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R E C O R D

Record 1989/30

A REVIEW OF GOLD MINERALIZATION IN EASTERN AUSTRALIA

A. R. WILDE

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CONTENTS

1: INTRODUCTION

1.1: SCOPE OF THIS REPORT

The purpose of this report is to review the different styles of mineralization encountered in Eastern Australia, their distribution and genesis, particularly in the light of discoveries which have resulted from intensive exploration in recent years, and has been compiled almost entirely on the basis of literature research. Only occurrences in the states of Victoria, Queensland and New South Wales were considered. The report is arranged by state, not because this is geologically justified but because the various state geological surveys, mines departments and mining journals are prime sources of data.

In preparing this report references were compiled into a bibliographic database using the software package PBS. A complete listing of the database is given in Appendix 1. Some of the existing stable isotope data has been compiled in Appendix 2.

1.2: HISTORICAL PRODUCTION

Gold has been mined in Australia since 1851, following the discovery of rich alluvial deposits in the Bendigo region of Victoria. Victoria was Australia's main producer until 1895, when Western Australia shot to prominence as the result of exploitation of its rich Archaean-hosted deposits. Thereafter Western Australia maintained its dominance of the Australian gold industry. Table 1.1 details the top twenty goldfields of Eastern Australia (excluding placer deposits) on the basis of figures compiled in Woodall (1979).

1.3: CURRENT PRODUCTION

The present decade has seen something of a renaissance of gold-mining in the Eastern States (Table 1.2), particularly in Queensland with combined production exceeding levels previously achieved in the decade from 1880 to 1890. Over 32 major (and innumerable smaller) gold-mining operations are currently active (Table 1.2; the location of the larger deposits is given in Fig. 1.1). Queensland is the major contributor, with a 1987 production of 14,832 Kg while New South Wales produced 2,529 Kg and Victoria 1,221 Kg.

DEPOSIT	STATE	PRODUCTION (Kg)
BENDIGO	VICTORIA	539,900
Mt. MORGAN	QUEENSLAND	245,605
CHARTERS TOWERS	QUEENSLAND	211,506
GYMPIE	QUEENSLAND	106,515
WALHALLA	VICTORIA	69,330
BALLARAT	VICTORIA	57,900
HILL END	NEW SOUTH WALES	55,986
MALDON	VICTORIA	54,425
STAWELL	VICTORIA	38,900
COBAR	NEW SOUTH WALES	38,773
CLUNES	VICTORIA	37,200
ROSEBERY	TASMANIA	32,154
BETHANGA	VICTORIA	31,000
DUNOLLY	VICTORIA	31,000
RAVENSWOOD	QUEENSLAND	27,993
BEACONSFIELD	TASMANIA	26,562
WOODS POINT	VICTORIA	26,198
Mt. LYELL	TASMANIA	24,704
CASTLEMAINE	VICTORIA	23,325
CRACOW	QUEENSLAND	19,910

Table 1.1: *Historical lode (or reef) gold production from the top twenty Palaeozoic deposits of Eastern Australia (from Woodall, 1979). Statistics to December 1977. Croydon (Queensland) is not included as it is commonly held to be Proterozoic in age.*

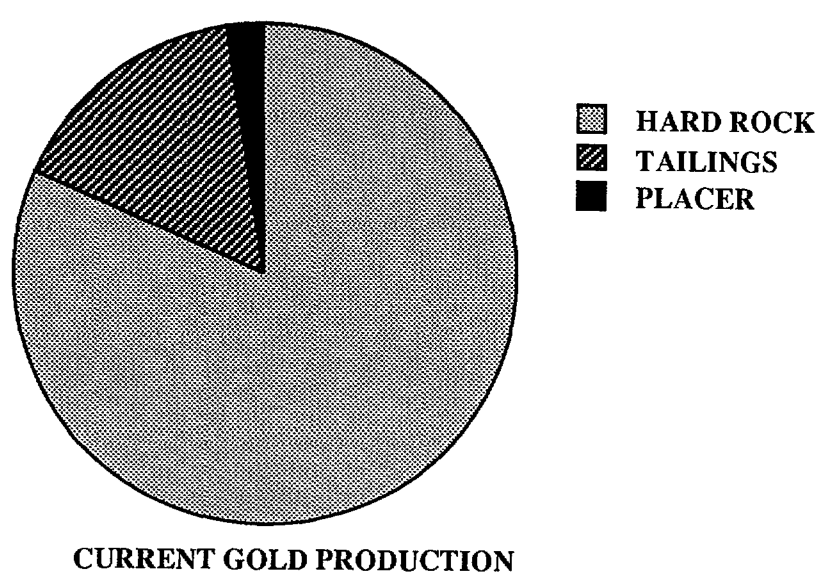


Fig. 1.2: *Percentage of current gold production as hard-rock mining, recovery of tailings from old dumps and placer mining.*

