold Belt

The Kanmantoo Fold Belt in South Australia is characterized by the very thick, rapidly deposited Kanmantoo Group, comprising quartz-rich sandstone, siltstone, and minor conglomerate. This partly turbiditic, partly nearshore marine sequence, was folded, regionally metamorphosed, and intruded during the Cambro-Ordovician Delamerian Orogeny (K/Ar 504 ± 16 to 470 ± 30 Ma*; Milnes et al., 1977; Daily, 1982). The transition between the Kanmantoo and Lachlan Fold Belts occurs in Western Victoria and may lie across the Grampians Zone (Fig. 1), or may lie on or near the Woorndoo Fault

*All ages have been recalculated to conform with the convention of Steiger and Jäger (1977) and are quoted to confidence limits of 2 SD.



W.R.H. (Ross) Ramsay graduated from the University of Auckland, New Zealand (1972), where he studied and described epithermal silver–gold deposits in the Tertiary volcanic Haurkaki Province. He worked for a period as mine geologist in Tasmania and in 1974 commenced Ph.D studies on the evolution of an ensimatic island arc, Solomon Islands, and its relationship to mineralization. Subsequently he joined industry and worked on a number of base metal and tin projects in Eastern Australia. In 1981 he joined the Victorian Geological Survey, where he is primarily concerned with mineralization in the State.
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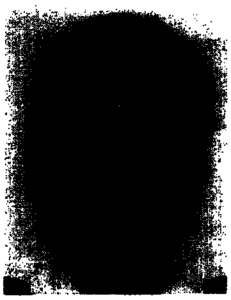

Mr. A.H.M. VandenBerg graduated at the University of Melbourne in 1968. After a brief spell in the Hydrogeology Section, he joined the Regional Geology Section of the Geological Survey of Victoria where his projects included detailed mapping of the Greater Melbourne area and the Palaeozoic stratigraphy and sedimentology of the western Melbourne Trough.

During a period of secondment to the Melbourne and Metropolitan Board of Works, he carried out a detailed study of the structure and stratigraphy along the Thomson–Yarra Tunnel and provided advice on the appropriate tunnelling methods. This work was extended into regional mapping of the Palaeozoic rocks into eastern Victoria, culminating in work on Silurian and Devonian acid volcanics and underlying rocks in the Benambra–Bendoc region.

This work led to the introduction of a new graptolite zonal scheme for the Upper Ordovician, and the discovery of Lower Silurian marine sediments which have recently been proved to extend well into New South Wales. His research on graptolites also proved the existence of a fully conformable Ordovician–Silurian boundary sequence at Darraweit Guim, near Melbourne, the first such documented sequence in Australasia.
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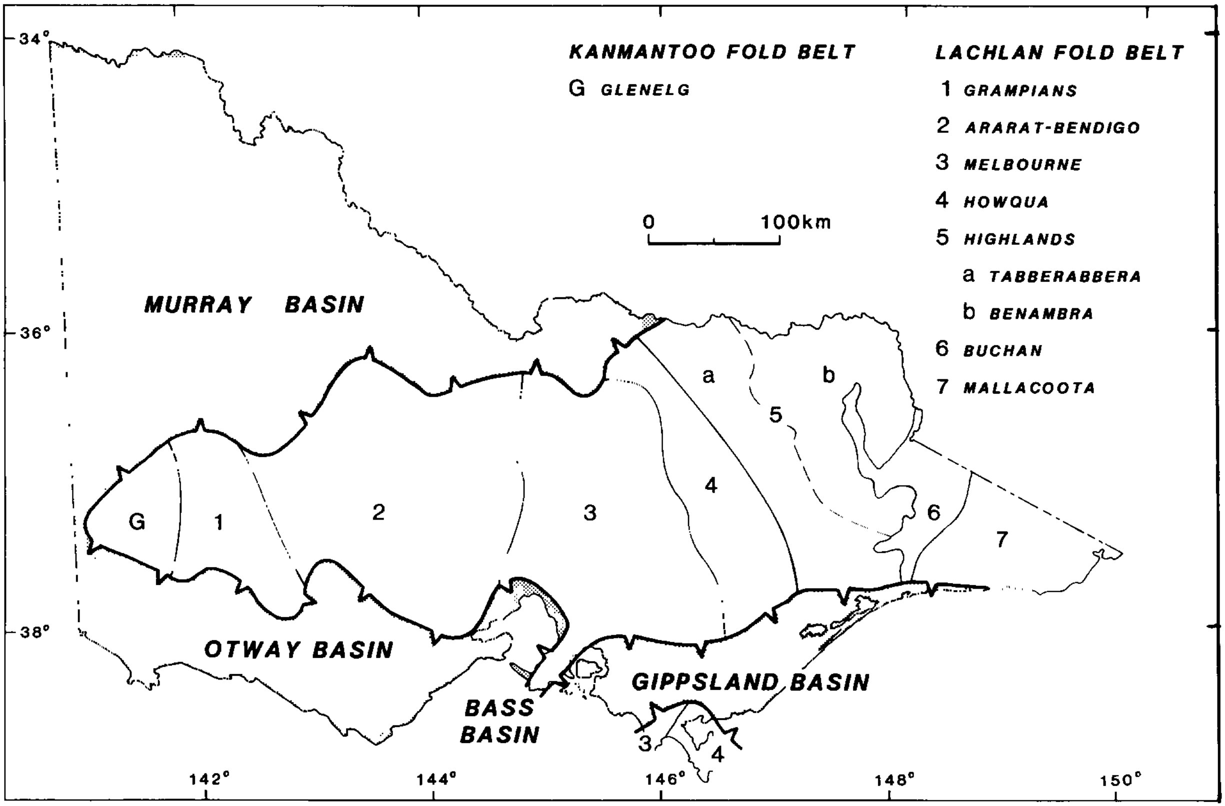

Fig. 1. Distribution of structural zones in Victoria (modified from VandenBerg, 1978a).

(Fig. 2). In the western portion of the Grampians Zone the Silurian (?) Rocklands Rhyolite and Grampians Group lie unconformably on the Glenelg River Beds and Glenelg Metamorphic Complex. In the east the same rocks overlie unconformably Cambrian (?) volcanics and quartz-rich sediments whose deformation history is uncertain.

Glenelg Zone

The sediments of the Glenelg Zone (Fig. 1) resemble those of the Kanmantoo Group, but also display important differences. They are more lithic and dolomitic and contain uncommon pods of dolomitic limestone. These Glenelg River Beds consist of a thick, tightly folded, unfossiliferous marine sedimentary sequence exposed in the valley of the Glenelg River and its tributaries, together with equivalent slate and greywacke east of the Wando Granodiorite [(54)541,5850]*. A Late Proterozoic or Early Cambrian age has been assumed for these sediments, which include graded quartz greywacke, laminated shale with subordinate lithic greywacke, black slate, argillaceous dolomitic limestone, laminated dolomitic slate, and uncommon volcaniclastics (VandenBerg and Wilkinson, 1982). Minor ultramafic pods and mafic dykes cut the sequence (Wells, 1956).

Near the western limit of the sedimentary belt near Wando Vale [(54)540,5848], the sediments have been regionally metamorphosed (Glenelg Metamorphic Complex) and at Glenelg River, sillimanite—muscovite-

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*Coordinates refer to map grid of Fig. 2, eastings, then northings; the prefix in brackets refers to the respective zone.

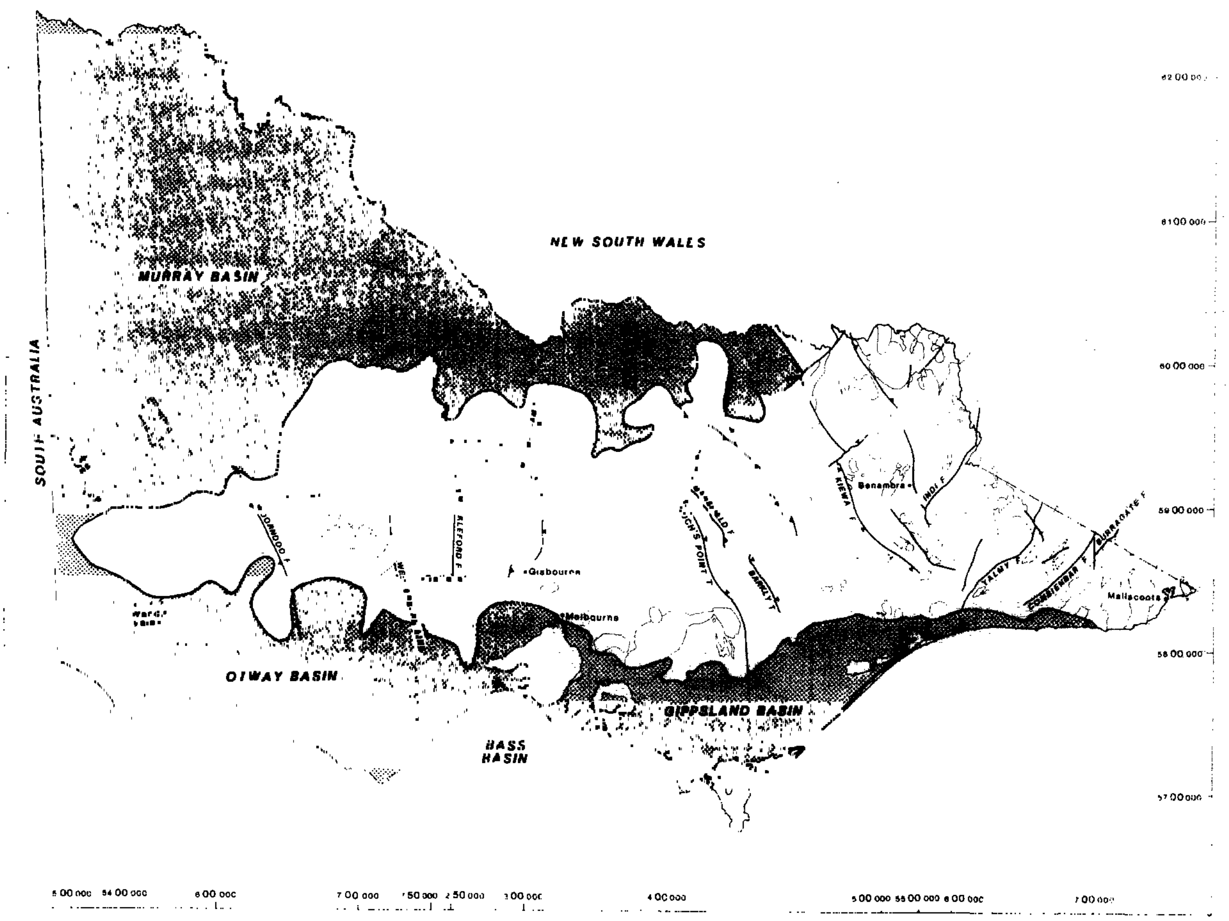

Fig. 2. Distribution of major fault systems, granitoids, and Mesozoic—Cainozoic sedimentary cover, Victoria. F = fault, T = thrust.

biotite gneiss is K/Ar dated at 512 ± 18 Ma (VandenBerg and Wilkinson, 1982). Other granitoid intrusions within the Glenelg Zone have been dated at 487 ± 6 to 466 ± 6 Ma (Richards and Singleton, 1981). These dates span the full range of pre- and post-kinematic granitoids associated with the Delamerian Orogeny in South Australia (Milnes et al., 1977) and indicate that the Glenelg River Beds form part of the Kanmantoo Fold Belt.

Because of poor exposure and extensive cover of younger sediments, associated mineralization is poorly known, with minor copper noted in a quarry near Wando Vale (Cochrane, 1982) and base-metal vein deposits at Nolan Creek [(54)529,5862] containing Pb, Zn, and Ag [Fergusson, 1894; Dunn, 1912; Western Mining Corporation (WMC), Exploration Licence (EL) 458, 1972—1974]. Host rocks to this mineralization consist of shales and an interbedded dolomitic limestone pod of the Glenelg River Beds.

Lachlan Fold Belt

The Lachlan Fold Belt comprises the Cambrian to Lower Carboniferous sequences of southeast Australia, which were deformed during the mid-Palaeozoic (Cas, 1983). Precambrian basement supposedly underlies the western margin of the Lachlan Fold Belt in Western Victoria and has acted as a sialic foreland for subsequent Palaeozoic volcanism and sedimentation. The nature of this sialic foreland is uncertain. Rutland (1976) suggested that the Tasmanian Late Precambrian sequence, characterized by quartzites, which have undergone deformation and metamorphism during the Penguin Orogeny (about 700—750 Ma; Collins and Williams, 1986, this volume), may have extended both north and south of Tasmania, although northern equivalents are not exposed on the mainland, with the possible exception of the Girilambone Beds in central New South Wales.

Within the Lachlan Fold Belt, Rutland (1973) extends the sialic basement well to the east, whereas others (Solomon and Griffiths, 1972; Crook and Felton, 1975) prefer a thinner oceanic or simatic setting. More recently, Crawford and Keays (1978) and Crawford et al. (1984) have developed a model based essentially on geochemistry and petrography, which involves rifted sialic blocks associated with arc volcanism and back-arc spreading. Three major north—south-trending belts of Lower Cambrian metavolcanic rocks are interpreted as apparent basement to the Lachlan Fold Belt by these workers and a critical examination of this proposal is given by Cas (1983).

Cambrian greenstones of Victoria

The oldest rocks recognised in the Lachlan Fold Belt of Victoria comprise various belts of north- to northwest-trending altered volcanic and minor plutonic rocks (Fig. 3). These metavolcanic rocks or greenstones have been traditionally grouped into three zones or belts, commonly called "axes" in the mistaken belief that they represent anticlinal structures (Thomas, 1939). Recent mapping and exploration has shown that in some instances these belts have various igneous rock types (Fig. 3). The greenstone belt nearest the Australian Precambrian craton is the composite Mount Stavely Belt. The Heathcote and Mount Wellington Belts (Fig. 3) form the structural boundaries to the Melbourne Trough in central Victoria, whilst the Barkly River and Waratah Bay Belts (Fig. 3) lie within the Melbourne Trough. A proposed stratigraphical correlation of Victorian greenstones is shown in Table 1.

Mount Stavely Belt

The junction of the western margin of this belt with the Glenelg Zone has been obscured by younger rocks in the Grampians Zone. The belt is assumed to include the Black Range (Fig. 3), where northerly trending inliers of now lateritised greenstone, chert, and shale with steeply plunging fold-axes (Spencer-Jones, 1965) are exposed. Subsequent mapping by O'Shea (1977, 1978) has identified the presence of chert, talc schist, silicified schist, and both fine- and coarse-grained mafic igneous rock. Farther west, within the Glenelg Zone near Wando Vale occur small pods of serpentinized olivine pyroxenite, serpentinized olivine cumulates, uralitized ultramafics and cross-cutting altered mafic dykes (Wells, 1956; Ramsay, 1983). VandenBerg and Wilkinson (1982) note that there is no evidence for correlating these with the Lower Cambrian greenstones.

Within the Mount Stavely Belt are a number of fault-bounded, northerly trending greenstone occurrences, which run from Mount Stavely to Mount Drummond in the north. They are coincident with several linear positive aeromagnetic anomalies, which outline the surface and subsurface extensions of these rocks. Positive linear magnetic anomaly trends have been identified running in a NNW direction into the Murray Basin (Buckland and Ramsay, 1982) and these collectively constitute a 50 km wide zone located along the western margin of Lake Hindmarsh and continuing towards Renmark [(54)476,6218].

The best-documented occurrence is at

TABLE 1

Stratigraphic sequences of Victorian Cambrian greenstones

	Mt. Stavely Belt	Heathcote Belt		Mt. Wellington Belt		
	Mount Stavely	Lancefield	Heathcote	Dookie	Howqua	Wellington River
Ordovician		Undifferentiated Ordovician (Be—Da) turbidites	Undifferentiated Ordovician (La—Da) Thick quartz--mica turbidites, channel deposits	Small faulted-bounded patch of Castlemainian	Undifferentiated Ordovician (Be—Da) greywackes, phyllitic slates, sandstones, black shale.	Mt. Easton Shale Upper Ordovician (Da—Bo) black shale (200 m)
		Romsey Group (La1—Be4) Turbidites, black shale, minor channel deposits (1200 m)	fault		Black shale (La) (100 m)	Lower Ordovician not represented
					fault	fault
Cambrian U	Glenthompson Sandstone Quartzose sandstone, siltstone, minor carbonaceous shale, intraclast pebble bands, assumed Cambrian—?Ordovician age	Goldie Chert Banded to massive chert (190—290 m)	Small chert outcrop at Ladys Pass? fault	Not represented	Not represented	Not represented
M	Towanway Tuff Dacitic lithic and crystal tuffs, silicified equivalents, chert, volcanogenic sandstone (600 m +) Nanapundah Tuff Andesitic, crystal lithic tuff (700 m +) Fairview Andesitic Breccia	Monegeetta Shale Black shale, black siltstone, minor chert, volcanogenic sandstone (200—580 m)	Knowsley East Formation. Similar lithology to Monegeetta Shale (150 m +) Unnamed conglomeratic limestone with archaeocyaths, relationship with Knowsley East Formation uncertain	Not represented		Dolodrook Limestone Shallow-water bioclastic limestone (10—20 m) Garvey Gully Formation Turbiditic ultramafic derived sandstone, siltstone plus pelagic siltstone (100 m +) Serpentinite, conglomerate
L	Coarse fragmental lava and minor flows of andesitic character, uncommon basalt (2500 m +) The entire volcanic sequence is intruded by Williamson's Road Serpentinite and Lalkaldarno Porphyry	Mt. William Metabasalt Metabasalt, rare metaboninite, thick flows with interbedded bands of siltstone and volcanogenic sandstone (1600 m +)	Fault Heathcote Greenstone MORB-related tholeiites which post-date low-Ti intermediate lavas of boninitic affinity.	Interbedded metabasalts, siltstones, volcanogenic shales, and sandstones intruded by gabbro	Pillowed tholeiitic lavas (800 m) Tholeiitic hyaloclastites and interbedded sediments (500 m) Mafic and ultramafic lavas of boninite? affinity, volcanogenic sandstones (1500 m) Andesitic pyroclastics, lavas and sediments (400 m+).	Ultramafic complex: Peridotite, harzburgite, lherzolite, serpentinite, plus minor metabasalt

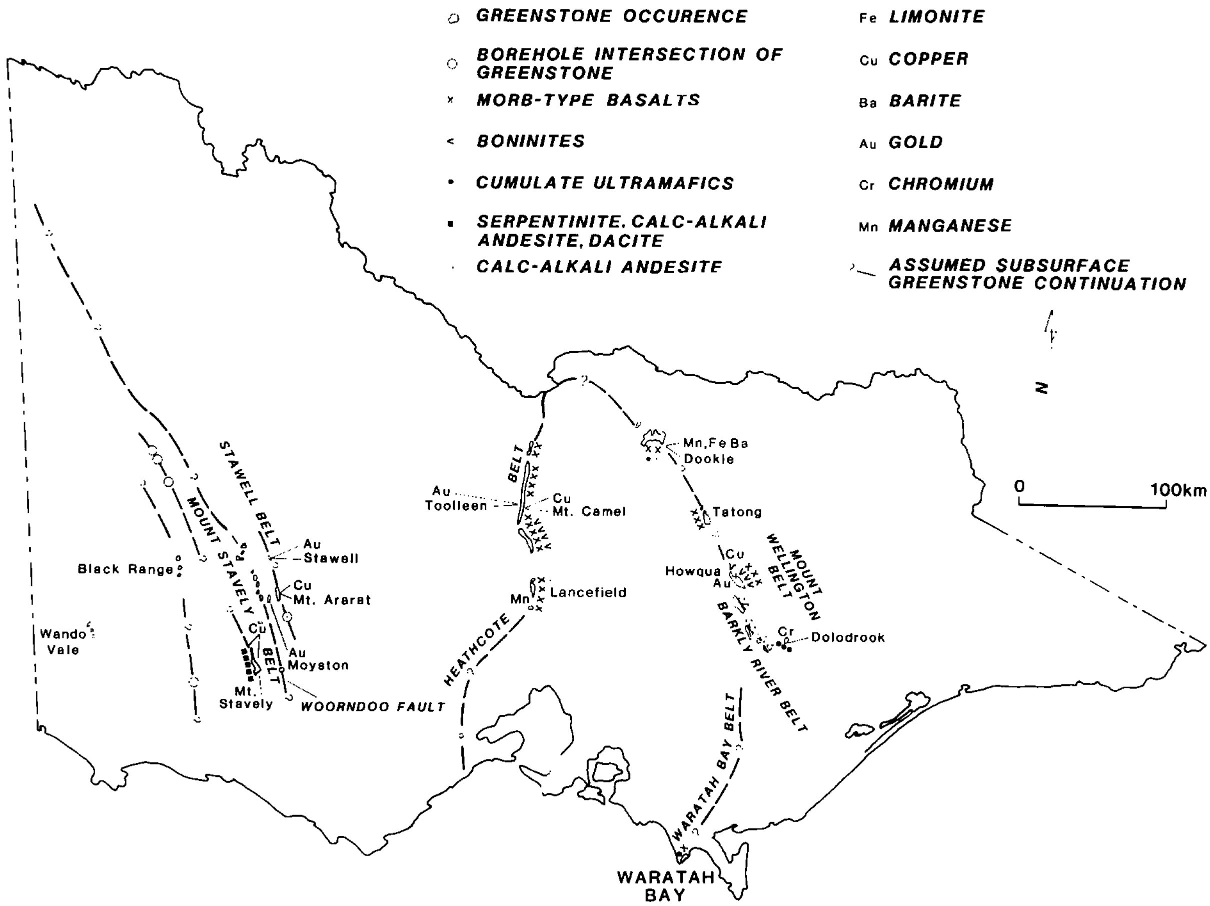

Fig. 3. Cambrian greenstone belts, sediments, and associated mineral occurrences, Victoria.

Mount Stavely (Mount Stavely Volcanic Complex; Buckland and Ramsay, 1982) of assumed Cambrian age, where an association of serpentinite, variolitic basalt, two-pyroxene and pyroxene—hornblende andesite, dacite, rhyolite, volcaniclastic equivalents of the intermediate to acid lavas, and high-level quartz porphyries has been described. Chemically and mineralogically the association constitutes a calc-alkaline assemblage. In the present paper the Mount Stavely Volcanic Complex is included within the Lachlan Fold Belt, though this interpretation depends critically on whether the Woorndoo Fault represents the eastern margin of the Glenelg Zone. Crawford (1984) has suggested a chemical difference between rocks of the Mount Stavely Volcanic Complex and greenstones to the north (Mount Drummond, Mount Dryden, Bellellen) with the latter subbelt containing a >1 km thick pile of comagmatic low-Ti, high-Mg andesites. However, additional data (Ramsay, unpubl.) suggest a much greater range in composition and chemistry for these more northern occurrences. Farther to the east, in a belt running southwards from Great Western through Mount Ararat (Fig. 3), is a sequence of regionally metamorphosed quartz—biotite schists, and minor graphitic and ferruginous schists (Dronseika, 1974). Pennzoil (EL 467/509, 1974—1981) reports that amphibole schists (altered mafic and intermediate lavas and volcanogenic sediments) form lenses interbedded with quartz—biotite schists, and mapping in the region to the north of Mount Ararat has identified the thickest occurrence of amphibolite, possibly representing a volcanic centre. Preliminary geochemistry suggests that some of the quartz—biotite schists and associated sericitic schists may have a silicic volcanic component. At Stawell, spilitised mafic lava has been recognised and the entire belt is here provisionally termed the Stawell Belt (Fig. 3). The relationships of these altered and schistose mafic rocks to the essentially non-schistose Mount Stavely Volcanic Complex is uncertain although Buckland and Ramsay (1982) have suggested they may be time equivalent. As yet no mineralogical or geochemical relationships have been established.

Central Victorian greenstone belts

The Cambrian of the Central Victorian greenstone belts (Fig. 3) differs in detail from place to place, but it typically comprises a lower portion dominated by igneous rocks, and an upper portion of non-terrigenous clastics and hemipelagic sediments. Metabasalt of MORB-affinity (mid-ocean ridge basalt) typically dominates in most localities; however low-Ti, magnesian lavas of boninite affinity have also been recognised from the work of A. Crawford (Fig. 3). In the Licola segment of the Barkly River Belt, meta-andesites of calc-alkaline character occur.

The identification of Cambrian MORB-related and magnesian, low-Ti lavas, by analogy (on geochemical and petrographical grounds) with comparable occurrences in the Western Pacific, has been used in various models (Crawford, 1984; Crawford et al., 1984) which involve thin oceanic crust, intra-oceanic island arcs, and back-arc spreading in the Lachlan Fold Belt of Victoria.

There is a marked absence of sheeted dykes, but there are thick sills, especially in the Mount Wellington Belt, ranging from olivine meta-pyroxenite to dolerite. Ultramafic intrusions are rare except at Dolodrook (Fig. 3) in the Mount Wellington Belt, where partly serpentinized peridotitic rocks predominate. Minor metaperidotite is reported from the Waratah Bay Belt (Crawford and Keays, 1978).

Faulting has removed substantial portions of the sedimentary Cambrian from most outcrops; only the Lancefield segment of the Heathcote Belt has a complete succession. There, the metabasalts are concordantly overlain by a non-terrigenous sequence which changes upwards from black shale to chert, and shows a decrease of volcanogenic interbeds. Argillites with interbedded volcanogenic/lithic arenites also overlie the igneous rocks at Howqua River and Wellington River — in the latter locality, there is a graded serpentinite conglomerate at the contact, and a thin band of shallow-water limestone higher up in the clastic sequence.

A thick sequence of unfossiliferous sediments lies in the western portion of the Ararat—Bendigo Zone (Fig. 1). Its boundary with the fossiliferous Lower Ordovician to the east is known as the "Wedderburn Line" (Fig. 2), but its nature is poorly understood, although the possibility of a major structural break or unconformity has been suggested (VandenBerg and Wilkinson, 1982). Apart from the lack of graptolites and the local development of regional metamorphics, the rocks are little different from the Lower Ordovician, and the assumed Cambrian age is therefore still tentative.

Mineralization of Cambrian mafic–ultramafic affiliation

Mineralization associated with Cambrian igneous activity is of variable economic importance and shows a variety of styles from minor orthomagmatic chromite deposits, to Au and Cu deposits of syngenetic or epigenetic origin, to Fe—Mn, Ba occurrences of exhalative volcanogenic affiliation.

The bulk of gold production in Victoria has been from deposits which show no obvious genetic relationship to mafic igneous rocks. However, there are a small number of occurrences, some significant, which have a spatial relationship with igneous rocks, especially of mafic affinity, and a number are found in the Cambrian sequences (Fig. 3). Deposits include Stawell, Toolleen, Moyston, and Howqua and a discussion of these is given in the section dealing with gold mineralization in Victoria.

Copper prospects of minor importance are associated with Cambrian volcanism (Mount Stavely, Mount Ararat, Mount Camel, and Howqua; Fig. 3). Buckland and Ramsay (1982) emphasised the calc-alkaline affinities of the Mount Stavely Volcanic Complex, its fragmental nature, and deposition in an aqueous environment. They also drew broad analogies with volcanic sequences in the Precambrian of Canada. Exploration within the Mount Stavely Volcanic Complex has recognised two prospective areas for copper (Pennzoil, EL 554, 1975—1982).

To the east within the Stawell Belt occurs the exhalative Mount Ararat copper body located within quartz—actinolite, quartz—biotite, and graphitic schists together with minor serpentinite. The sequence has been thermally metamorphosed by the Ararat Granodiorite (380 ± 15 Ma; Richards and Singleton, 1981). Exploration by Pennzoil (EL 467/509, 1974—1981) has indicated reserves of a little over one million tonnes at 2.7% Cu, 9 g MT^{-1} Ag, 0.6 g MT^{-1} Au, and 0.5—1% Zn.

Minor manganese-bearing exhalative concentrations are associated with sediments interbedded with volcanics in the Heathcote Belt (Crohn, 1951) and to the north, at Dookie, barite lenses occur within metavolcanics on Mount Major. On the eastern flank of Mount Major are located limonitic zones which are contained within thinly bedded siliceous shales. Here several thousand tonnes at between 30—50% Fe have been estimated to occur together with associated manganese oxides (Bain and Medwell, 1956).

Orthomagmatic segregations of chromite are of limited occurrence and occur either as fine disseminations in serpentinite in the Mount Stavely Volcanic Complex and in talcose olivine cumulates at Dookie, or as podiform segregations at Dolodrook (Bell, 1968).

In summary, the earliest development of the Lachlan Fold Belt in Victoria is manifested by the presence of volcanism, which is typically mafic to intermediate, together with associated volcaniclastic, pelagic, and hemipelagic sediments. The western Mount Stavely Belt has in part a calc-alkaline character, and this portion may represent an Andean-type setting adjacent to the Precambrian Australian Craton. The tectonic setting of the other greenstone belts is more equivocal and depends on the nature of the subcrustal rocks. Conflicting proposals include Proterozoic sialic crust or thin oceanic crust with the latter being associated with island arcs and back-arc spreading. An alternative suggestion is proposed for the Tasmanian Cambrian greenstones (Collins and Williams, this volume), where the metavolcanics are considered to represent narrow simatic tension zones developed during rifting of Precambrian sialic crust.

Exhalative mineralization associated with the initial formation of the Lachlan Fold Belt is typically hosted by mafic and ultramafic rocks and is often characterised by Cu and Au, minor Zn, and negligible Pb. Au may also occur in epigenetic stockworks. Exhalations contained within fine-grained sediments intercalated with, or overlying mafic rocks often contain Fe and Mn concentrations. Orthomagmatic occurrences of Cr within altered peridotites are either disseminated or podiform in character.

Ordovician sedimentation and tectonics

The varied lithofacies of the Cambrian are followed by Lower Ordovician turbidites which appear to be broadly uniform throughout the State. The exception is at Waratah Bay (Fig. 3), where instead of turbidites, the Cambrian is succeeded by shallow-water

Digger Island Limestone, of Tremadoc (= Lancefieldian) age. This is the oldest of several shallow-water deposits on this belt, which collectively indicate a persistent high during much of the Early Palaeozoic. Evidence that the other Cambrian belts behaved in similar fashion is singularly lacking, at least until the end of the Ordovician. At Heathcote, Lancefield, and Howqua River, the Cambrian is followed by thick quartz–mica turbidite sequences, and a similar sequence is exposed on the Mornington Peninsula, within the future Melbourne Trough. All this indicates a relatively flat seafloor, without narrow "highs" which would have presented obstacles to sedimentation. There is thus little evidence in support of the five Ordovician basins or troughs, separated by structural highs, as postulated by Beavis (1976).

The Ordovician turbidites are quartz-rich with some detrital mica and very little feldspar. Their provenance is of mixed, low metamorphic grade quartz-rich sediments and granites with a small input from regional high-grade metamorphics. A northerly transport direction is predominant, both in the eastern portion of the Ararat–Bendigo Zone (Fig. 1) (Cas et al., 1983) and in eastern Victoria (Byrne, 1983). As well as the turbidite facies described by Cas et al. (1983), the sequence in the eastern portion of the Ararat–Bendigo Zone also contains channel sandstones, grits and fine conglomerates with low cut-and-fill structures, normal and reverse grading, and medium-scale cross-lamination.

Broad facies differences first appeared at the beginning of the Late Ordovician. The Riddell Sandstone, exposed in the Darraweit Guim Province northwest of Melbourne (Fig. 4) represents a turbidite fan facies with

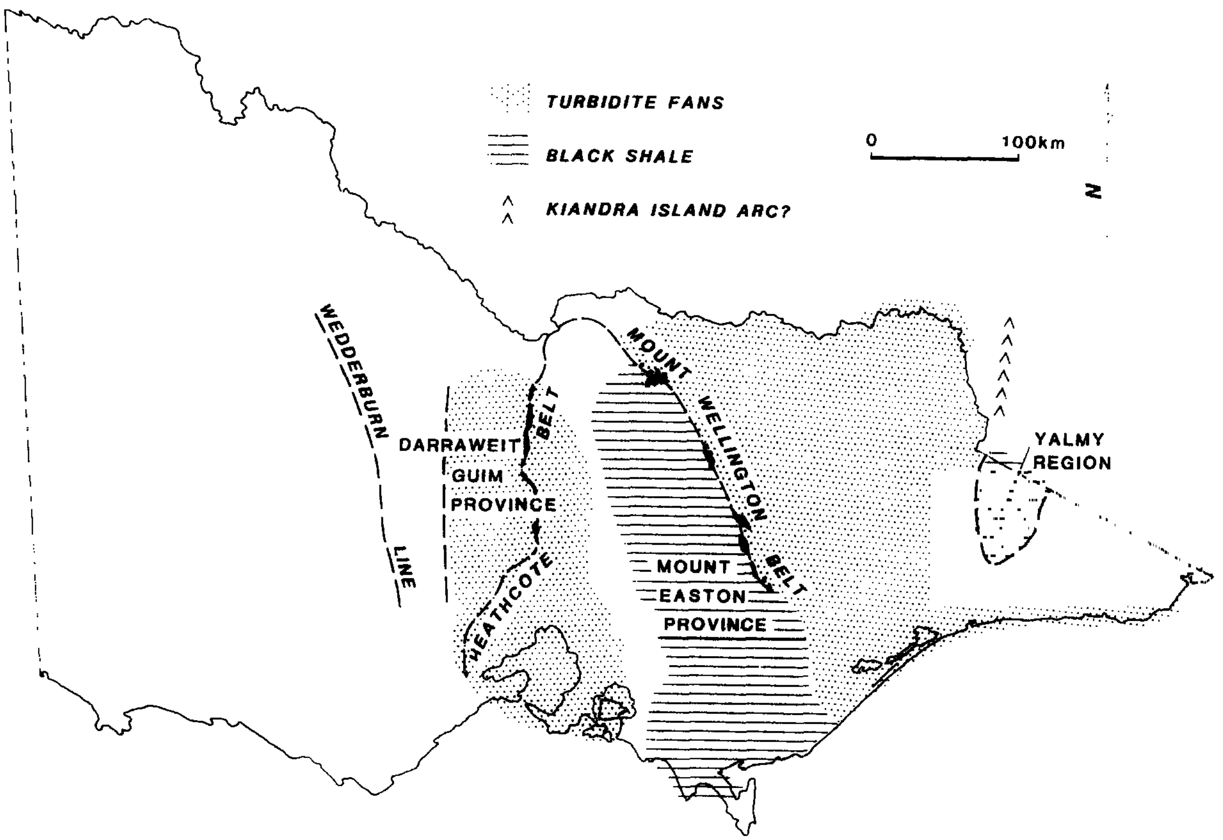

Fig. 4. Late Ordovician sedimentary provinces, Victoria.

channel sandstones, which is little different from the underlying Lower Ordovician. Farther east, however, the entire Upper Ordovician (Fig. 4) consists of a black shale (Mount Easton Shale) representing prolonged undisturbed euxinic conditions. This extends at least as far east as the Mount Wellington Belt. East of this, fossil and structural data are sketchy, but there is growing evidence that the sequence here likewise consists of Lower Ordovician turbidites with uncommon cherts and Upper Ordovician black shale. This subdivision occurs at Tabberabbera (C. Fergusson, pers. commun., 1985) and persists at least as far east as the Yalmy region. At Yalmy the turbidites of the Lower Ordovician Pinnak Sandstone (VandenBerg, in Webby, 1981) (= Adaminaby beds, = "Mallacoota Beds") are largely of the quartz–mica rich types, but a few consist of feldspathic lithic material, perhaps derived from the volcanic arc of Kiandra. Powell (1983a,b) envisages these sediments as an accretionary prism in an eastward-facing fore-arc setting.

The Benambran Orogeny

The Ordovician style of sedimentation was ended by the Benambran Orogeny and henceforth, sedimentation took place in more localized basins separated by emergent blocks. Benambran folds are best documented in the Mitta Mitta—Eskdale region [(55)524,5960] where two ductile deformations are recorded. The early (D_1) folds are upright to steeply inclined, non-plunging or gently plunging tight to isoclinal mesoscale folds with a well-developed axial plane slaty cleavage (S_1) (Bolger et al., 1983). Little is known of the strike of the axial surfaces, although mapping at Eskdale (Kilpatrick, 1979) suggests that D_1 folds trend northeasterly and are slightly recumbent with southeast-dipping axial planes. The later (D_2) folds trend 150° and vary in profile from open to isoclinal, with steeply plunging to reclined hinges and an axial plane crenulation cleavage (S_2) (Kilpatrick, 1979; Bolger et al., 1983). Farther west at Kiewa, the style of both deformations is similar but D_2 folds trend more westerly (Beavis and Beavis, 1976). At Delegate, on the New South Wales border, Benambran folds include tight upright NNE-trending F_1 folds with an axial surface cleavage and locally overturned F_1 folds (Glen and VandenBerg, 1985).

High heat flow during the deformation produced the Omeo Metamorphic Complex, a broad belt of regional metamorphics which trends from Ensay [(55)574,5864] NNW to the NSW border at Albury and forms part of the Omeo-Wagga Metamorphic Belt. The belt consists of magmatic gneiss, schist, phyllite, and foliated granites, with increasing grade marked by development of cordierite, andalusite, sillimanite/K-feldspar, and garnet.