DEPOSIT	OPERATOR	Kg Au 1987	g/tonne	TONNAGE
QUEENSLAND				
KIDSTON	Kidston Gold Mines	7,533	1.82	39,217,000
Mt. MORGAN*	Mt. Morgan Ltd.	2,108	1.08	26,500,000
RED DOME	Elders Resources	2,101	2.50	8,600,000
Mt. LEYSHON	Pan Australian Mining Ltd.	1,871	1.97	6,600,000
GOLDEN PLATEAU*	Sedimentary Uranium N.L.	649	4.00	12,500,000
CROYDON	Barrack Mines Ltd.	93	3.80	1,200,000
KILKIVAN¶	Centamin	92		
PALMER RIVER¶	Australian Diversified Res.	90	0.35	20,000,000m^3
FAR FANNING	North Queensland Co. Ltd.	87	2.30	500,000
Mt. MADDEN¶?	Aur N.L.	77		
FINE GOLD CREEK¶?	Austwhim	70		
LUCKY BREAK¶?	East-West Minerals	49		
GILBERT RIVER¶	Balmoral	45		
GILBERTON¶	Portman	27		
CAPE RIVER¶	Associated Goldfields	16		
BLACK JACK	Charters Towers	11		
NEW SOUTH WALES				
GIDGINBUNG	Paragon Gold Pty. Ltd.	1383	2.5	4,500,000
COBAR	Mincoa	>770		
BROWNS CREEK	BHP Minerals Pty. Ltd.	483		
HILLGROVE	New England Antimony	256		
WEST WYALONG*	Cluff Minerals Aus. P.L.	112	2.1	188,000
CANBELEGO*	Epoch Exploration N.L.	111	0.95	2,700,000
COWARRA	Horizon Pacific Ltd.	>106	10.6	165,000
MITCHELL'S CREEK*	Cluff Minerals Aus. P.L.	78	1.88	240,000
WOODLAWN*	Denehurst	>28		9,000,000
OALLEN FORD¶	Abaleen Minerals Ltd.			
ROCKY RIVER MINE¶	Saga Minerals N.L.		<1 g/m^3	1,500,000
VICTORIA				
STAWELL	Western Mining Corp.	974	4.0	270,000
LAST CHANCE	Delta	161		
WEST BENDIGO	Bendigo Goldfields	58†	14.0?	464,205?
GAFFNEYS CREEK	Broken Hill Holdings P.L.	28		

TABLE 1.2: *Economic data for major gold mines of Queensland, Victoria and New South Wales. * indicates gold recovered from old tailings. ¶ indicates an alluvial operation. † includes production from tailings reprocessing and alluvial operations at Inglewood and Moliagul. Ore resource in proved and probable category*

DEPOSIT	STATE	OPERATOR	GRADE (g/t)	TONNAGE
STARRA	Qsld	Elders Resources		
PAJINGO	Qsld	Battle Mountain	12.6	1,400,000
AGRICOLA	Qsld	Astrik Resources		
GYMPIE	Qsld	BHP Gold		
Mt. RAWDON	Qsld	Placer Pacific	1.3§	20,000,000§
WIRRALIE	Qsld	Australian Cons. Minerals		
DISRAELI	Qsld	Northern Queensland Res.		
Mt. COOLON	Qsld	RGC/Crusader		
CROYDON	Qsld	Pancontinental Mining Ltd.	4.0	600,000
HORN ISLAND	Qsld	Augold/Giant Resources		
THE PEAK	NSW	Cobar South Pty. Ltd.	7.0	4,000,000
SHEAHAN-GRANTS	NSW	Climax Mining Ltd	3.4	1,400,000
DRAKE (KYLO)	NSW	Mt. Carrington Mines	3.6	650,000
LONDON-VICTORIA	NSW	Alkane Exploration N.L.	3.1	800,000
PEAK HILL	NSW	Alkane Exploration N.L.	2.1	2,000,000
MINERAL HILL	NSW	Triako Resources Ltd.	5.0	500,000
Mt. BOPPY*	NSW	Epoch Minerals Exploration	6.0	80,000
NEW OCCIDENTAL*	NSW	Ranger Exploration N.L.	0.95	2,700,000
BALLARAT	VIC	Ballarat Goldfields		
CASSILIS	VIC	Paringa Mining Ltd.		

TABLE 1.3: *Projects under construction or evaluation in Eastern Australia as of 1987 . Starra is located near Mt. Isa and is not considered further in this report. Sources of data: Cleary (1987), Annual Report of the New South Wales Dept. Mines for 1987. §"Preliminary figures" other symbols as for Table 1.1.*

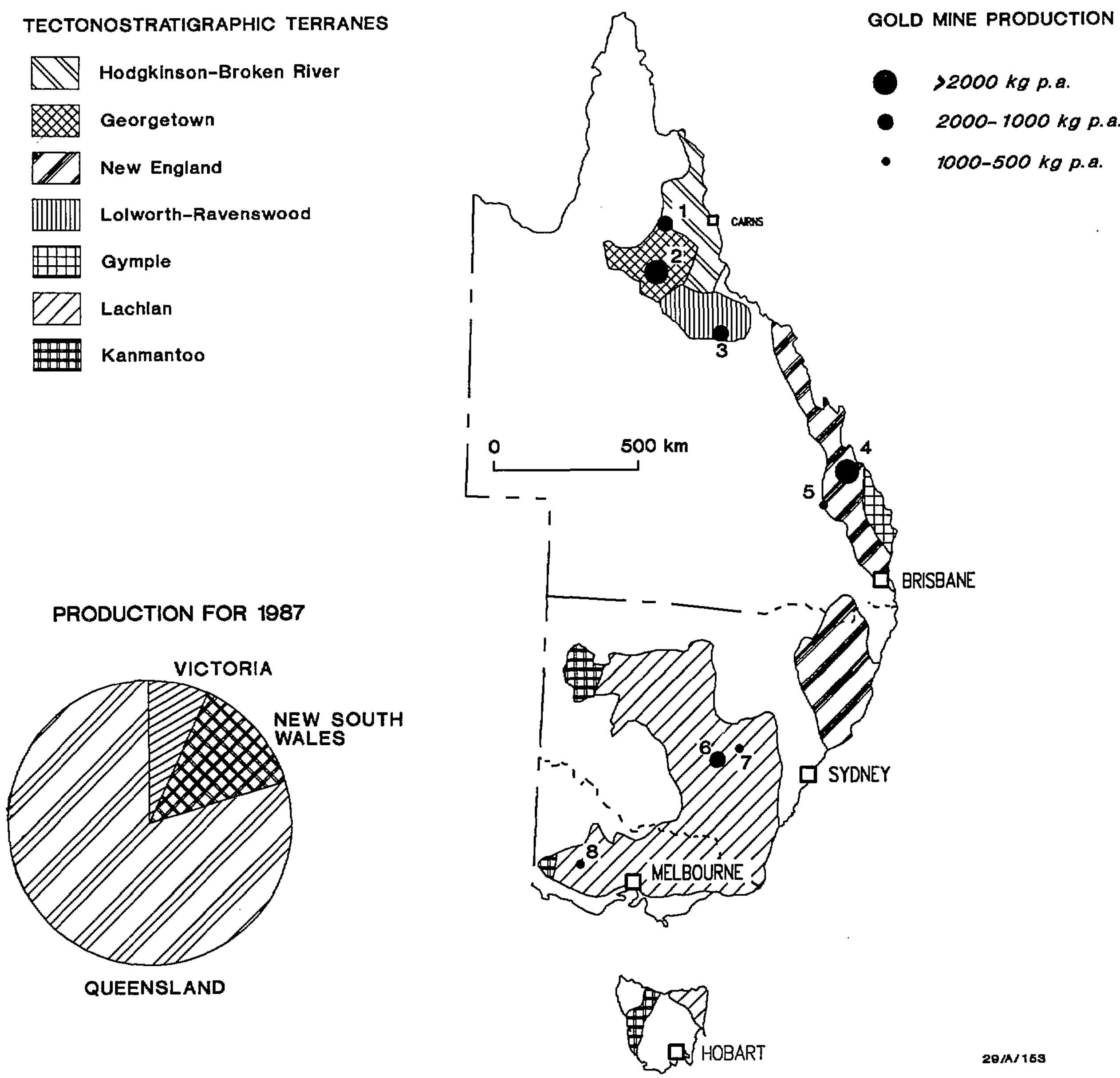


Fig. 1.1: *Map of Eastern Australia showing the distribution of major gold mines in relation to terranes. 1 - Red Dome, 2 - Kidston, 3 - Mt Leyshon, 4 - Mt Morgan, 5 - Golden Plateau, 6 - Gidginbung, 7 - Browns Creek, 8 - Stawell.*

1.4: THE LACHLAN TERRANE IN VICTORIA

Victoria's Lower Palaeozoic rocks which host the primary reef deposits of the area, form part of the Lachlan Fold Belt, herein termed the Lachlan terrane. Much of the following also applies to New South Wales (Fig. 1.1). The oldest exposed rocks are a sequence of metamorphosed Cambrian "greenstones" representing a mafic calc-alkaline igneous assemblage to the west (Stavely belt) and a MORB assemblage in Central Victoria, including low Ti, high Mg rocks of boninite affinity (Ramsay and VandenBerg, 1986). Hamlyn et al. (1985) have found high gold contents in some of these Cambrian rocks and conclude that they represent important source rocks for mineralization inn the area.

These rocks are overlain by unfossiliferous black shale (now slate) and chert believed to be Cambrian in age. The Lower Ordovician is marked by uniform deposition of turbidites throughout the state. During the Upper Ordovician, black shales were deposited in Central Victoria. At the close of the Ordovician there was a marked unconformity in west and central Victoria and high-grade metamorphism to the east, in the Omeo-Wagga belt, the Benambran orogeny.

Following the Benambran orogeny, deposition was confined to north-south trending troughs or rifts. In Central Victoria a thick sequence of Silurian to Early Devonian turbidites accumulated, while to the west redbeds and felsic volcanics (Rocklands Rhyolite) were deposited. To the east Lower Silurian rocks overlie poly-deformed Upper Ordovician rocks of the Benambran event. Sediments here include: felsic volcanics, shallow marine sediments and limestones. A major deformation event, the Tabberaberan orogeny, occurred during the Lower to Middle Devonian and resulted in upright close folding of the Lower Palaeozoic rocks.