Age constraints for the deformation and metamorphism are not good. At the type locality of the Benambran Orogeny in the Wombat Creek region (Fig. 5), the timing is poorly constrained by Eastonian (middle Late Ordovician) graptolites below, and Late Silurian shelly fossils above the unconformity. Rocks immediately east of the Omeo Metamorphic Complex and gradational with it contain Late Ordovician graptolites, the youngest being late Bolindian at Walwa [(55)566,6020] (VandenBerg, 1980). Unconformable relationships between Upper Ordovician and Lower Silurian rocks are known from the Canberra region in NSW (Crook et al., 1973; Owen and Wyborn, 1979), but not in Victoria, where these tectonic movements are only expressed as facies changes in the Melbourne Trough and in the Yalmy region. Indeed, the regional context of the Bolindian graptolites at Walwa suggests that a significant thickness of (presumably Lower) Silurian sediments must once have provided a cover for the large granite plutons surrounding Walwa. Unconformities within the Lower Silurian are recorded from the Canberra region (Owen and Wyborn, 1979) and from the Orange district on the Molong High (Packham, 1969), but again cannot be demonstrated within Victoria. In

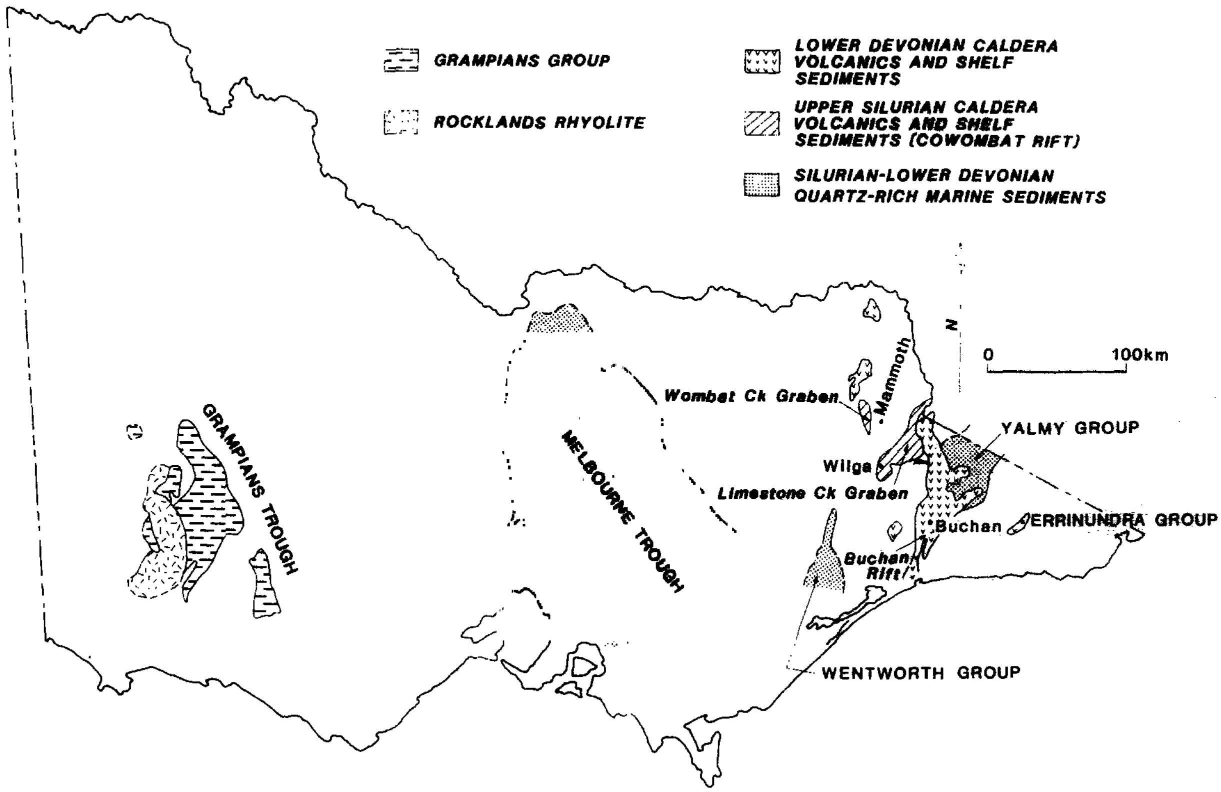

Fig. 5. Silurian and Lower Devonian sedimentation and associated mineral occurrences, Victoria.

the Yalmy region, the earliest recorded deformation is late Llandovery and cannot at this stage be distinguished from the "Quidongan" Orogeny of Crook et al. (1973).

Strong local contrast of the effects of the Benambran deformation is best demonstrated in the Yalmy—Delegate region. In the Mallacoota Zone, east of the Yalmy Fault (I-S line) Glen and VandenBerg (1985) have recorded two fold phases from the Ordovician rocks, which are overlain with angular unconformity by the Lower Silurian Tombong beds. In the Buchan Zone immediately west of the fault, however, the relationship between the Upper Ordovician Warbisco Shale and Lower Silurian Yalmy Group is essentially concordant, albeit marked by zones of complex thrusting.

Age constraints are also very poor for the deformation of the rocks of the Ararat—Bendigo Zone in western Victoria. VandenBerg and Wilkinson (1982) record two deformations in the unfossiliferous St. Arnaud Beds of assumed Late Cambrian age, and a single deformation in the fossiliferous Lower Ordovician. The latter has produced closely spaced tight upright NNW-trending folds with a well-developed axial plane slaty cleavage and numerous high-angle west-dipping reverse faults. An upper constraint on the age of the deformation is that it predates the intrusion of the 400 Ma cluster of granites in the Early Devonian; a Benambran age is therefore quite possible.

We therefore envisage the Benambran Orogeny as an initial period of regional diastrophism causing facies changes and local unconformities, combined with, or followed by folding on a more localized scale, with restricted zones of high thermal gradient and melting, producing the regional metamorphic belts. The main uplift and erosion appears to have taken place fairly late, perhaps in the late Llandovery, represented possibly by the Quidongan Orogeny.

Plutonism associated with, and immediately following the Benambran Orogeny marks the initiation of recorded Sn mineralization together with associated W and Mo. Examples include the tungsten—scheelite—cassiterite-bearing quartz veins at Koetong [(55)445,990] and the cassiterite-bearing lodes at Mount Cudgewa [(55)478,786].

Middle Palaeozoic troughs, rifts, and associated mineralization

In contrast with the extensive Ordovician turbidite and black shale sequences, the Silurian—Lower Devonian deposits are confined to a small number of well-defined troughs and rift-like grabens. A feature of this interval is the strong regional diversity, with each trough having its own depositional and deformational history.

Grampians Trough

The Grampians Trough (Fig. 5) located in the Grampian Zone straddles the boundary between the Glenelg Zone and the Lachlan Fold Belt. It represents a north—south trending graben filled with some 6 km of dominantly non-marine quartzose sandstones, and green and red sandstone and siltstone (Grampians Group). Soft-sediment deformation and trough cross-bedding are common in some of the sandstones. West of the Grampians Group lies the Rocklands Rhyolite, a caldera sequence of acid pyroclastics, lavas, and their reworked products.

Spencer-Jones (1976) interpreted the Grampians Group to overlie the Rocklands Rhyolite, but field relations are not clear and the rhyolite has yielded a K/Ar age of 392 ±10 Ma (McKenzie et al., 1984), which is similar to ages of granitoid intrusives into the Grampians Group (range 402 ± 4 Ma; Bowen, 1975; Richards and Singleton, 1981). On this evidence the Rocklands Rhyolite is Lower Devonian. Deformation of the Grampians Group includes broad open folds and local overturning due to thrusting along the Woorndoo Fault. This folding occurred prior to intrusion of Early Devonian granitoids and is probably Silurian. Mineralization associated with the Grampians Group and Rocklands Rhyolite is negligible, possibly reflecting the dominant non-marine to subaerial character of the rocks.

Melbourne Trough

The Melbourne Trough in Central Victoria (Fig. 5) contains a thick unbroken sequence of Silurian—Lower Devonian sediments which lie conformably on Ordovician turbidites and black shales. Its western boundary is sharply defined by the Mount William Fault (Fig. 2), but its eastern boundary is still poorly documented. It is by convention drawn along the Mount Wellington Belt, in the Howqua Zone.

Facies differences within the trough and with adjacent areas are traceable to the Gisbornian (early Late Ordovician) and the broad facies patterns established at that time continued through the Silurian and into the Early Devonian. The Darraweit Guim Province (Fig. 4) in the west contains a much thicker basal Silurian to Pragian sequence (9—10 km) than the Mount Easton Province to the east (2.2 km thick for the same interval). The Melbourne Trough sequence as a whole consists of alternating (outer?) shelf mudstone units and turbidite fan deposits with channel conglomerates and slumped beds. Apart from reef quartz, quartzite, and chert the channel conglomerates contain rock types which indicate distant source areas (rhyolite, basalt, and biotite schist clasts in the Silurian and granite clasts in the lowermost Devonian).

Whereas within the Melbourne Zone there is no evidence for a break between the Ordovician and the Melbourne Trough succession, circumstantial evidence exists for diastrophism at the end of the Ordovician. The highest Ordovician unit (Darraweit Guim

Mudstone) contains over 40% finely disseminated carbonate (VandenBerg et al., 1984b), which is not clastic but appears to be a primary precipitate. Excessive evaporation seems the most likely explanation, and this requires that the Melbourne Trough behaved like a barred basin. After progressive shoaling in the Lower Devonian, sedimentation in the Darraweit Guim Province ceased with deposition of shallow-marine limestone (VandenBerg and Wilkinson, 1982). The Mount Easton Province underwent some kind of rejuvenation marked by the deposition of the thick (5 km +) turbiditic Walhalla Group, which in contrast with most other units in the Melbourne Trough, had its source to the east. Sedimentation here ended at about the close of the Early Devonian with deposition of the 2–4 km thick, regressive Cathedral Group (VandenBerg, 1978b; VandenBerg and Wilkinson, 1982).

Buchan Zone

The relationship between the Lower Silurian Yalmy Group and the Upper Ordovician Warbisco Shale in the Buchan Zone, is obscured by duplex bedding-parallel thrust faulting, which has produced a series of stacked thrusts. The Yalmy Group is several kilometres thick and appears to be largely shallow marine with a thick basal unit of coarse deltaic sandstones passing up into mudstone and turbidites. The group contains middle Llandovery graptolites, slightly older than recorded from the Tombong beds which lie a short distance to the east [(55)672-5803] (Crook et al., 1973). There is no evidence here of any epi-Ordovician deformation, despite the strong facies difference between the Yalmy Group and the Warbisco Shale.

The deformation of the Yalmy Group is not well constrained -- it may have occurred during the late Llandovery (Quidongan Orogeny of Crook et al., 1973) or the epi-Silurian Bindian Orogeny (VandenBerg et al., 1984a).

Rocks of undoubted Llandovery age are not known from the western part of the Buchan Zone, but there is evidence that the Towanga Sandstone of the upper Buchan River [(55) 598,5907] underlies the Thorkidaan Volcanics and may thus be Lower Silurian or even older (contra Talent et al., 1975; VandenBerg et al., 1984a). The relationship of the Towanga Sandstone with the adjacent Ordovician rocks is obscured by faulting, but its contact with the Thorkidaan Volcanics is an angular unconformity (Dugdale, 1982) indicating some degree of folding, perhaps during the epi-Llandovery Quidongan Orogeny.

The Quidongan Orogeny was followed, in perhaps late Wenlock time, by crustal extension and rifting of two large grabens in eastern Victoria (Limestone Creek Graben and Wombat Creek Graben) known collectively as the Cowombat Rift (Fig. 5; VandenBerg and Wilkinson, 1982). Both grabens were filled with thick acid pyroclastics and lava, followed by shallow-marine sediments containing Late Silurian shelly fossils. A resurgence of volcanism within the Limestone Creek Graben includes a significant andesitic component (Fig. 6).

Mineralization of volcanogenic affiliation occurs in a number of localities within the Cowombat Rift. When compared to the Cambrian mafic-dominated, metallogenic event, the current style of mineralization with increased amounts of Zn, Pb, and Ag appears to reflect the evolving nature of volcanism, which is now characterised by intermediate to acid effusives. The two most significant prospects are Wilga (Fig. 5) and Currawong located 3.5 km to the northeast. The subvolcanic or exhalative, complexly mineralized, Mammoth Lode (Fig. 5) is now known to be hosted also by Late Silurian sediments.

Limestone Creek Graben

This is equivalent to the Reedy Creek Graben of VandenBerg and Wilkinson (1982). Recent work by Dugdale (1982) indicates that the Thorkidaan Volcanics dip more or

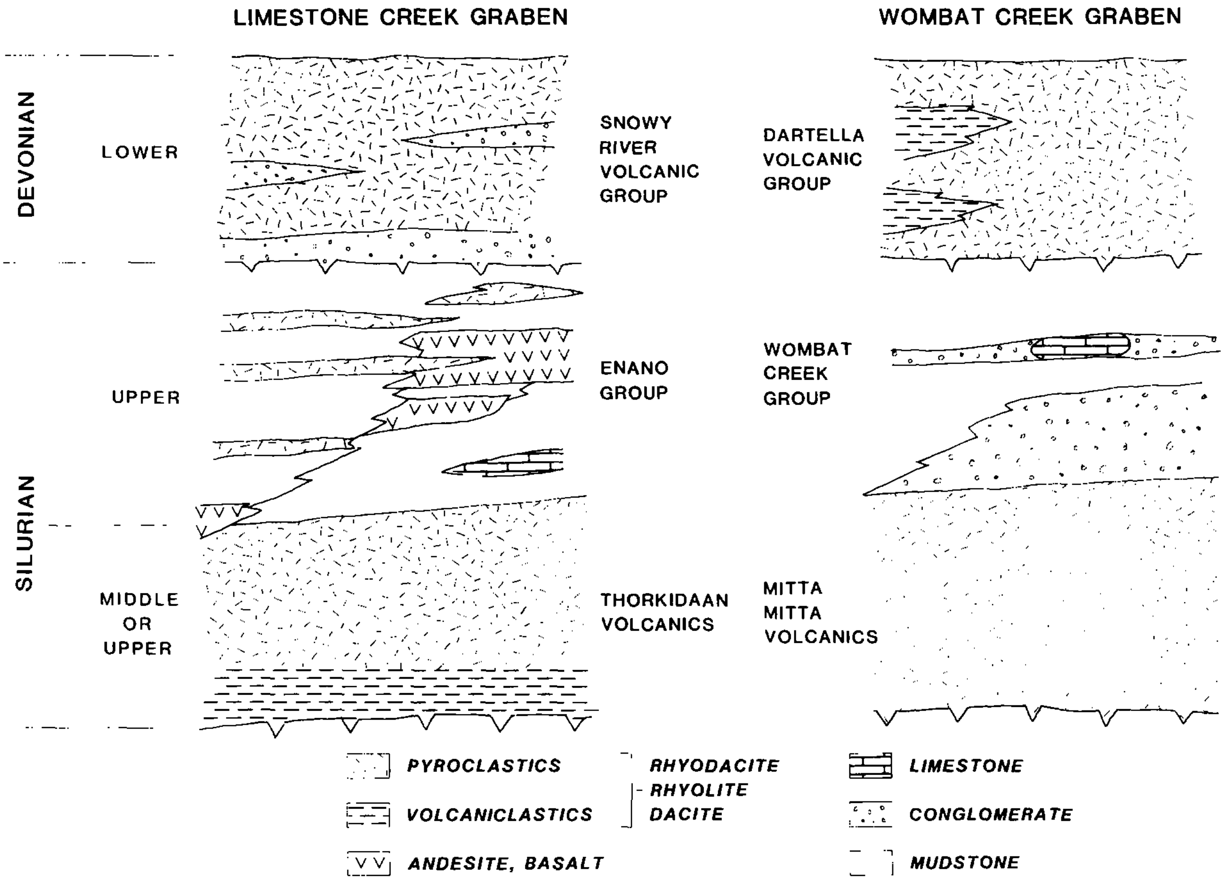

Fig. 6. Silurian and Devonian stratigraphy of Cowombat Rift, northeast Victoria (not to scale).

less uniformly to the northwest and may be as much as 6 km thick. They overlie the Towanga Sandstone with angular unconformity and consist mostly of extrusive lava and ignimbrite, with minor fluvio-lacustrine sediments (Wood, 1979; VandenBerg et al., 1984a; R. Allen, pers. commun., 1985). The basal 400 m exposed in the Buchan River [(55)597,5912] consists of coarse volcanogenic sandstone with generally poor bedding, indicating rapid deposition in a subaqueous, perhaps marine environment.

The stratigraphic relationships within the Enano Group overlying the volcanics are still somewhat conjectural. In the southwestern part of the graben, e.g. at WMC's Wilga and Currawong prospects, the Thorkidaan Volcanics pass up into interbedded volcanics and argillite with limestone lenticles, a sequence which is best placed in the Gibsons Folly Formation (VandenBerg et al., 1981). Farther northeast, however, these two units are separated by a broad belt of Cowombat Siltstone, which resembles the Gibsons Folly Formation but lacks volcanics. Recent work by Orth, VandenBerg and Wyborn has investigated the relationship of the Bumble Creek Andesite. This unit of andesitic lava, andesite breccia, minor argillites and small diorite pods was initially thought to be quite discrete from the surrounding Gibsons Folly Formation, perhaps even representing a southerly extension of the Ordovician volcanics which outcrop near Khancoban. The andesite is now known to extend to Dead Horse Creek [(55)594,5924], where andesite flows are interbedded with acid volcanics and argillites of the Gibsons Folly Formation. There now seems little reason to doubt that the Bumble Creek Andesite is an integral part of the Enano Group.

Wombat Creek Graben

The Wombat Creek sequence has been revised recently by Bolger et al. (1983). The thick Mitta Mitta Volcanics consist of dacite and rhyodacite which is largely without textural evidence of its origin, but is assumed to be a mixture of pyroclastics and lavas. It is overlain by the Wombat Creek Group, which consists of nearly 4 km of shallow-marine conglomerate with limestone lenses, siltstone, and turbiditic sandstone (Fig. 6). Unlike the Enano Group, there are no interbedded volcanics, nor any significant volcanogenic sediments.

Mineralization

The interplay of marine conditions and volcanism has resulted in the formation of a number of base metal, Ag, Au and Fe prospects, some of which show a spatial relationship to interbedded limestones within the Cowombat Rift. Such deposits include the Danes Creek Ag—Pb prospect near Dartmouth [(55)552,5953] and numerous gossans within the Limestone Creek Graben (Cochrane, 1982; VandenBerg et al., 1984a). The most significant gossans discovered to date occur on McDougal Spur above the Tambo River at Wilga (Fig. 5) and at Currawong. Both prospects are regarded as originating through exhalative volcanogenic activity and are believed to represent time equivalents to other exhalative base-metal deposits to the north within the Captains Flat Synclinorial Zone in New South Wales.

Beneath the Wilga deposit there are massive felsic volcanics overlain by argillites including a persistent brecciated and conglomeratic layer which forms the footwall of the sulphide deposit. Argillite continues above the deposit where it includes interbedded units of felsic and mafic/intermediate volcanics and volcaniclastic sediments (Fig. 7).

A thin selvedge of intense chloritic alteration encloses most of the massive sulphide lens and silica, sericite, and pyrite are extensively developed as alteration of the argillites on the flanks and above the sulphides. The sulphides occur as banded and massive pyrite, sphalerite, and chalcopyrite with minor chlorite and silica—sericite gangue. Chalcopyrite is also developed within the chloritic alteration zone and particularly where this zone has formed as a band between massive sulphide strata on the western edge of the deposit.

The ore reserve at Wilga is 4×10^6 t at an average grade of 3.3% Cu, 0.4% Pb, 5.4% Zn, and 29.6 g MT^{-1} Ag.

The Currawong deposit consists of several lenses which are also hosted by argillites. Although no stratigraphical relationship has been established between the Wilga and Currawong deposits, the lithological sequence at each deposit is similar.

The several lenses of massive sulphides forming the Currawong deposit may have initially constituted a single mineralised zone subsequently disrupted by a reverse fault or thrust. The massive sulphide lenses consist of very fine-grained pyrite, sphalerite, and chalcopyrite. There has been no ore reserve announced for Currawong but the weighted average of the grades of drill intersections announced are 1.8% Cu, 0.8% Pb, 4.6% Zn, and 37 g MT^{-1} Ag.