Upper Devonian post-tectonic volcanism and granitoid intrusion is widespread throughout the state. A huge volume of magma was added to the upper crust during this time This presumeably reflects anomalous thermal gradients *on a regional scale.* In Central Victoria there are cauldron type eruptive centres, which produced piles of lavas up to 3 km thick. By the Carboniferous Victoria was evidently emergent. Two to three Km of red-bed sediments and bimodal subaerial volcanics occur as a north-south trending belt in Eastern Victoria. Minor red-bed copper mineralization is found in these sediments, but no gold mineralization has been reported. The Permo-Triassic was a period of apparent tectonic quiescence, and outcrops of rocks of this age (glacial and fluvio-glacial sediments) are exceedingly uncommon. Permo-Triassic igneous activity is very uncommon, a striking contrast to the New England terrane (fold belt) in Queensland (see below). A flatlying cap of Tertiary fluvial sediment (which may host placer gold deposits) and Quaternary basalt completes the geological evolution of the Victorian goldfields.

Sandiford and Keays (1986), Fergusson et al. (1986) and Cox et al. (in prep.) attribute the large scale structural features of the Lower Palaeozoic of western Victoria to "thin-skinned tectonics". That is to say the slate belt and its basement were decoupled during peak deformation (probably Lower to Middle Devonian); major north-south striking listric faults having developed at the zone of decollement. These are thought to splay upwards in the direction of tectonic transport, and eventually become vertical, when they expose elongate belts or "axes" of greenstones (see next Section). This is significant for some genetic models for gold mineralization since substantial lateral fluid flow can be envisaged along the flat-lying component of the faults, scavenging metals from a large area.