On the southeastern side of the Gibbo River some 30 km NNE of Benambra (Fig. 2) is a sequence of deformed Upper Silurian* siltstones and sandstones. Within these sediments is a quartz—feldspar unit striking north for some 5 km and having a maximum width of 0.4 km. In the Mammoth Lode, iron oxides

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*A provisional graptolite age of late Silurian was announced as this manuscript was being prepared (Marathon, EL 1228, 1983). Recent mapping by Pan Australian Mining Ltd. geologists in the vicinity of the Mammoth prospect, has discovered additional graptolites, which have been identified by F.C. Beavis as early Ordovician.

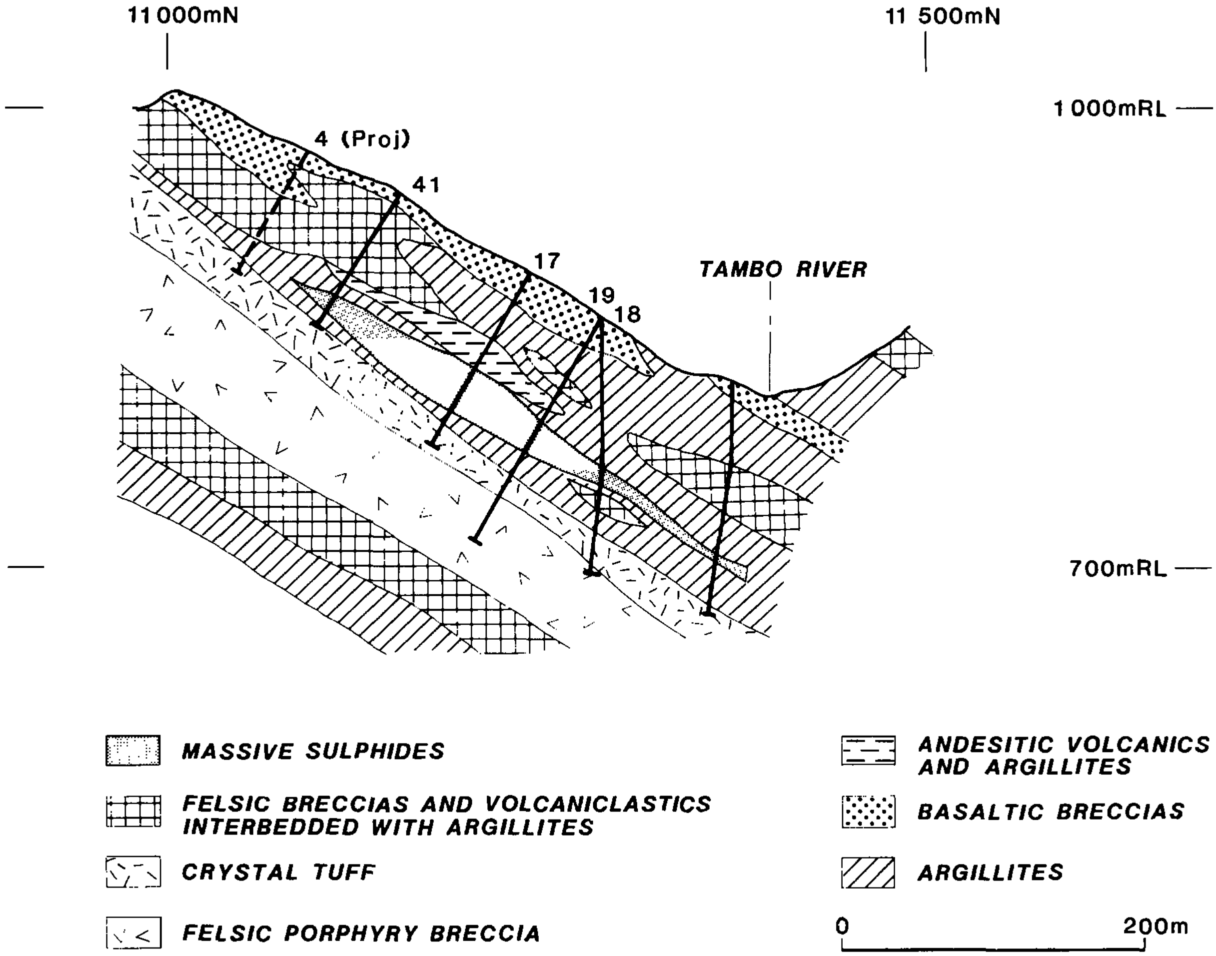


Fig. 7. Geological cross-section 14050mE, Wilga prospect, Benambra (with permission WMC Ltd.).

— limonite, haematite (goethite) — are particularly well developed, especially where bedrock has been brecciated. Pyrite is freely disseminated within the quartz—feldspar "porphyry" and is concentrated along margins of wider masses. Pyrite content estimates from drill core are as high as 50% (Cochrane, 1982).

Traditionally the quartz—feldspar units have been regarded as intrusive porphyry dykes and stocks indicative of a high-level or sub-volcanic setting in the late Silurian or Devonian. The massive vein pyrite with minor amounts of Sn, Cu, Pb, Zn, Au, Bi, ±Mo and associated quartz—ankerite—barite—gangue, is thought to have resulted from hydrothermal activity related to one of the intrusive phases.

Assays of gossans have yielded the maximum values of 6.25% Sn, 3.6 ppm Au, 132 ppm Ag, 105 ppm W, and anomalous Pb and Cu. Mineralization appears to be related to the porphyries/volcaniclastic units and is outlined by broad Sn, Pb, Ba lithogeochemical haloes. In the southern portion of the Mammoth prospect, stockwork or footwall mineralization has developed within porous breccia units adjacent to the mineralizing conduits.

The Bindian Deformation

Although Talent (1965, 1969) recognized that some sort of angular discordance occurs below the Lower Devonian Buchan Group at Bindi, it was not realized until recently that two distinct volcanic units underlie the Buchan Group (VandenBerg et al., 1981).

Talent included all the volcanic rocks in the Lower Devonian Snowy River Volcanics and regarded the deformation as a period of block faulting and planation which took place before the deposition of the Buchan Group. Packham (1969) introduced the term Bindi Orogenic Phase for this event, regarding it as the final phase of the Bowning Orogeny. Recent work, however, has shown that there is little or no discernible break between the Snowy River Volcanics and the Buchan Group (Lew, 1979; Wood, 1979; Orth, 1982; VandenBerg et al., 1984a), but that a strong angular unconformity exists between the Snowy River Volcanics and the underlying cleaved and silicified Thorkidaan Volcanics (VandenBerg and O'Shea, 1981; VandenBerg et al., 1984a).

This relationship is maintained throughout the Limestone Creek Graben, and has been recognized recently also in the Wombat Creek Graben, where the Upper Silurian rocks were folded prior to the deposition of the Lower Devonian Dartella Volcanic Group (Bolger et al., 1983). In both grabens, the Bindian Deformation produced tight to isoclinal folds with slaty or reticulate cleavage, or, less commonly, more open folds. Metamorphic grade is characteristically of the lower greenschist facies.

It seems likely that the Grampians Group of western Victoria was also folded at about this time — certainly before the intrusion of the Early Devonian granitoids. These granitoids form a distinct grouping extending across the "Wedderburn Line" into the fossiliferous Lower Ordovician.

This relationship is interesting because it provides direct evidence that the Ordovician rocks were folded prior to the Middle Devonian Tabberabberan Orogeny, which is the only folding event recorded in the Melbourne Trough. There is also evidence of an early folding event quite close to the western boundary of the Melbourne Trough near Gisborne [(55)292-5851], where Upper Ordovician shales are overlain unconformably by the Kerrie Conglomerate. Thomas (1932) assigned the Kerrie Conglomerate to the Upper Devonian on lithological grounds, but mapping by one of us (AHMV) indicates that the Kerrie Conglomerate was folded during the Tabberabberan Orogeny and hence is most probably Early Devonian. The age of the unconformity underneath it can only be guessed at, but regional geological relationships suggest that it is unlikely to be much older than Early Devonian.

Buchan Rift

The Bindian Deformation was followed by yet another episode of crustal extension in the Buchan Zone, causing the formation of the broad meridional Buchan Rift, which was partly superimposed on the earlier Limestone Creek Graben (Fig. 5). Renewed rifting also took place in the Wombat Creek Graben. Deposition in the Buchan Rift began with the Snowy River Volcanics, a thick (2.5 km +) stratigraphically complex sequence of mostly thick welded rhyolitic and rhyodacitic ignimbrites or ash flow tuffs (Cas and Wright, 1983). Associated sediments comprise conglomerates, breccias, sandstones, black pyritic shales, and mudstones of predominantly volcanogenic origin. Recent mapping by mining companies and members of Monash University has delineated individual caldera-type complexes, rhyolite domes, and associated tuff ring deposits. Thin fluviatile pebbly volcanogenic beds also contain pebbles derived from outside the rift, indicating that the rift was a persistent depositional "sink". In the south, late Early Devonian marine sediments are intercalated with the volcanics. Subsidence within the rift continued after volcanism had ceased and led to deposition of the Buchan Group comprising about 900 m of fossiliferous, shallow-marine limestone and calcareous argillite.

In the Wombat Creek Graben, this episode is represented by the thick Dartella Volcanic Group, formerly regarded as part of the Mitta Mitta Volcanics. It consists largely of ignimbritic rhyolite, rhyodacite, dacite, and some andesite and minor interbedded clastics (Bolger et al., 1983). Marine sediments are lacking.

Mineralization

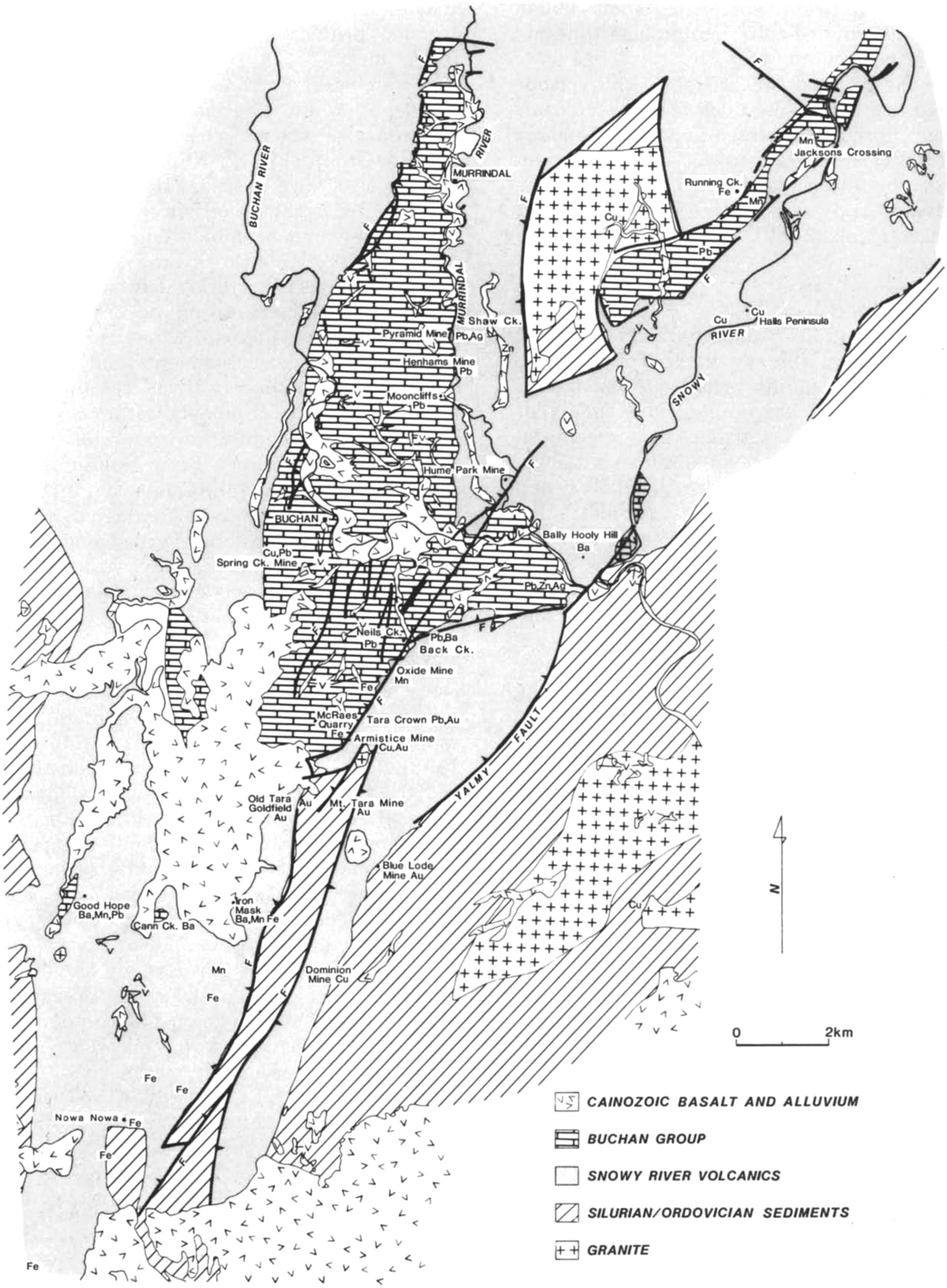
The evolution from essentially subaerial acid volcanism (Snowy River Volcanics) to transgressive marine shelf sedimentation (Buchan Group) has resulted in a variety of mineralizing styles and deposits. Mineralization varies from epigenetic veins containing anomalous Cu, Bi, Ag, and Au (Halls Peninsula, Fig. 8) to a variety of base metal, Fe, Mn, Ba deposits and prospects of volcanogenic exhalative affinity, to Pb—Zn occurrences spatially associated with younger shelf sediments having a marked carbonate component. Several stratabound iron formations are associated with either the top of the Snowy River Volcanics (Iron Mask, Fig. 8) or the overlying limestones of the Buchan Group (McRaes Limonite Quarry).

Within the Snowy River Volcanics, many of the exhalative deposits appear to be localised in the higher portion of the group. This transitional unit (Spring Creek Member) comprises interbedded volcanogenic sediments, limestones, shales, and cherty sediments (in part pyritic). Geochemical results indicate that the transitional sediments at Jackson Crossing—Running Creek (Fig. 8) are strongly anomalous in Pb, Zn, Ag, and Au (Preussag Australia, EL 564/1203, 1983). At Shaw Creek (Fig. 8) also located at the top of the Snowy River Volcanics, graded volcanogenic sandstones and shales are interbedded by thin (up to 300 mm thick) bands of lapilli-sized epiclastic detritus, which has a component of detrital sphalerite and lesser galena. Syngenetic pyrite is enriched in the tops of the underlying sandstone—shale bands, thus forming distinct metal-rich sub-units up to 0.5 m thick.

A number of Pb—Zn sulphide deposits and Fe deposits are associated with dolomitic limestones or volcanogenic units within the Buchan Group (Fig. 8). Numerous prospects and deposits have been described (Cochrane, 1982) and several have produced small quantities of base-metal sulphide concentrate. An example is the Back Creek Lead Mine, which possibly has been Victoria's largest lead producer. Here, mineralization occurs as veins and lenses within dolomitic limestone, which overlies volcanogenic sediments and calcareous shales of the Snowy River Volcanics. At the Pyramids, Pb—Zn mineralization is found in the lowest dolomite horizon, which likewise overlies the Snowy River Volcanics. At this prospect Murray (1885) reported that the mineralization tended to be confined to a 1 m thick brecciated limestone. At the Good Hope Mine a line of manganiferous ironstones, in part baritic, are present close to the contact between the Snowy River Volcanics and overlying limestone.

South of Buchan a series of Fe—Mn prospects associated with the Snowy River Volcanics were initially reported to contain gold values as high as 10.5–66 g MT^{-1} (Murray, 1898). Two such prospects are the Iron Mask and the Iron Knob, which lie approximately 2 km apart in north—south direction (Fig. 8). Exposures around Iron Knob comprise bedded fine-grained volcaniclastics, agglomerates, jasper bands, and bedded iron-rich (haematite/goethite) formations, which in places carry apatite. The sequence was apparently deposited after a period of explosive volcanism in a basin or lake, whose waters were enriched in iron-bearing hydrothermal solutions. Iron Mask, however, may have been deposited under essentially marine conditions (Preussag Australia, EL 564/1203, 1983).

At McRaes Limonite Quarry, the limonite contains secondary silica, manganese, and barite and at depth the limonite gives way to pyrite and marcasite. Such a deposit would


BUCHAN RIVER
MURRINDAL
MURRINDAL RIVER
Jacksons Crossing
Running Ck.
Shaw Ck.
Pyramid Mine Pb,Ag
Henhams Mine Pb
Mooncliffs Pb
Hume Park Mine
Halls Peninsula
SNOWY RIVER
BUCHAN
Bally Hooly Hill Ba
Spring Ck. Mine Cu,Pb
Pb,Zn,Ag
Neils Ck. Pb
Pb,Ba Back Ck.
Oxide Mine Mn
McRaes Quarry Fe
Tara Crown Pb,Au
Armistice Mine Cu,Au
YALMY FAULT
Old Tara Goldfield Au
Mt. Tara Mine Au
Blue Lode Mine Au
Good Hope Ba,Mn,Pb
Cann Ck. Ba
Iron Mask Ba,Mn Fe
Dominion Mine Cu
Nowa Nowa
N
0 2km
CAINOZOIC BASALT AND ALLUVIUM
BUCHAN GROUP
SNOWY RIVER VOLCANICS
SILURIAN/ORDOVICIAN SEDIMENTS
GRANITE

appear to be analogous to the so-called barren pyritic ore bodies of exhalative volcanic affiliation.

In contrast, a pyrometasomatic origin has been proposed for various haematite–magnetite–jasper–quartz bodies emplaced along north striking shears at Nowa Nowa (Fig. 8). These shears cut the Snowy River Volcanics and underlying Silurian limestones and shales. The most significant occurrence is the Nowa Nowa Five Mile Iron Ore deposit and this has apparently replaced basement shales and limestones (Bell, 1959; Hill, 1976).

Boulder Flat

The Errinundra Group (Fig. 5) of Boulder Flat [(55)669,5852] is situated in a narrow, fault-bounded syncline flanked by Ordovician turbidites and meta-sediments. The northeast-trending structure is 2 km wide and at least 13 km long, disappearing to the northeast under a cover of Upper Devonian red-beds. The group is about 950 m thick and comprises two units, a lower Blackwatch Formation and an upper Boulder Flat Limestone. The sequence has in the past been compared with that of Buchan, but the similarity is not marked. Conodonts also show it to be somewhat older, early Pragian rather than late Pragian as is the case for the Buchan Caves Limestone (Pickett, 1984).

The Blackwatch Formation shows a great deal of stratigraphic complexity, consisting of thin, mostly non-welded ignimbrites, epiclastic sediments, lithic to quartz-rich sandstone, slate, and limestone. The Boulder Flat Limestone consists of interbedded limestone and black shale.

Mineralization in the Errinundra Group is similar to the Pb–Zn–Ba style mineralization associated with the Buchan Group and is typically located close to the transition from the acid explosive volcanics of the Blackwatch Formation, to the calcareous sediments of the Boulder Flat Limestone. The limestones are largely recrystallized, dolomitic, weakly baritic, and pyritic with minor chert veins. At Boulder Flat several subzones of mineralization have been encountered (Jennings Mining Ltd., EL 455, 1975) extending some 1200 m in length and 15–30 m width. Gold values, where analysed, were below detection level. Two types of mineralization have been recognized, namely fine-grained sulphides of probable volcanic exhalative affinity associated with baritic limestones, and coarser sulphides often associated with baritic limestones, and coarser sulphides typically associated with veining.

Wentworth Group

At Wentworth River, crustal extension in the Early Devonian resulted in the deposition of the Wentworth Group (Fig. 5), a thick (1360 m+) marine sequence of terrigenous mudstone and sandstone with rare thin limestone and a basal conglomerate. Much of the sequence is turbiditic (McCaw, 1983) although the rich shelly faunas suggest shallow-marine conditions. There is no record of mineralization in this sequence.

In summary, exhalative mineralization within the Silurian–Lower Devonian sequences of Eastern Victoria may be regarded as the southern equivalents of a variety of mineral occurrences and prospects occurring in the Lower Palaeozoic sediments of New South Wales (e.g. Woodlawn and Captains Flat; Degeling et al., this volume) It was in these Lower Palaeozoic sediments of NSW, west of Sydney, that the importance of the interplay between volcanism, shallow-water sedimentation including limestone deposition, stratigraphic position, and the possible relationship with modern active island arcs, was first enunciated (Stanton, 1955). Comparable geological environments occur within the eastern Victorian rifts with acid to intermediate volcanism, associated volcaniclastics, shales, mudstones, and shelf limestones. A

Fig. 8. Geological map of Buchan area showing location of various mineral occurrences.

variety of volcanogenic exhalative ores and their subvolcanic associates have attracted attention for over a century. However, low tonnages have tended to hinder exploitation. Mineralization tends to be Pb—Zn dominated though there are significant exceptions, such as Wilga, which has an average grade of 3.3% Cu.

Tabberabberan Orogeny

At the type locality at Wentworth River [(55)535,5853], the Tabberabberan Orogeny is marked by a high-angle unconformity between folded and cleaved Lower Devonian (Praguian) Wentworth Group and almost flat-lying Upper Devonian red-beds. A better age constraint occurs in the Melbourne Trough, where intrusion of the Woods Point Dyke Swarm [(55)434,5842] (387 ± 14 Ma) and the Mt. Buller—Mt. Stirling hornblende granodiorites (average 381 ± 7 Ma; Richards and Singleton, 1981) took place after folding of the Melbourne Trough and before deposition of the Upper Devonian red-beds.

The youngest folded unit, the Cathedral Group, contains no useful fossils, but shelly fossils of late Early Devonian (probably Emsian) age occur high in the underlying Walhalla Group (VandenBerg, 1975). The oldest dated post-Tabberabberan sediments are part of the Marysville Igneous Complex [(55)389,5847], which has Late Devonian (Frasnian?) fish fossils (Marsden, 1976).

Deformation was strongest in the eastern part of the Melbourne Trough, where the rocks are tightly to isoclinally folded and have a penetrative slaty cleavage throughout (Mount Useful Slate; VandenBerg and Wilkinson, 1982). Farther west, however, folds become more open and widely spaced and cleavage changes from slaty to reticulate. Metamorphism throughout the Trough is of lower greenschist facies.

The Tabberabberan Orogeny was a truly regional event, affecting the rocks within and adjacent to the Melbourne Zone and in eastern Victoria. It produced a penetrative slaty cleavage and apparently also a spaced crenulation cleavage in the Errinundra Group (Hitchings, 1983; Byrne, 1983), tight folding and reticulate cleavage in the Wentworth Group (Talent, 1963; McCaw, 1983) and folds of a more open style in the Buchan Group (Teichert and Talent, 1958), which were protected largely by the underlying competent Snowy River Volcanics. At Bindi, where the volcanics are much thinner the Buchan Group argillites display a strong, closely spaced reticulate cleavage.

Late Devonian—Carboniferous sedimentation and magmatism

A complex sequence of post-orogenic events followed the Tabberabberan Orogeny. They can be broadly grouped into three tectonic provinces:

(1) Central Victorian Magmatic Province, characterized by intrusion and extrusion of acid magmas; this overlaps in part with:

(2) Mount Howitt Province, with extensive non-marine "red-bed" sedimentation and bimodal but predominantly acid volcanism;

(3) East Gippsland Province, with non-marine "red-bed" sediments preserved in grabens.

Central Victorian Magmatic Province

We prefer the above name to the "Central Victorian Cauldron Volcanic Province" used by McLaughlin (1976) because we regard the numerous scattered granitic stocks as an integral part of the one province.

The intrusions typically vary in outcrop-pattern from rectangular, to elliptical, to ovoid, and are discordant, with their long axes more or less perpendicular to the fold trend of the host sediments. Most of the igneous masses are concentrated into two broad east—west bands, one extending from Maryborough to Mansfield, the other from Skipton and Lismore to Heyfield (Fig. 9). This pattern is unrelated to surface structure and may reflect deeper features.

Magma types include (dominantly) S-type and some I-type of the White and Chappell (1977) classification, and sometimes both types occur in a single body (e.g. the Cobaw intrusion, 283—285 in Fig. 10). The presence of S-type magmas to the west of the Melbourne Trough may indicate the existence of a sialic crust under the exposed Cambrian—Ordovician sequence (VandenBerg, 1983; Cas, 1983).

The granitoid magmas were intruded to high levels in the crust and many broke to the surface, where they formed thick volcanic piles in cauldron subsidences. The cauldrons are characterised by an overwhelming volumetric predominance of mostly crystal-rich ignimbrites of rhyolitic to rhyodacitic type, whose primary textures have been commonly obliterated by autometamorphism. This points to rapid deposition of large volumes of pyroclastics, resulting from the rapid evacuation of magma chambers after its collapse (Hills, 1959; Birch et al., 1978; Birch, 1983).

This period of post-orogenic volcanism was probably associated with minor vein Au

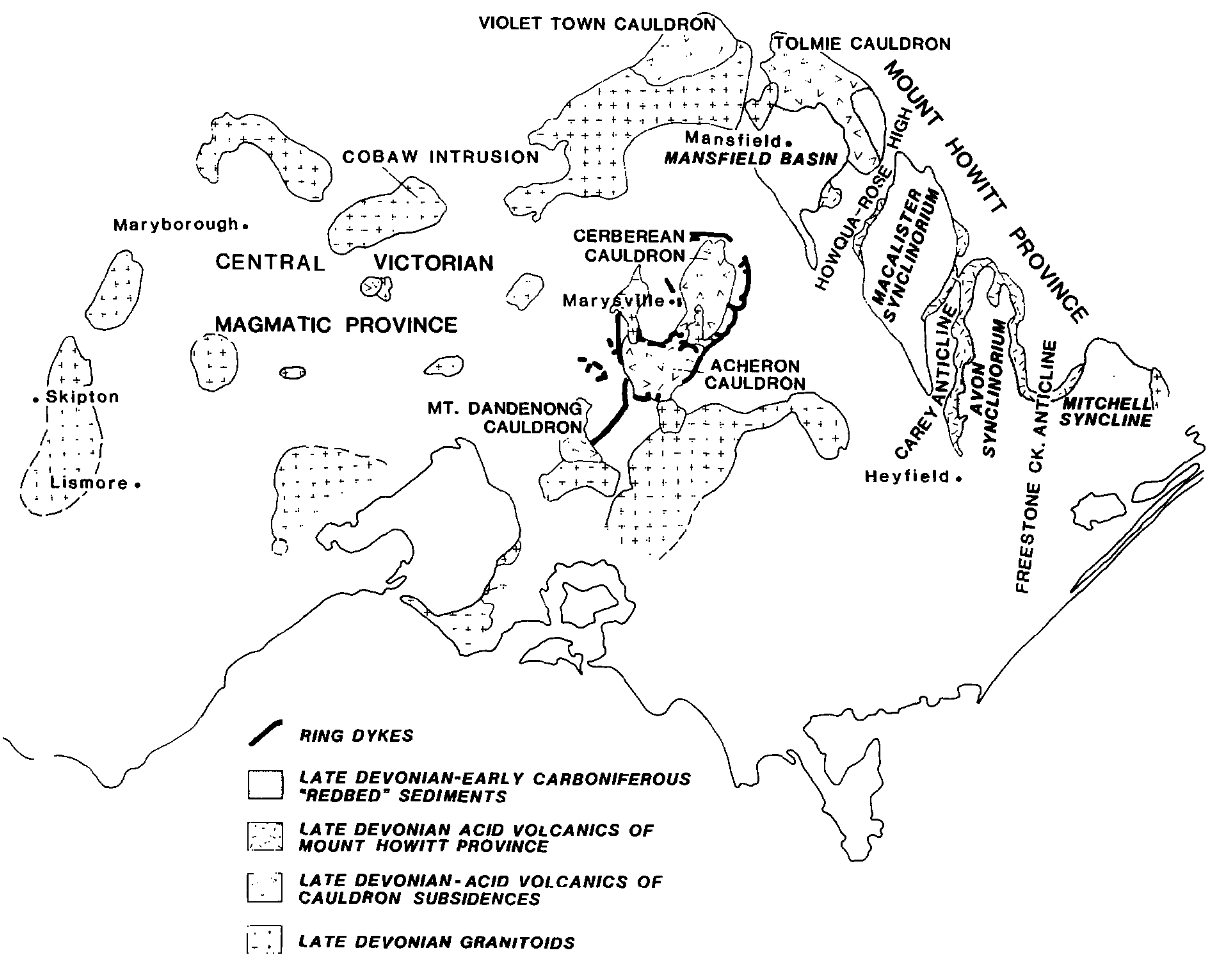


Fig. 9. Late Devonian Central Victorian Magmatic Province and Mount Howitt Province.

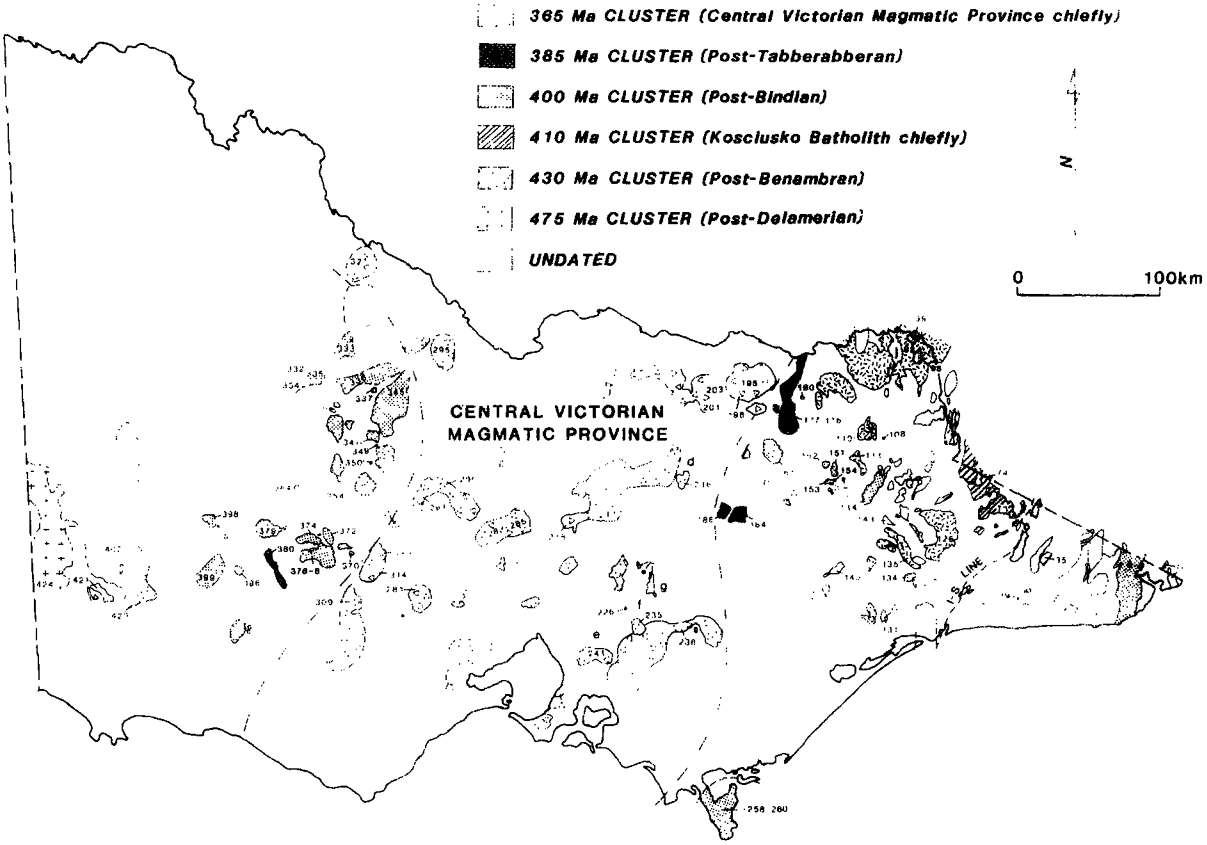


Fig. 10. Age distribution of granitoids. Plutons are numbered using a numbering system devised by A.J.R. White and A.H.M. VandenBerg. Numbers are shown only for dated plutons (see also Fig. 12). These are: *5* = Croajingolong; *35* = Errinundra; *39* = Murrungowar; *71* = Amboyne; *74* = Suggan Buggan; *92* = Corryong; *98* = Mt. Mittamatite; *99* = Pine Mountain; *108* = Eustace Ck; *110* = Banimboola; *111* = Mt. Wills; *114* = Anglers Rest; *126* = Nunnett; *131* = Clifton Ck; *134* = Tambo Crossing; *135* = Doctors Flat; *140* = Dargo; *143* = Tongio Gap; *151* = Spion Kopje; *152* = Big Hill; *153* = Niggerheads; *154* = Pretty Valley; *161* = Mt. Buffalo; *176* = Baranduda; *177* = Yackandandah; *180* = Kergunyah; *184* = Mt. Stirling; *186* = Mt. Buller; *195* = Beechworth; *198* = Everton; *201* = Kelly Gap; *203* = Warby Springs; *216* = Barjarg; *217* = Strathbogie; *218* = Trawool; *226* = Mt. Toole-be-wong; *235* = Warburton; *238* = Toorongo; *241* = Lysterfield; *258—260* = Wilsons Promontory (sensu lato); *281* = Gong Gong; *283* = Pyalong; *284* = Baynton; *285* = Cobaw; *290* = Harcourt; *291* = Maldon; *295* = Pyramid Hill; *309* = Warrawidgee; *313* = Beckworth; *314* = Bolton; *321* = Lake Boga; *332* = Wycheproof; *333* = Glenloth; *334* = Jeffcott; *335* = Teddywaddy; *336* = Buckrabanyule; *337* = Mt. Egbert; *345* = Wedderburn; *347* = Kooyoora; *349* = Rheola; *350* = Moliagul; *364* = Navarre (subsurface); *370* = Burnbank; *372* = Glenlogie; *374* = Ben Nevis; *376* = Langi Ghiran; *377* = Buangor; *378* = Mt. Cole; *379* = Stawell; *380* = Ararat; *396* = Mafeking; *398* = Zumsteins; *399* = Victoria Valley; *407* = Harrow; *420* = Konong Wootong; *421* = Wando River; *424* = Dergholm. Letter symbols refer to dated volcanics (see Fig. 11).

occurrences in and around the Melbourne Trough, together with vein Sb—Au mineralization at Costerfield and Ringwood.

Mount Howitt Province

The Mount Howitt Province is a broad, NW—SE trending graben-like depositional basin extending from Benalla [(55)407,5954] in the northwest, to Maffra [(55)498,5898] in the southeast, where it disappears under Cainozoic sediments. It is broken up by anticlinal structures into four structural depressions, known as the Mansfield Basin, Macalister Synclinorium, Avon Synclinorium, and Mitchell Syncline (Fig. 9; Marsden, 1976).

The sequence of the southeastern part of the belt is the simplest, consisting of the Moroka Glen Formation, a basal conglomerate and sandy unit up to 300 m thick, followed by the Wellington Rhyolite, an ignimbritic rhyolite with interbedded lavas, epiclastic sediments and fluviatile sediments (Neilson, 1976; Birch, 1983). The Wellington Rhyolite is up to 900 m thick and extends over most of the Macalister Synclinorium, the whole of the Avon Synclinorium, and half the Mitchell Syncline, and marks a major phase of caldera volcanism. Unlike the Central Victorian Cauldrons, however, it is not associated with ring fractures and lacks a 'collapse-phase' biotite—hypersthene rhyodacite. It also contains a few thin flows of weakly alkaline basalts.

An upward-fining fluvio-lacustrine sequence overlies the Wellington Rhyolite, beginning with up to 600 m of very coarse to fine conglomerate, sandstone and mudstone (Mount Kent Conglomerate), and ending with the very thick (2400 m) Snowy Plains Formation consisting of mudstones, quartzose and feldspathic sandstones, and a few conglomerates. Flows of alkaline basalt are intercalated in both of these clastic units (Neilson, 1976).

The sequence in the northern region is much more complex and is broken by several unconformities. The Howqua-Rose High which separates the Mansfield Basin from the Macalister Synclinorium was a structural high during much of the time and a source for much of the lithic material in the adjacent basins (Marsden, 1976).

Sedimentation in the Mansfield Basin began with the Kevington Creek beds (VandenBerg, 1976), a fluvio-lacustrine red-bed sequence up to 900 m thick with a thin basal conglomerate containing clasts derived from Cambrian greenstone and Mount Buller Hornblende Granodiorite, which are exposed on the Howqua-Rose High (Fig. 9). Feldspathic sandstone high in this unit may reflect the first influx of volcanogenic material, probably from the Tolmie Highlands Igneous Complex (Fig. 9; Marsden, 1976).

The next unit, which follows a small erosion break, is much less extensive and consists of rhyodacite and minor rhyolite ignimbrite of about 150 m thick, overlying a thin conglomerate with clasts of acid volcanics which again appear to be derived from the Tolmie Highlands Igneous Complex.

Broadly correlating with this on the flanks of the Howqua-Rose High is a complex sequence of diachronous fluvio-lacustrine sediments and intercalated rhyolite and rhyodacite ignimbrites. The coarser clastics are dominated by volcanic material, suggesting correlation with the Mount Wellington Rhyolite farther south. The sequence also contains a thin black shale band.

In the western part of the Mansfield Basin, this first depositional phase was followed by a folding event in which the Jamieson Syncline was formed. In it, a strong angular unconformity separates the Kevington Creek beds from the overlying Mansfield Group. This unconformity is recognisable over much of the Mansfield Basin, but dies out on the Howqua-Rose High and is absent from the other synclinoria. The Mansfield Group is thus the lateral equivalent of the Snowy Plains Formation and consists of mostly fine-grained fluvio-lacustrine red-bed sediments (Marsden, 1976). The Mansfield Group has yielded Early Carboniferous fish fossils from a single locality; much of the group is probably Late Devonian, like the Avon River Group farther south.

Sedimentary copper ores occur in several places in the Mansfield Basin, with exploration by Jennings Mining Ltd. (EL 401/409, 1972–1975) recognising cupriferous sandstones and shales containing copper sulphides and hydrated carbonates with grades averaging 1—1.5% Cu. Jennings concluded that there are similarities with overseas red-beds which contain Cu, U, V mineralization, but the small areal size of the depositional basin makes the chance of economic tonnages unlikely.