There has been discussion as to whether different tectono-stratigraphic terranes can be defined (Cox et al., in prep.; Sandiford and Keays (1986), Fergusson et al. (1986); Stump et al. 1986; Scheibner, 1987). It is generally agreed that 4 or 5 terranes can be recognized, mainly on the basis of the dominant age of the sediments in each terrane. Structural style, however, and lithological assemblage seems to be rather similar between the postulated terranes. This report adopts the approach that the Lachlan fold belt in its entirety defines a terrane, and is referred to herein as the Lachlan terrane. There is no obvious spatial relationship between the occurrence of ore and regional tectonic features, except that the gold fields are often aligned north-south parallel to axial traces of major D_1 folds (Wall, 1987), a reflection of structural control on mineralization exerted by the pervasive regional folding (see below).

1.5: LACHLAN TERRANE IN NEW SOUTH WALES

A significant difference between the Lachlan Terrane in New South Wales compared to Victoria, is the abundance of Ordovician to Lower Silurian volcanic rocks in New South Wales. Both Clarke (1987) and Wyborn (BMR Newsletter, 1988 - in press) have drawn attention to the shoshonitic nature of these volcanics and have implicated them in mineralization. Wyborn (1988) considers that the volcanics resemble chemically volcanic rocks on Lihir and Fiji which host important gold mineralization, and goes on to say that the "Ordovician volcanics and high level intrusives in the Lachlan fold belt form a major gold province". According to Wyborn the shoshonites were derived by partial melting of a mantle already depleted in sulphur, and with Au and PGE concentrated into residual sulphides. Resultant melts would have been enriched in Au and PGE, and these would have been further concentrated into the melt phase during fractionation. Clarke (1987) speculated that gold-enriched magmatic fluids debauched onto the seafloor and gold was then dispersed into local sediments (citing gold-enriched cherts) where it could then be concentrated at some later date into an ore deposit.

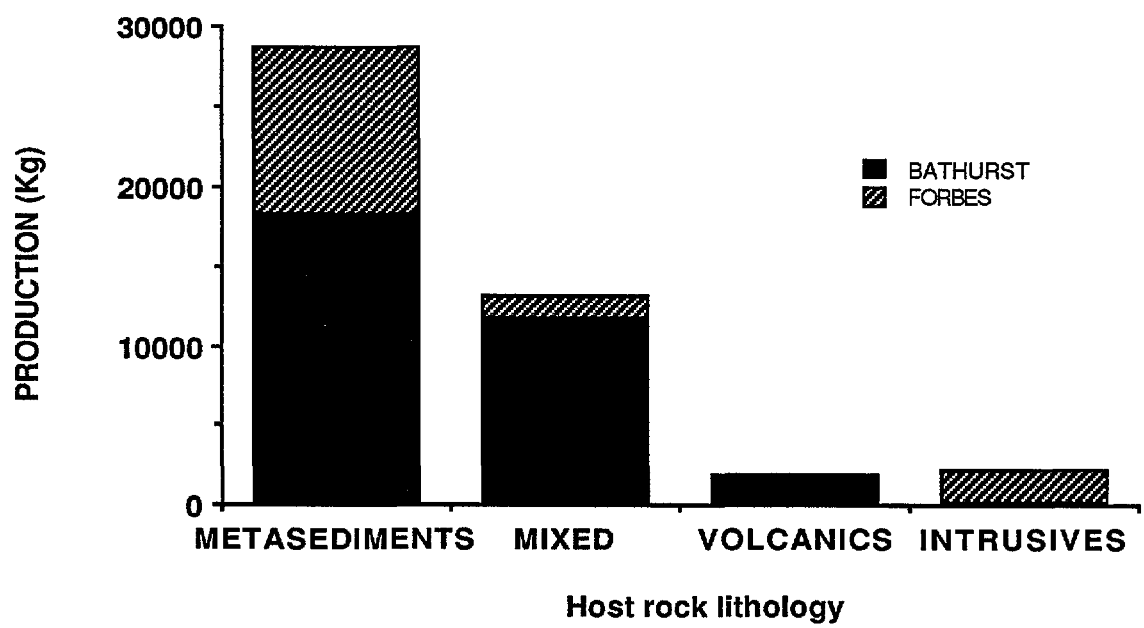


FIG. 1.3: Historical gold production by host rock lithology from the 1:250,000 sheet areas of Forbes and Bathurst (data of the Geological Survey of New South Wales). The "mixed" category is dominated by the Wentworth deposit, which is hosted by supposedly intrusive andesite and serpentinite.