A similar deposit occurs at the eastern margin of the Mansfield Basin in a unit of fluvio-lacustrine sandstone, siltstone, and calcareous shale at Mount Typo [(55)456,5909] (Table 2).

TABLE 2

Chemical analyses of two samples from mineralized bed — Unit 5, Mt. Typo (after Northern Mining, and Samedan, EL 412, 1972—1975)

	Sample GC-10	Sample GC-12
Cu (%)	5.0	4.3
Pb (ppm)	140	130
Zn (ppm)	120	76
Ag (ppm)	39	37
Mn (ppm)	50	70
U (ppm)	680	398
V (ppm)	330	250

East Gippsland Sedimentary Province

In this province, Upper Devonian rocks occur in relatively small, widely scattered structural depressions; in the Croajingolong District east of the Snowy River, these represent down-faulted remnants of a formerly extensive sheet of fluvio-lacustrine sediments.

The Mount Tambo Group near Benambra is the thickest and perhaps most interesting of these deposits. It overlies gneissic granite and a broad mylonite zone developed on the Indi Fault with a sharp angular unconformity, and consists of about 5 km of very rapidly deposited fluviatile sediments. The sequence shows upward fining on a broad scale and contains clasts of granite, Thorkidaan Volcanics, Enano Group slate, and fresh rhyolite pebbles apparently derived from the Dartella Volcanic Group (Lew, 1979; VandenBerg et al., 1984a). A thin rhyolitic ignimbrite is interbedded.

The Upper Devonian sequences, which are preserved in the three structural depressions at Club Terrace, Combienbar and Buldah, are essentially similar and were once continuous (Spencer-Jones, 1967). We therefore prefer Howitt's (1875) original name Combyingbar Beds to include all of these, and feel that the subdivision into units based largely on post-depositional events (Douglas, 1974; Marsden, 1976) is unjustified. This probably applies also to the Genoa River Beds.

The Combyingbar Beds represent an upward-fining and fluvio-lacustrine sequence of at least 1200 m thick, beginning with up to 100 m of lenticular very coarse conglomerate, pebbly sandstone and mudstone, and ending with purple mudstones and fine sandstones. The sediments are of local provenance (Spencer-Jones, 1967; Hitchings, 1983; Byrne, 1983). A small outcrop of rhyolite lava near Combienbar (VandenBerg et al., in prep.) represents the only volcanic rock recorded from this region. The Genoa River Beds are similar in every respect to the Combyingbar Beds (Marsden, 1976).

The Kanimblan Orogeny

In the absence of any evidence to the contrary, the deformation of the Upper Devonian—Lower Carboniferous rocks is customarily assigned to the Kanimblan Orogeny. Its effects were quite varied. In the East Gippsland Sedimentary Province, downfaulting and warping led to the formation of several grabens or half-grabens, within which the sediments were mildly deformed into broad, open folds with gentle limbs.

The events involving the Indi Fault were perhaps the most spectacular. This fault forms one boundary of the Mount Tambo Group near Benambra, [(55)574,5900] and the deformation involved the following steps: (1) folding of the Mount Tambo Group into a single, tight syncline with ubiquitous, penetrative slaty cleavage; (2) truncation of the syncline by (dextral?) transcurrent movement along the Indi Fault; and (3) underthrusting of this entire block, including the Indi Fault, along the southwestward-dipping Bindi Fault (VandenBerg et al., 1981, 1984a).

The Mount Tambo Group itself, overlies a broad mylonite zone which was created during even earlier transcurrent movement along the Indi Fault.

The style of deformation in the Mount Howitt Province is very similar to that in the East Gippsland Province, with predominantly open, often ill-defined fold hinges and gently dipping limbs. The basin margins are again more deformed, with steeply dipping to occasionally overturned beds, e.g. along the Cobbler and Viking Faults.

Large-scale thrusting took place along the Barkly Thrust, which forms the western margin of the Macalister Synclinorium. Here, the entire western limb of the Licola Syncline is missing and is overthrust by Lower Palaeozoic basement, including Cambrian greenstone. A strong reticulate to weak slaty cleavage is developed in this region, but elsewhere the Upper Devonian rocks are either uncleaved or have a weak reticulate cleavage.

The Central Victorian Magmatic Province seems to have been unaffected by the Kanimblan Orogeny. Deformation within the cauldron volcanic sequences is generally mild and can be explained entirely by block faulting and roof collapse of the underlying basement.

Granites

Now that many Victorian granite plutons have been dated (Bowen, 1975; Richards and Singleton, 1981; McKenzie et al., 1984) it appears that their ages fall into six reasonably well-defined clusters, which for the absence of better names, we will refer to by their mean ages. In several cases, these clusters also have well-defined areal boundaries, with the youngest typifying the Central Victorian Magmatic Province, flanked by progressively older clusters to the west and east (Figs. 10 and 11).

The geographical distribution of the clusters is shown in Fig. 10, whilst Fig. 11 shows age determinations from various plutons. Pluton names can be cross-checked using the numbering system shown in both figures.

The oldest granites belong to the 475 Ma cluster and intrude Cambrian sediments and metamorphics of the Glenelg Zone. Dates obtained from the granites (487 ± 6 to 453 ± 6 Ma; Richards and Singleton, 1981) are significantly younger than the single dated metamorphic (512 ± 18 Ma; VandenBerg and Wilkinson, 1982) suggesting that granite intrusion postdated the regional metamorphism by a significant period, or that large-scale reheating has occurred.

The 430 Ma cluster is only known from eastern Victoria, from granites associated with the Omeo Metamorphic Complex. These include both foliated, relatively concordant, and unfoliated discordant plutons with regional aureoles of biotite schist and higher grade. The cluster is poorly defined and the intrusion age is often masked by younger ages which reflect subsequent reheating and Ar loss on a regional scale. The best ages are from Eustace Creek (108) (440 ± 9, 433 ± 17 Ma from hornblende; Richards and Singleton, 1981), Mount Wills (111) (434 ± 17 Ma from muscovite, Richards and Singleton, 1981) and Mount Stewart (126) (430 ± 13 from biotite, after Evernden and Richards, 1962) but even these show younger ages in other minerals.

The small 410 Ma cluster represented by the Kosciusko Batholith is probably distinct from the next event, even though the datings are difficult to discriminate at the present. It is represented by two dates (407 ± 13 and 416 ± 16 Ma, after Evernden and Richards, 1962) from the Amboyne Granodiorite (71) which intrudes the Lower Silurian Yalmy Group, and from unpublished datings in NSW for which Richards and Singleton (1981) give a mean of 410 ± 5 Ma. Several intrusions in western Victoria have given a similar age [410 ± 8 Ma from Konong Wootong (420) and 411 ± 8 Ma from Mount Jeffcott (334); McKenzie et al., 1984; 411 ± 8 Ma from Rheola (349); Richards and Singleton, 1981], but the true extent of this cluster in western Victoria is still difficult to estimate because of widespread reheating associated with the slightly younger 400 Ma cluster.

The 400 Ma cluster is well represented in western Victoria, forming a broad belt

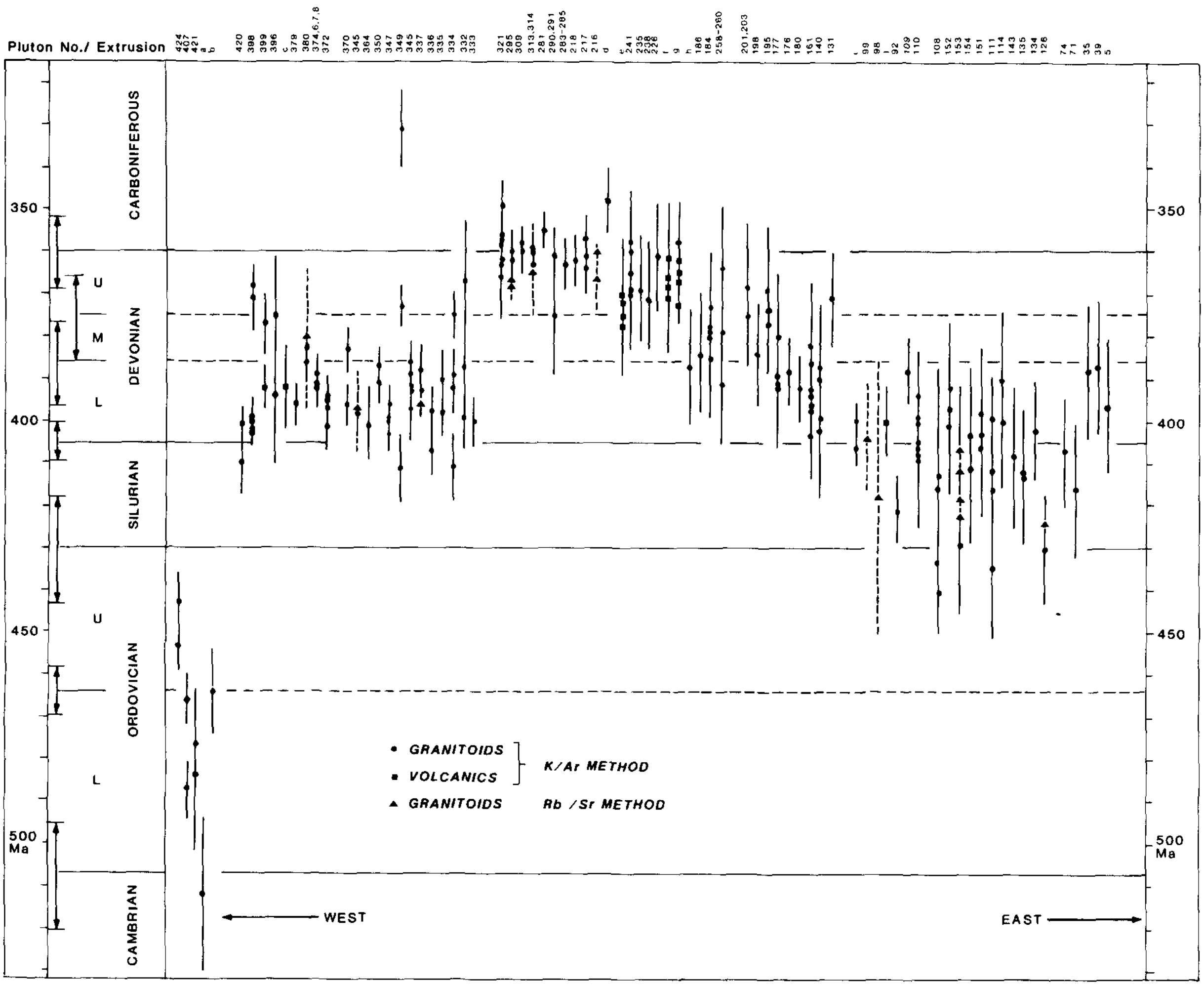


Fig. 11. Schematic chart showing granitoid and volcanic age groupings. System and period boundaries shown are approximate and reflect the uncertainty in dating boundaries. Numbers refer to granitoid plutons whose names are listed under Fig. 10. Letter symbols refer to other dated rocks, which are: *a* = sillimanite—muscovite—biotite gneiss at Glenelg River; *b* = garnet—biotite—quartz hornfels, Hotspur 1 bore, Hamilton; *c* = Rocklands Rhyolite; *d* = Ryans Creek Rhyolite, Tolmie Igneous Complex; *e* = Mount Dandenong Volcanic Complex; *f, g* = Volcanics from Marysville Igneous Complex; *h* = dyke, Woods Point Dyke Swarm; *i* = gneiss, Bethanga Bridge and Hawkesview; *j* = Jemba Rhyolite.

between the 475 Ma cluster of the Glenelg Metamorphic Belt and the 365 Ma cluster of the Central Victorian Magmatic Province (Figs. 10 and 11). Richards and Singleton (1981) were able to distinguish two sub-clusters here, one with an average age of 398 Ma, the other 390 Ma.

In eastern Victoria, intrusion ages that fall within this cluster have been obtained from granites at Mount Buffalo (161) (394 Ma), Dargo (140) (397 Ma), Banimboola (110) (403 Ma), and the Big Hill Diorite (152) (397 Ma) (all average ages; Richards and Singleton, 1981). The comagmatic Mount Mittamatite (98), Pine Mountain (99) plutons (404 ± 2) and Jemba Rhyolite (400 ± 8 Ma; after Brooks and Leggo, 1972) also belong here. Widespread reheating at this time was responsible for Ar escape from older intrusions and from paragneissic rocks. Examples are ages of 400 ± 5 and 406 ± 5 Ma from gneisses east of Albury, 408 ± 16 Ma for granite at Mount Mungoballa (143), and 412 ± 13 and 413 ± 16 Ma for the gneissic quartz diorite of Doctors Flat and Ensay South (135) (Evernden and Richards, 1962; Richards and Singleton, 1981).

The 385 Ma cluster is much smaller in areal extent, being confined to the eastern margin of the Central Victorian Magmatic Province (Fig. 10). Within this province, it constitutes the oldest post-Tabberabberan intrusive event with ages of 387 ± 14 Ma obtained from a Woods Point dyke and an average of 381 Ma from the Mount Buller plutons (184,186) (Richards and Singleton, 1981). The Yackandandah Granite (177) and small satellite intrusions (176,181) (average age 387 Ma) also being here.

Two dates obtained from foliated granites in the Kuark Metamorphic belt [Errinundra (35), 388 ± 16 Ma; Murrongowar (39), 387 ± 16 Ma; after Bowen, 1975] are not well defined. The dates, in any case, reflect the age of the foliation, not the age of intrusion which is, at this stage, still not resolved but is probably Middle or Late Silurian.

The 365 Ma cluster is the youngest Palaeozoic cluster and is represented by the Central Victorian Magmatic Province (see above). Rocks within this cluster range from about 370 Ma [Warby Range (203–206) and Pilot Range (195) plutons, Mount Dandenong Volcanics] to about 360 Ma; the youngest rocks are most abundant in the western part of the province (Fig. 11).

White et al. (1976) have shown that the Jindabyne Thrust in southeastern NSW separates a region of mixed S- and I-type granitoids to the west, from a region to the east with no S-type granitoids. This boundary, the "I-S line", continues southwards into Victoria where it coincides with the Yalmy Fault. Recent mapping (Glen and Vandenberg, 1985) has emphasised the importance of this fault on the surface, and White et al. (1976) equate it with the eastern edge of a Precambrian sialic subcrust which they propose as a source for all the S-type granitoids west of the "I-S line".

In Central and Western Victoria, the age clusters do not fit very well with major, exposed, stratotectonic boundaries — the Heathcote Greenstone Belt, for instance, lies wholly within the Central Victorian Magmatic Province and the Mount Wellington Greenstone Belt cuts the eastern boundary of this province at an angle. The western boundary of the Central Victorian Magmatic Province lies close to, but is not parallel with, the Wedderburn Line. Work by White and Chappell (1977) indicates that this is an important geochemical boundary as well: there are no S-type granitoids in the Ararat—Bendigo Zone west of the Wedderburn Line, suggesting that the line coincides with a deep crustal change, analogous perhaps with the "I-S line" (Yalmy Fault) in Eastern Victoria.

The mechanism of emplacement of the granitoids is still a matter for conjecture. Pluton boundaries are typically vertical or near vertical and sharp, completely truncating bedding and other structures in the host rock. In outline, plutons are usually subquadrate or oval, with boundaries that can be fitted to a small number of arcuate lines (see, for instance, Stewart, 1966). Stoping is unlikely to be important as a mechanism for emplacement, judging from the relative rarity of xenoliths and the lack of chemical contamination. Diapiric intrusion is ruled out by the absence of plastic deformation inside, and brittle deformation outside the plutons. Stewart (1966) suggested that the Cobaw pluton was emplaced by the complete collapse of its roof, i.e., that it is a cauldron subsidence from which the volcanic portion has been completely removed by erosion. Since this collapsed roof contains part of the Cambrian greenstone Heathcote Belt it should form a detectable magnetic anomaly, but there is no trace of it on the aeromagnetic map (Bureau of Minerals Resources, 1984). The most likely mechanism of emplacement of this and other intrusions is upward displacement of the missing plug of sedimentary rock, much like a cork being extracted from a bottle.

Mineralization associated with granitoids

Various small deposits and prospects, spatially associated with granitoids and associated aplite and greisen dykes, occur within Victoria. Mineralizing events extend from the Benambran intrusives (Koetong Granite, 101) to post-Tabberabberan phases, which encompass the Late Devonian tin—tungsten province of Tasmania and King Island and include the Marysville Igneous Complex. Mineralization has not yet been recognized associated with the oldest intrusives in West Victoria (Glenelg Zone), but this apparent absence is more likely a reflection of poor outcrop.

The coincident Yalmy Fault and "I-S line" (White et al., 1976) noted above, apparently demarcates an eastern I-type granitoid province characterized by minor molybdenum mineralization and no significant tin occurrences, from a western mixed S- and I-type province containing both tin and molybdenum prospects and mines (White et al., 1977).

Molybdenum

Small sporadic occurrences are scattered through the State, often associated with the margins of intrusives. Mineralization, generally in the form of molybdenite, occurs as concentric pipe deposits (Everton, 198); as flakes in quartz veins (Mount Moliagul, 350); as disseminations within acid plutonics, quartz veins, and aplite/pegmatite dykes (Korong Vale, Fig. 12); and as fine coatings along joint planes within intrusives (Mafeking Granodiorite, 396).

The earliest recorded occurrences of Mo mineralization are widespread and are associated with the post-Bindian intrusive phase. Localities include Mount Douglas, Korong Vale, Mount Moliagul, Mafeking, and a cluster of prospects in Eastern Victoria, Wangarabell, Genoa, and Genoa Peak (Fig. 12). At Mount Moliagul, Mo and Cu mineralization occurs within a multiple phase felsic stock intrusive into deformed Lower Ordovician mudstones and siltstones (McKenzie, 1980). The dominant rock type comprises an initial intrusive hornblende granodiorite, into which has been emplaced a central core of leuco-microgranodiorite with some biotite-rich and hybrid phases. Subsequently, an aplite has formed an irregular ring, largely within the leuco-microgranodiorite, with various aplite dykes forming a radial pattern.

Alteration is sericitic and is developed adjacent to veins, dykes, and joints being intensely developed in the central core west of the annular aplite. Mo and Cu mineralization is located within and adjacent to the intrusive stock. Molybdenite and pyrite also occur within aplite dykes and with minor chalcopyrite, along joints and in quartz veins.

At Mount Douglas, molybdenite is found within quartz veins and disseminated within the adjacent muscovite granite of the Wedderburn Pluton (345).

Minor Mo is associated with the post-Tabberabberan 385 Ma granitoid cluster at Mount Stanley, whilst magmatism in the 365 Ma cluster developed Mo occurrences at Harcourt, Violet Town, Mount Cunningham, together with Victoria's major producer at Everton. This mine produced 325 t of concentrate averaging about 90% molybdenite from 21,936 t of ore (McKenzie, 1976). Here, two central barren cores of fine-grained quartz biotite porphyry are surrounded by mineralized zones of disseminated molybdenite in porphyritic granodiorite and quartz veins. Grade decreased with depth so that at the lowest level worked (46 m) the recoverable grade was 0.6/ MoS_2 in the No 1 pipe (Fisher, 1953).