A compilation of mine production data by lithology shows that few of the major deposits are hosted by volcanics, and most production in the past came from metasediments (Fig. 1.3). Even if the gold contained in the volcanic-hosted Peak Hill and Gidginbung deposits is added (ca. 16,000 Kg) the picture does not change significantly. Thus it is concluded that gold enrichment in the volcanics is unimportant in ore genesis. This is further supported by the remarkable concentration of gold deposits around Bendigo where there is a singular dearth of Ordovician to Silurian volcanics. The possibilty of a direct contribution from a gold-enriched fluid of magmatic origin has yet to be tested. Most deposits appear to post-date the volcanics (with the possible exception of Gidginbung and Peak Hill - Clarke, 1987). A model such as Clarke's may apply, but it is questionable whether a particular gold-enriched source rock is necessary for the genesis of an economic deposit.

1.6: NEW ENGLAND TERRANE (FOLD BELT)

The New England terrane hosts the Cracow Gold Provinces (Section 3) as defined in this report. Few Cambro-Ordovician rocks are preserved, and this terrane is thus quite different from the Lachlan terrane. Overlying Siluro-Devonian rocks have been interpreted as a relic island arc, "the Calliope Arc" (Murray, 1986). Andesitic volcanics dominate the sucession, with volcaniclastic sediments, limestones (coral-bearing) and conglomerates. These rocks were deformed during the Mid Devonian, when the tectonic regime changed to that of an Andean-type continental margin (Murray, 1986). Following deformation, granitoid plutons were intruded, possibly comagmatic with undeformed, predominantly andesitic Mid Devonian volcanics. To the east of the proposed continental margin sediments of the "Wandilla slope and basin" were deposited. These are defined by chert, spilitized basalt, argillite, rare limestone, and felsic volcanics grading eastwards into greywackes and argillites (probably turbidites).

The Late Carboniferous to Early Permian is interpreted as a change from Andean-type situation to a strike-slip dominated fault system analagous to the San Andreas Fault in California (Murray, 1986). Thus any associated gold deposits might be anticipated to be quite different to those produced earlier, during a different tectonic regime. The Early to Mid Permian period saw the establishment of the north-south trending "Camboon volcanic arc" which produced dominantly andesitic volcanics associated with lacustrine sediments. To the west of the arc marine sediments are preserved suggesting that the arc was separated from the Australian mainland, and may have been analogous to the present-day Indonesian arc. Some folding occurred in this period. The Late Permian to Late Triassic was a period of post-orogenic plutonism and widespread felsic to intermediate continental volcanism. In the main the Permian strata are undeformed and dip at shallow angles, except adjacent to faults as in the Esk Trough. The Esk Trough is regarded as a grabenal structure (Murray,

1986) but could be a product of strike-slip faulting, which may also result in the formation of deep, elongate sedimentary basins. During the Late Triassic and Jurassic S.E. Queensland was evidently a stable craton and emergent above sea level.

1.7: GYMPIE TERRANE

Rocks in the Gympie terrane, Queensland (host to deposits of the Gympie and Kilkivan districts) have had a different history to the rest of S.E. Queensland. The oldest rocks seen are Permian in age, and marine sedimentation is evident here during the Lower Triassic whereas it had ceased prior to this elsewhere in the N.E.T. The older rocks were deformed during the end of the Early Triassic. A penetrative axial-planar slaty cleavage developed and the rocks were metamorphosed to the greenschist facies (Murray, 1986). They were then unconformably overlain by felsic volcanics. This province can be regarded as an exotic block, possibly derived from New Zealand (Murray, 1986) and hence can be regarded as a distinct tectonostratigraphic terrane.