Tungsten

Various tungsten prospects are located with a number of intrusives (Linton, Mount Cunningham, Tin Creek/Monkey Gully, Warburton, Marysville; Fig. 12) associated with

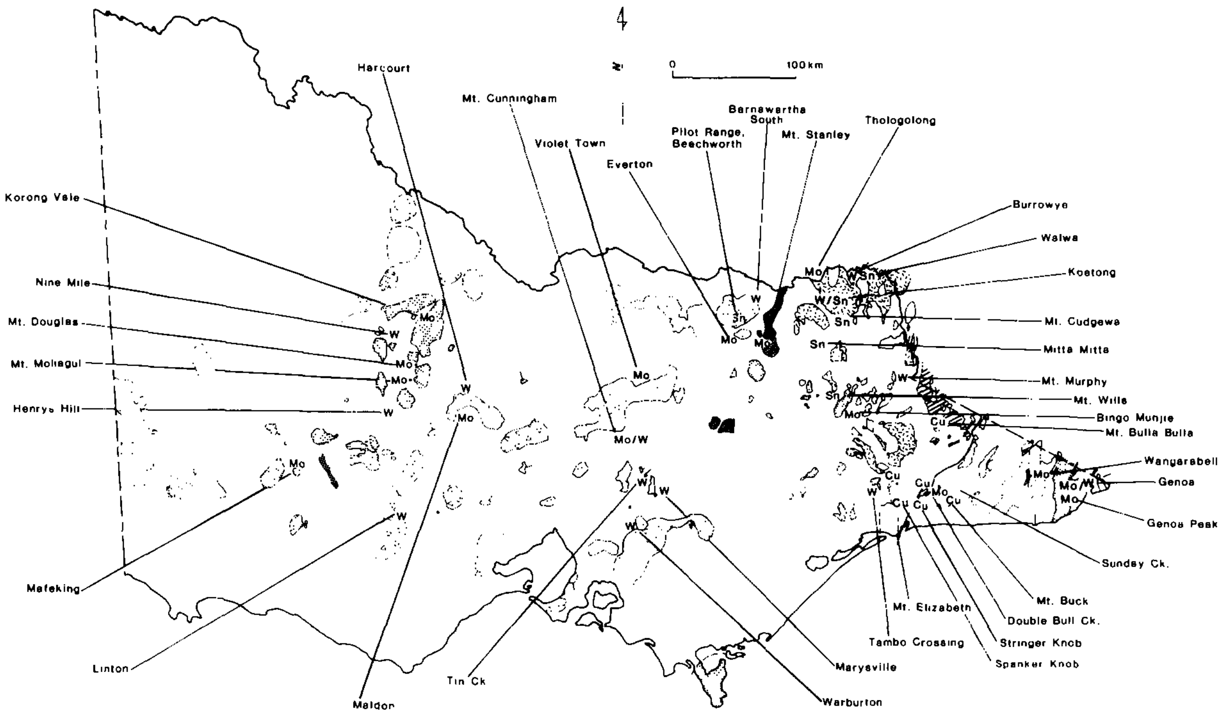


Fig. 12. Location map of tin, tungsten, molybdenum, and copper occurrences in Victoria associated with acid plutonics. Granitoid symbols as for Fig. 10.

the post-Tabberabberan 365 Ma granitoid cluster. However, the best-known occurrence is at Mount Murphy in the northeast of Victoria (Fig. 12). Although undated, this intrusive is likely to fall in the period 430–400 Ma. Mineralization at Mount Murphy is localised along the contact between a two-mica granodiorite and adamellite with Ordovician metasediment. Both granitoid and country rock are cut by quartz–tourmaline veins and aplite and pegmatite dykes. Abundant tourmaline occurs with patchy greisen, within the granitoid. The quartz—tourmaline veins appear to pass up into wolframite, molybdenite, quartz veins with associated scheelite, chalcopyrite, and pyrite (Gippsland Minerals, EL 155/156, 1971; Essex Minerals, EL 893, 1982).

A possible time-equivalent prospect exists at Henrys Hill (Fig. 12) within the aureole of the Mount Hooghly Pluton (354). Here wolframite-bearing quartz veins cut tourmalinised hornfels of the St. Arnaud Beds and mineralization appears related to the cooling of the pluton (McKenzie and Nott, 1981).

Examples of mineralization associated with Late Devonian magmatism occur at Marysville in veins within granodiorite and rhyodacite of the Marysville Igneous Complex. Subeconomic values of W in the form of wolframite and scheelite associated with tourmaline, pyrite, and minor cassiterite, appears related to late-magmatic hydrothermal alteration (Nott, 1982).

Extending northwest from Marysville are a number of small high-level, recently unroofed granodiorite bodies (Black Range Pluton, 233). Prospects include Monkey Gully and Tin Creek and at the former, stockwork veining contains scheelite, molybdenite, chalcopyrite, pyrrhotite, and arsenopyrite (Rossiter, EL 934, 1982).

Tin

Although the bulk of tin production has been from alluvial deposits [e.g. 9144 t concentrate from the Beechworth—Eldorado tin field ((55)472,5976) to 1971] a small amount has been obtained from veins and disseminations associated with the margins of granitoids (Pilot Range batholith, 195–198) or in aplite and porphyry dykes which transect sediments and their metamorphosed equivalents (Mitta Mitta, Walwa, Fig. 12).

The most important primary tin deposits are associated with S-type granitoids in north-eastern Victoria, and these include intrusives of the 430 Ma Cluster (Mount Wills, 111; Koetong—Granya batholith, 101—103) and the younger Pilot Range batholith of the Late Devonian 365 Ma cluster. This triangular zone extends northwards to include Ardlethan in New South Wales (Hill, 1976). Also important is the Wilsons Promontory S-type batholith (258—260; 400 Ma cluster) which is the source for the Toora tin field. This field produced 413 t of concentrate from Tertiary gravels prior to 1939 (Spencer-Jones, 1955).

Porphyry-style mineralization

This style of mineralization is associated with a number of granitoids in eastern Victoria and was recognised at Double Bull Creek (Fig. 12) from stream sediment sampling (Rio de Janeiro Mines, EL 50, 1966). Additional prospects include Sunday Creek, Mount Buck, and Stringer Knob (Fig. 12) As a group they are characterised by the presence of high-level intrusions, anomalous stream and/or soil geochemistry for Cu (and in some instances Zn and Mo — Mount Bulla Bulla; Gippsland Minerals, EL 92, 1970), and characteristic fracture and alteration patterns involving development to varying degrees, of silicification, and argillic, potassic, and propylitic alteration. Mineralization varies from minor disseminations to vein-type which tend to be characterised by chalcopyrite and pyrite. Cochrane (1982) suggests that the subeconomic nature of these prospects probably reflects erosion to the root zones of these porphyry systems.

Gold

Victoria is a gold province of world significance having produced, according to official figures 2,449,388 kg of the metal to the end of 1981. Peak production was in 1856 with some 94,950 kg gold being mined. Approximately 40% of Victoria's production came from reef workings with the remainder from Cainozoic placer deposits. Some of these alluvial workings were very rich, an example being the Castlemaine—Chewton field, where some 200 kg gold was transported to Melbourne each week for the first ten years (Thomas, 1953a). The early years after gold discovery in 1851, were spent in working the shallow placer deposits; however, by 1854 the first public quartz battery was established at Bendigo and the first reported successful attempt at deep reef mining was at Clunes in 1857.

There are numerous reports and bulletins on the gold fields of Victoria, and summary accounts are given by Junner (1921), Baragwanath (1929), Thomas (1951), and Whiting and Bowen (1976). These latter workers following Bell and Liddy (1970) grouped the various primary gold producing centres of Victoria into a number of subprovinces (Fig. 13), whose boundaries tend to coincide with major structural features. Whiting and Bowen (1976) suggest that the differences between these subprovinces may reflect different mineralizing events. Consideration of placer gold production would increase considerably the significance of some fields such as Ballarat (Fig. 13) and the Chiltern—Rutherglen field in the north where total production is estimated to have been 22,000 kg.

The various primary deposits may be broadly divided into: (1) deposits spatially associated with Cambrian? altered mafic lavas and their volcaniclastic equivalents (Stawell, Moyston, Toolleen); (2) gold—quartz veins

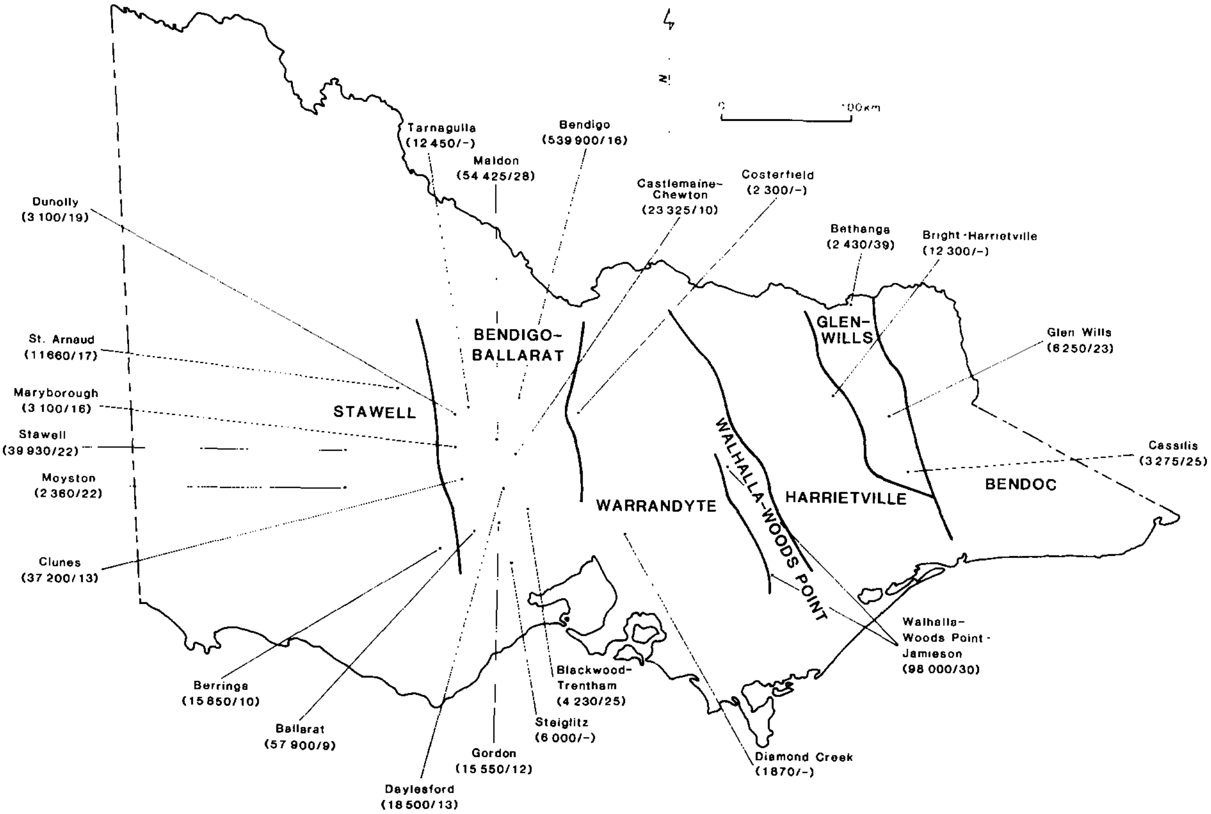


Fig. 13. Gold sub-provinces of Victoria and major primary production centres showing total gold output (kg) and grade (g MT^{-1}) after Whiting and Bowen (1976).

hosted by cleaved turbiditic sandstones and shales and their metamorphosed equivalents (Harrietville, Bendigo, Daylesford, Maryborough); (3) gold—quartz veins associated with mafic, intermediate, and quartz porphyry intrusives that cut Palaeozoic sediments (Woods Point, Maryborough); and (4) minor gold occurrences associated with granitoids (Warburton, Mafeking, Buffalo, Harcourt).

Cambrian(?) mafic lava-hosted deposits

A small number of gold occurrences are either hosted by, or spatially associated with, mafic volcanics of known or assumed Cambrian age. These include Stawell, Moyston, Toolleen, and Howqua (Fig. 3). The most significant deposit is Stawell where total recorded production was 39,935 kg Au from 1,775,241 t at an apparent grade of 22.5 g MT^{-1} (Clappison, 1970). The mine area has been deformed into a number of folds with northwest trending axes and the Stawell Granite (379) (396 ± 5 Ma; Richards and Singleton, 1981) cuts the sequence to the south.

Four major types of gold lodes have been recognised, namely vertical reefs, flat reefs, Magdala Reef, and Mundic Lode, with ore shoots localised by the intersection of two of the reef types. Clappison (1970) suggested a hydrothermal origin for the sulphide mineralization on the basis, of vein injection, siliceous replacement, together with bleaching and carbonate metasomatism. The source of these solutions was believed to be from the adjacent granitoid intrusive.

Recent drilling by WMC on the western

limb of the Moray anticline (Fig. 14) has established the following sequence overlying the altered mafic volcanics: (1) schists and slates in part carbonaceous (youngest): (2) thin 0.5 m chlorite mafic volcaniclastics: (3) 5—15 m quartz—magnetite zone apparently conformable with the underlying greenstone contact; (4) 0.5 m chlorite mafic volcaniclastics; and (5) greenstone (oldest).

There is now a belief amongst some WMC geologists (J. Lalor, pers. commun., 1982) that at least a component of the gold mineralization may be of exhalative volcanogenic origin. This belief is based in part on the mine stratigraphy, the occurrence of a "conformable" quartz—magnetite unit, and the anomalously high gold content in sediments overlying the metabasalts.

Gold mineralization at Moyston (Fig. 3) may also belong to this group of mafic-hosted deposits of the Stawell-type. The presence of serpentinite emplaced along a north-striking fault was reported by Pennzoil (EL 467/509, 1974–1981) and petrographic examination of mullock material (Ramsay, 1984) has reported the presence of mafic rocks, now

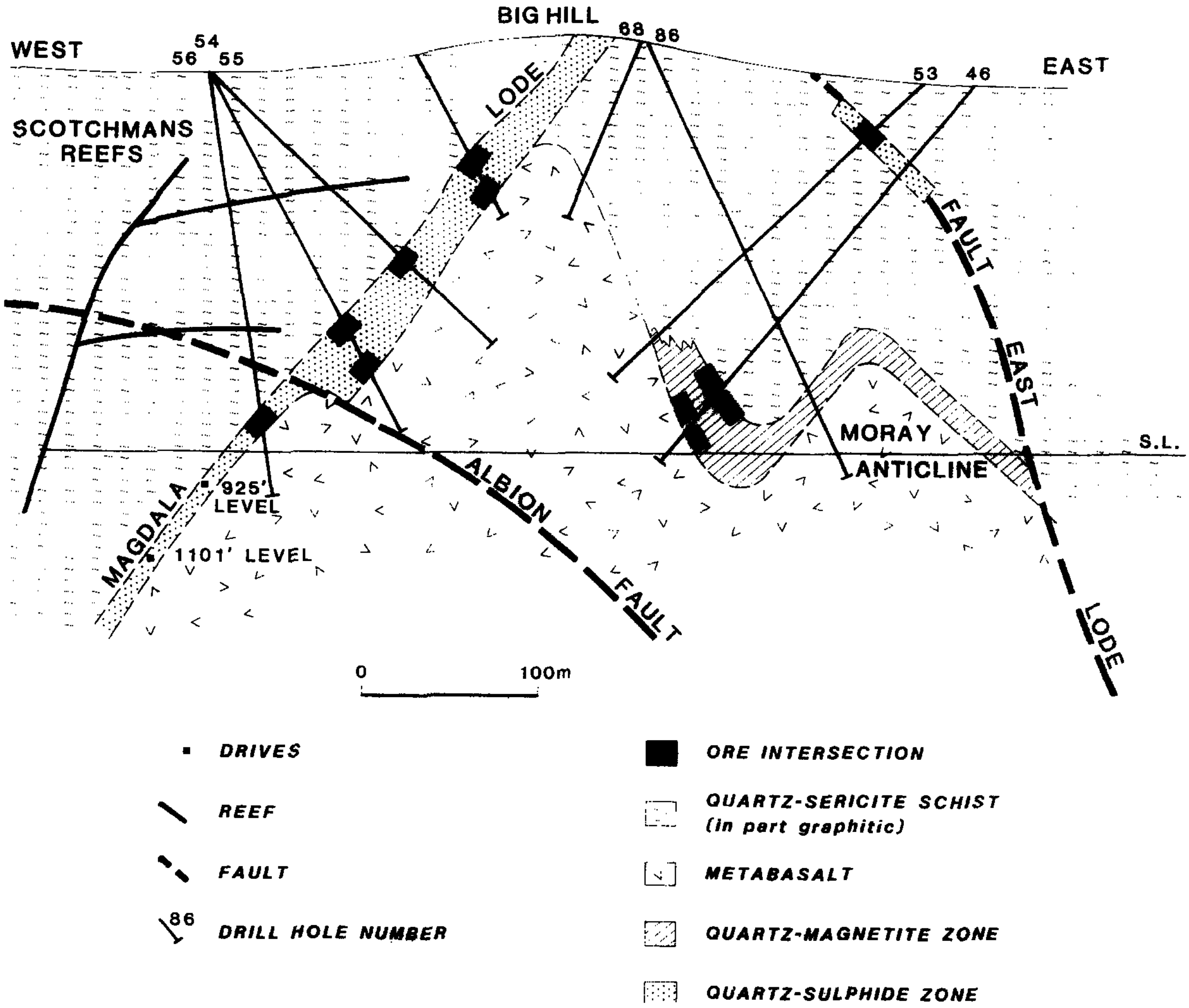


Fig. 14. Cross-section 255 Stawell Western Victoria (with permission WMC Ltd.).

extensively altered by chlorite, sericite, albite, secondary magnetite, and abundant carbonate.

At the Toolleen goldfield, gold-bearing veins strike NNW and occur within bedded cherts and siltstones of the Knowsley East Formation (Table 1). In the case of the Toolleen Mine, northeast-striking shears occur within the underlying greenstone. These shears contain quartz, calcite, pyrite, arsenopyrite stockworks and the gold is reported to occur either as inclusions within pyrite or as fillings between pyrite and the associated gangue (Freeport, EL 588/1249, 1984).

Within the Howqua region of the Mount Wellington Belt several small gold occurrences have been reported, including Rippins Reef Mine, Camerons Creek Mine, Howqua United, and the Great Rand Mine. The Great Rand Mine is located within mafic and ultramafic lavas of possible boninite affinity, together with associated volcaniclastic sediments. Reserve estimates from drilling (215,000 t at 6 g MT^{-1}) were considered by Aberfoyle to be too small for extraction. Exploration models formulated for gold mineralization in the Howqua area include epigenetic fault-controlled deposition and syngenetic strata-bound deposits confined within the interbedded lavas and associated sediments.

Quartz-vein deposits hosted by turbidites

Within the Palaeozoic sediments, especially those of Lower Ordovician age, gold-bearing quartz veins are concentrated in various elongate north–south trending zones, which follow the structural grain of the rocks. These zones, which may be only a few hundred metres wide (Ballarat East Field) may have numerous important mines extending for several kilometres along strike (Ajax Line, Daylesford). The host sediments are typically quartz-wacke turbidites, siltstones, and mudstones (in part carbonaceous), which have been deformed into tight upright folds with shallow axial plunges either to the north or south. This reversal of plunge, as seen at Bendigo (Thomas, 1953b), gives rise to basin and dome interference patterns. Axial surfaces to the folds generally have steep dips to the east (Maldon, Bendigo) or to the west (East Ballarat, Castlemaine). Associated axial plane cleavage has been estimated in some instances to have resulted in up to 30% mass loss by solution transfer processes (Cox et al., 1983a). Wave-length of the folding varies from 250 m at Maldon, 150–600 m at Castlemaine–Chewton (Cox et al., 1983a) to 65–400 m at Daylesford (Baragwanath, 1953).

Auriferous quartz deposition is located preferentially in favourable strain sites (saddle reefs, spurs, within-fault vein systems) and this deposition has been variously ascribed to fissure filling (Dunn, 1896), growth by accretion (Hulin, 1929), replacement (Stillwell, 1918), vein growth (Stillwell, 1953), or a combination of these processes. These favourable strain sites in many cases are apparently related to folding and fracturing of the host sediments.

Cox et al. (1983b) propose that vein systems from Castlemaine developed in dilatant sites characterised by $P_{\text{fluid}} > P_{\text{total}}$. Vein microstructures indicate that vein growth has occurred by repeated hydraulic fracturing and associated crack-seal mechanisms. They claim that veins only 10 mm wide involved as many as 2000 crack-seal increments.

Typically, the auriferous reefs within the Palaeozoic sediments contain only a few percent sulphides and these may include arsenopyrite, pyrite, pyrrhotite, chalcopyrite, sphalerite, galena, and stibnite. Such sulphides, especially pyrite, may be auriferous and on concentration may yield over 100 g MT^{-1} gold (Howitt, 1913). At Maldon, in reefs adjacent to the Harcourt Granite, bismuth, bismuthinite, molybdenite, and a Au–Bi alloy, maldonite, have been recorded (Ulrich, 1866, 1870). In the St. Arnaud area (Fig. 13), such as the Lord Nelson Mine (Baragwanath, 1921), there is a higher silver content with both native silver and silver chloride being noted.

In contrast, several gold producing areas contain significant sulphides. At Costerfield in the Warrandyte sub-province, the dominant sulphide is stibnite and some 22,400 t of antimony metal has been produced with gold values as high as 125 g MT^{-1} from small high-grade ore shoots within the main lode which cuts Silurian sediments of the Melbourne Trough (Hill, 1976). At Ringwood 3500 t of ore was obtained between 1869 and 1892, with up to 70 g MT^{-1} Au in stibnite concentrate and 26 g MT^{-1} Au in pyrite concentrate (Hill, 1976).

At Bethanga, in the Glen Wills sub-province, complex ore contains up to 60% sulphides including pyrite, pyrrhotite, arsenopyrite, chalcopyrite, and a little galena and sphalerite. Bethanga Mine (Fig. 13), located in gneisses and schists of the Omeo Metamorphic Complex produced 2430 kg gold of an average grade of 39 g MT^{-1} (Whiting and Bowen, 1976, table 12.26) whilst average assays gave 60 g MT^{-1} Ag, 3% Cu, and 6% As (Whiting and Bowen, 1976, p. 448).

Typical alteration assemblages associated with the turbidite-hosted quartz—gold vein deposits include quartz, carbonate, sericite, chlorite, and sulphide. For example at the Williams United Mine, Bright—Harrietville (Fig. 13), the carbonate ranges from calcite to iron-rich ankerite to ankerite, and the fine greenish chlorite falls in the ripidolite and magnesian chamosite fields. Cox et al. (1983b) report that both aqueous and CO_2-rich primary fluid inclusions occur in quartz from Wattle Gully. Salinities of the inclusions are low and homogenization temperatures are consistent with entrapment around 300°C at 2 kbars pressure. A fluid-inclusion study at the Fiddlers Creek gold mine, Pyrenees Range (McKenzie, 1981) has shown the mineralizing fluid to be dominated by CO_2. Salinities were low and estimated temperature in the 100—300°C range.

Gold—quartz deposits spatially associated with dykes

In a number of localities (Stawell, Maryborough, Castlemaine—Chewton, Maldon, Diamond Creek) various mafic and/or porphyry dykes occur within the mine sequences. For example at Wattle Gully (Chewton) and Bendigo, thin monchiquite dykes of probable Jurassic age have been intruded parallel to the axial surface of folds, and at Maryborough Howitt (1913) regarded cross-cutting lamprophyre dykes as having a distinct spatial connection with gold occurrence. Within the Warrandyte sub-province, gold—quartz veining is associated with quartz diorite and feldspar porphyry dykes, which cut Silurian sediments of the Melbourne Trough.

There is a close spatial and probable genetic association between gold mineralization and NNW-striking dyke swarms within the Lower Devonian sediments of the Walhalla Group, located in the Walhalla—Woods Point sub-province (Junner, 1920; Hills, 1952). Compositionally, the dykes vary from hornblende peridotite to hornblende diorite to hornblende-free leucodiorite (Marsen, 1976). Mineralized veining is typically located close to the dyke walls, within faults and tension gashes, or less commonly within faults entirely contained within the host sediments. The most significant mines were at Walhalla, where Cohens Reef was followed to a depth of 1130 m with a production of 46,600 kg from 1.4×10^6 t of ore (Whiting and Bowen, 1976).

At the Thompson River Mine within the Woods Point—Walhalla sub-province, some 2540 t of ore were produced in the period 1906—1913 with average grades of 3.75% Cu, 0.34% Ni, 1.3 g MT^{-1} Au, 11 g MT^{-1} Ag, 1.9 g MT^{-1} Pt, and 3.2 g MT^{-1} Pd (Keays and Kirkland, 1972). These authors noted that the precious metals appear to occur as discrete phases in the ores, with both sperrylite and merenskyite being determined semi-quantitatively.

Gold associated with granitoids

Thomas (1953a) reports primary gold associated with various granitoid bodies at

Warburton, Harcourt, Buffalo among others, and auriferous veins at Cobaw, Swifts Creek, and Budgee Budgee. The most significant occurrence appears to be the Mafeking Granodiorite (Fig. 12), at Mount William (Murray, 1914). Here ferruginous quartz veining within the granodiorite has shed fine gold into the overlying Tertiary gravels and finer sediments.

With the recent interest in low-grade, bulk-tonnage gold deposits, a reappraisal of the plutonic--subvolcanic gold association in Victoria is currently occurring.

One group of deposits, which may be loosely termed porphyry gold style, is typically associated with I-type granitoids and sulphide vein deposits. The intrusives are often in the diorite—granodiorite range and may be highly magnetic. Alteration varies from silicic, argillic, to propylitic. An example is the Banimboola Quartz Diorite (Bolger et al., 1983) located in the northeast of the State (110, Fig. 10). The intrusion has extensive surface alluvial workings on its western flank and chemically the bulk of the pluton lies in the region of 60% SiO_2 with high K_2O (2.5% K_2O at 60% SiO_2). Hesp (1974) reports moderated to high background copper (50--200 ppm) in the rock.

A second group of deposits is associated with breccia pipes in the subvolcanic environment. These breccia bodies and stockworks may be located within or around intrusives and may pass up into overlying volcanic sequences under the agency of hydraulic fracturing and high fluid pressure. A recently recognised example (BHP, EL 854, 1985) involves narrow stibnite--siderite breccias in a quartz diorite ring-dyke adjacent to the Cerberean Cauldron (Fig. 9). Broad argillic, pyritic, and carbonate alteration haloes commonly carry 0.1- 0.5 g MT^{-1} gold.

Age of gold mineralization

The Cambrian mafic-hosted gold deposits are in a number of instances thought to be temporally associated with the extrusion of the host lavas and hence are of probable Cambrian age. The gold--quartz vein deposits hosted by Palaeozoic sediments are generally considered to have been emplaced contemporaneously with the deformation of the enclosing turbidite sediments. In Western and Central Victoria this deformation is ascribed to the Mid-Devonian Tabberabberan Deformation, though evidence has been presented elsewhere in this paper to suggest that within the Ararat—Bendigo Zone of Western Victoria the folding and associated faulting may reflect a Benambran event. However, at Costerfield and Ringwood in the Melbourne Trough, Au--Sb quartz veining is probably Mid- to Late Devonian and was associated with the development of the Central Victorian Magmatic Province. In the Woods Point Dyke Swarm, mineralization is considered to be contemporary with the igneous intrusions. which post-date the Tabberabberan Orogeny but do not intrude the overlying Upper Devonian sediments.

Source of the gold

Various theories on the origins of gold deposits in Victoria have been considered. Murray (1895), largely influenced by the ideas of A.W. Howitt, proposed a secretion hypothesis with granitoid intrusions or mafic dykes acting as the heat source. Bowen and Whiting (1975) comment on the poor spatial correlation between granitoids and gold mineralization and they suggest mobilization of quartz and gold from within the Palaeozoic sedimentary pile during folding. However, Glasson and Keays (1978) demonstrated that in the Clunes goldfield insufficient gold (0.53 ppb average) was released from the surrounding sediments during metamorphism and cleavage development to account for the local ore bodies.

Patterson (1974) working in the Ballarat--Wedderburn area proposed that at least some of the laminated quartz associated with indicator beds and auriferous quartz reefs could once have represented silica-rich sediments, that gold in the Ordovician sedimentary rocks could have been deposited syngenetically in siliceous layers associated with carbonaceous shales or within iron-rich deposits, and that the gold and quartz were subsequently remobilised during deformation with subsequent deposition in saddle reefs, trough reefs, and spurs.

Recently the relation between mafic rocks and gold deposition has received strong support from research by Keays and co-workers (e.g., Keays and Scott, 1976; Keays, 1983; Keays and Donnelly, 1984). Keays (1983) emphasises the relationship between intrusion/extrusion of high-temperature, high-magnesian melts, which attain sulphur-saturation just prior to eruption, and gold deposition. Subsequent deformation and leaching of gold by carbonate-rich solutions from these mafic and ultramafic rocks and their associated sulphide-rich interflow sediments has led to the formation of structurally controlled gold deposition higher in the crust. In some instances the gold is considered to have been remobilised during a prograde metamorphic event in deeper crustal levels and elsewhere there is thought to be a genetic link between dyke intrusion and gold mineralization, such as the Woods Point Dyke Swarm (Keays and Donnelly, 1984).

Support for a metamorphic or magmatic origin for the transporting fluids comes from stable isotope studies. At Wattle Gully, Chewton, calculated $\delta^{18}O$ values for aqueous fluids in equilibrium with vein quartz at 300°C range from +8 to 10% (Cox et al., 1983b). At Stawell, Golding and Wilson (1981) conclude that the ore fluids had a $\delta^{18}O$ value of +7 to 8%.

Summary

In Victoria, the Lachlan Fold Belt is divided into seven structural zones and its eastern margin is truncated by coastline or obscured by younger sedimentary rocks, whereas the western margin most likely lies within the Grampians Zone.

The oldest rocks recognised in Victoria are Cambrian and typically occur as narrow elongate greenstone belts which are dominated by mafic and intermediate submarine volcanics and minor ultramafic intrusives. These rocks are host for minor orthomagmatic chromite deposits, and syngenetic or epigenetic Au and Cu mineralization.

The greenstones are often overlain by condensed hemipelagic and volcanogenic Upper Cambrian sediments with minor limestones in places and these sediments host minor Fe–Mn deposits of probable volcanogenic exhalative origin.

Overlying these Cambrian rocks, a sheet of quartz-rich turbidite-sandstones, shales, and associated mudstones extended over much, if not all of Victoria east of the Grampians Zone. The westernmost, portion of this turbidite sheet (St. Arnaud Beds) is probably Upper Cambrian but the remainder is Ordovician in age. Local development of black shales is found in the Upper Ordovician (Mount Easton Province, Yalmy region). The source of the turbidites lay probably to the south of Victoria in a mixed terrain of (meta) sediments and granites, with no record of volcanic detritus.

This broad turbidite fan setting was broken by the first of several regional deformations, the epi-Ordovician Benambran Orogeny. The intensity of the Benambran event varies widely: from multiple deformation, recumbent folding, regional metamorphism and granite intrusion in the Omeo Metamorphic Belt, to no deformation in the Melbourne Trough, where the event is marked by a facies change at the top of the Ordovician sequence. It is possible that the St. Arnaud Beds and perhaps even the Ordovician sediments of the Ararat—Bendigo Zone were folded during this event, but evidence is largely circumstantial. Sn—W granitoid-hosted mineralization commenced in northeastern Victoria during the Benambran event.

Subsequent to the Benambran Orogeny, deposition was mainly confined to a few large basins or rifts, the Grampians "Trough", Melbourne Trough, and the Buchan Zone. In the Melbourne Trough, marine sedimentation continued without interruption until the end of the Early Devonian resulting in a very thick sequence of mudstones and turbidites. In the Grampians "Trough" a large angular unconformity exists between the Grampians Group and the underlying (Upper Cambrian?) sediments. The Grampians Group, which is probably Silurian in age, consists of a thick "red-bed" type sequence, largely non-marine, and probably deposited in a large delta. Broad, open folding of the Grampians Group probably took place in the epi-Silurian Bindian deformation, and was closely followed by intrusion of Early Devonian granitoids which may contain minor Au and Mo (Mafeking Granodiorite). The Rocklands Rhyolite, a large caldera complex west of the Grampians Group, probably belongs to this event, although in the past it has been placed stratigraphically below the Grampians Group.

The Yalmy Fault in eastern Victoria, which coincides with the I-S granite line, marks the boundary between the Buchan Zone and Mallacoota Zone and is an important structural and geochemical boundary. East of the fault, at Delegate, the Upper Ordovician rocks were multiply deformed during the Benambran Orogeny prior to the deposition of the Lower Silurian Tombong Beds.

There is no trace of such deformation west of the fault where the Benambran Orogeny is marked by a strong facies change. Here the first major deformation took place in the Late Llandovery, Quidongan Orogeny and produced an unusual series of broadly folded, stacked thrust sheets.

This was followed by the formation of two large graben-like rifts located in the Buchan Zone, namely the Wombat Creek Graben and Limestone Creek Graben, which together comprise the Cowombat Rift. The sequence in both grabens is similar, with thick acid, volcanics followed by a shallow-marine, partly volcanogenic sequence, and local carbonate development. Various syngenetic basemetal deposits, showing a significant increase in Zn and Pb contents over earlier Cambrian mafic-hosted base-metal deposits, occur. These deposits are typically located at the transition between volcanics and sediments. Time equivalent base-metal deposits are to be found to the north in NSW at Captains Flat and Woodlawn.

Strong folding of the graben sequences in the Buchan Zone occurred at the close of the Silurian, during the Bindian deformation. The rocks were near-isoclinally folded, faulted, and metamorphosed up to lower greenschist facies with extensive silicification and chloritization of the volcanics.

The intrusion of granites in the Early Devonian (405—395 Ma approximately) was the most extensive episode of granite intrusion in Victoria, affecting the Glenelg, Grampians, and Ararat—Bendigo Zones in Western Victoria, and the Highlands and Mallacoota Zones in Eastern Victoria. Wilsons Promontory, located in the Howqua Zone, probably belongs to this intrusive cluster, as do the poorly dated granites and biotite schists of the Kuark Metamorphics in the Mallacoota Zone. Mineralization associated with this event includes Mo—Au (Mafeking), Mo (Mount Douglas, Mount Moliagul, Korong Vale), Sn associated with pegmatites and greisen (Mount Wills), and in Tertiary alluvials derived from Wilsons Promontory. To the east of the Yalmy Fault mineralization is dominated by Mo and lesser W (Genoa and Genoa Peak).

Renewed crustal extension in eastern Victoria in Early Devonian time led to the formation of four basins or fault-controlled depressions (Buchan Rift, Errinundra, Tabberabbera, and Wombat Creek Graben). These contain thick sequences that range from entirely marine terrigenous clastics (Tabberabbera) to silicic volcanics followed by calcareous marine sediments (Buchan, Errinundra), to entirely silicic volcanics (Dartella Volcanics in the Wombat Creek Graben). Exhalative volcanogenic mineralization is typically located at the transition between volcanics and calcareous sediments at both Buchan and Errinundra, and is dominated by Pb—Zn—Ba and lesser amounts of Cu.

Associated Fe—Mn mineralization is typically restricted to the southern part of the Buchan Rift and was deposited under lacustrine (Iron Knob) or shallow-marine conditions (Iron Mask). The major iron deposit (Nowa Nowa) was emplaced along north-striking shears.

The effects of the Middle Devonian Tabberabberan Orogeny were widespread but variable. All the Lower Devonian sequences were folded with the strongest deformation occurring in the sedimentary sequences and the weakest in the acid volcanics. In the Melbourne Trough, this is the oldest recorded compressional deformation and its effects were strongest in the eastern half of the trough, where it produced near isoclinal folding in the Mount Useful Slate Belt.

The major quartz—Au mineralization in the Bendigo—Ballarat gold sub-province and elsewhere, occurred when the host Ordovician turbidites were folded, but the age of this event is poorly constrained. It is certainly no younger than Tabberabberan and cannot be older than Benambran.

Minor vein Sb—Au mineralization (Costerfield, Ringwood) and fracture-fill quartz—Au veins are located within the Melbourne Trough and are likely to have been associated with the development of the Central Victorian Magmatic Province.

Crustal relaxation after the compressional Tabberabberan Orogeny led firstly to intrusion of dyke swarms and very localised I-type granitoids in the late Middle Devonian, followed by widespread igneous activity and the creation of epicontinental grabens in the Late Devonian—Early Carboniferous.

The Middle Devonian, Woods Point Dyke Swarm in the Melbourne Zone encompasses dykes ranging from hornblende peridotite to hornblende diorite to hornblende-free leucodiorite. Fractures both in the brittle dykes and in associated wall rocks are host for quartz—Au mineralization within the Walhalla—Woods Point gold sub-province.

Intrusion of predominantly S-type granitoids in the Late Devonian was restricted to the Central Victorian Magmatic Province and led in several cases to the formation of large volcano-tectonic ("cauldron") subsidence structures containing very thick piles of rapidly extruded largely silicic volcanics. The intrusives may carry minor amounts of Sn, W, Mo, Bi, or Au. The Marysville Igneous Complex with associated W mineralization may be regarded as a northern equivalent of the Late Devonian Tasmanian—King Island tungsten province, whilst to the north in the Pilot Range, Sn mineralization associated with quartz veins in granite and greisen has apparently given rise to the considerable alluvial deposits around Beechworth. Concentric pipe deposits within porphyritic granodiorite at Everton was the major producer of Mo for Victoria.

The Mount Howitt Province, which lies east of and partly overlaps with the Central Victorian Magmatic Province, is the main site of Late Devonian—Early Carboniferous sedimentation and contains a 2—3 km thick sequence of fluviolacustrine red-beds and bimodal subaerial volcanics, with minor sedimentary Cu mineralization of red-bed affinity. Red-bed style sediments with very minor acid volcanics occur in a series of small grabens in Eastern Victoria.

The last major compressional deformation was the epi-Lower Carboniferous Kanimblan Orogeny, and its effects are largely restricted to the Upper Devonian grabens. Deformation is generally mild, with broad open folds, but stronger deformation occurs especially along boundary faults of the Mount Howitt Province, which became thrust faults. There was very minor post-Kanimblan igneous activity marked chiefly by intrusion of a few acid dykes in the red-bed sequence at Tabberabbera.

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