1.8: GEORGETOWN TERRANE (INLIER)

The Georgetown terrane, host to deposits of the Kidston province, including the major Kidston deposit itself (North Queensland; Fig. 1.1), is dominated by Proterozoic rocks. The oldest rocks are metasediments of early to Mid Proterozoic age, assigned to the Etheridge Group (Withall et al., 1980). Regional meta- morphism attained granulite facies to the east and five episodes of deformation have been recognized (Withnall et al., 1980). These rocks were intruded by granitoids (Esmeralda granite to the east and Forsaythe granite to the west). There was a period of Siluro-Devonian granitioid intrusion, and significant development of cauldron structures (Bain and Withnall, 1980; MacKenzie, 1987). This extensive magmatic event may possibly be correlated to the extensive plutonism observed through out the Lachlan terrane during this time (Ramsay and Vandenberg, 1986). Addition of such large volumes of magma to the upper crust would undoubtely have resulted in anomalous thermal gradients (or been a reflection thereof) and triggered or perturbed fluid patterns on a regional scale, and possibly given rise to gold mineralization (*c.f.* Bain et al., 1988). Magmatic fluid, however, may not necessarily have been involved in this system.

2: VICTORIA

2.1: INTRODUCTION

Ramsay and VandenBerg (1986) recognize five styles of gold mineralization in Victoria:

1 - Gold-quartz veins associated with altered Cambrian mafic lavas and volcaniclastic equivalents . The best example of this type is the Stawell deposit, Eastern Victoria.

2 - Gold-quartz veins hosted by cleaved turbidites (sandstones, shales and metamorphosed equivalents). The best examples of this type are at Bendigo and Ballarat in Central Victoria.

3 - Gold-quartz veins in mafic to intermediate dykes. The best examples of this type occur at Woods Point and Walhalla, Western Victoria.

4 - Occurrences in granitoids (examples occur at Warburton, Mafeking, Buffalo and Harcourt). These deposits have made a very small contribution to Victoria's total gold production.

5 - Disseminated gold. One example of this style is in the Banimboola quartz diorite (a possible porphyry-style deposit). Some deposits in subvolcanic pipes (stibnite and siderite cemented breccias) have been located adjacent to the Cerberean cauldron. These are associated with argillic, carbonate and pyrite alteration. There has been no production from this type of deposit as yet.

To this can be added placer (or "alluvial") deposits, both recent and ancient. A major part of Victoria's gold production (60% according to Ramsay and VandenBerg, 1986, or 1,469,000 Kg) was, in fact, derived from Tertiary placer deposits or "deep leads" which occurred beneath a cover of Quaternary basalt. The following text will concentrate on types 1-3 because information on types 4, 5 and placer deposits is minimal. Deposit types 1-3 will be discussed as one group, although the author acknowledges that the deposits of different areas may have been produced at different times and by different mechanisms.

2.2: GOLD PROVINCES

Primary reef (vein) gold deposits are found in Lower Palaeozoic "slate belt" metasediments and/or dykes (lamprophyre or quartz diorite and related rocks) of Cambrian to Devonian age. Seven sub-provinces, whose boundaries tend to coincide with major structural features (Fig.

SUB-PROVINCE	Kg GOLD	HOST-ROCKS	AGE?
BENDIGO-BALLARAT	791,580	Lower Ordovician sediments	Upper Devonian
WALHALLA-WOODS POINT	93,000	Mid Devonian Dykes	Mid/Upper Devonian
STAWELL	42,420	Cambrian sediments	Cambrian
GLENN WILLS	12,625	Upper Ordovician sediments	>Upper Devonian
HARRIETVILLE	6,850	Upper Ordovician sediments	>Upper Devonian
WARRANDYTE	<5,000	Silurian/Lower Devonian seds.	Mid/Upper Devonian
BENDOC	<5,000	Upper Ordovician sediements	>Upper Devonian

SUB-PROVINCE	Rb-Sr GRANITOID AGE	ASSOCIATED MINERALS
BENDIGO-BALLARAT	365 m.y.	sulphide - poor
WALHALLA-WOODS POINT	400 - 365 m.y.	sulphide - poor
STAWELL	400 - 385 m.y.	sulphide - rich
GLENN WILLS	430 - 400 m.y.	sulphide - rich
HARRIETVILLE	430 - 400 m.y.	sulphide - poor
WARRANDYTE	365 m.y.	antimony - rich
BENDOC	430 - 410 m.y.	sulphide - poor

TABLE 2.1: *Features of the seven sub-provinces defined by Bowen and Whiting (1975). Note that Bowen and Whiting (1975) used K-Ar ages in their classification, but more recent Rb-Sr data (as compiled in Ramsay and Vandenberg, 1986) is used here. Gold production excludes alluvial deposits.*

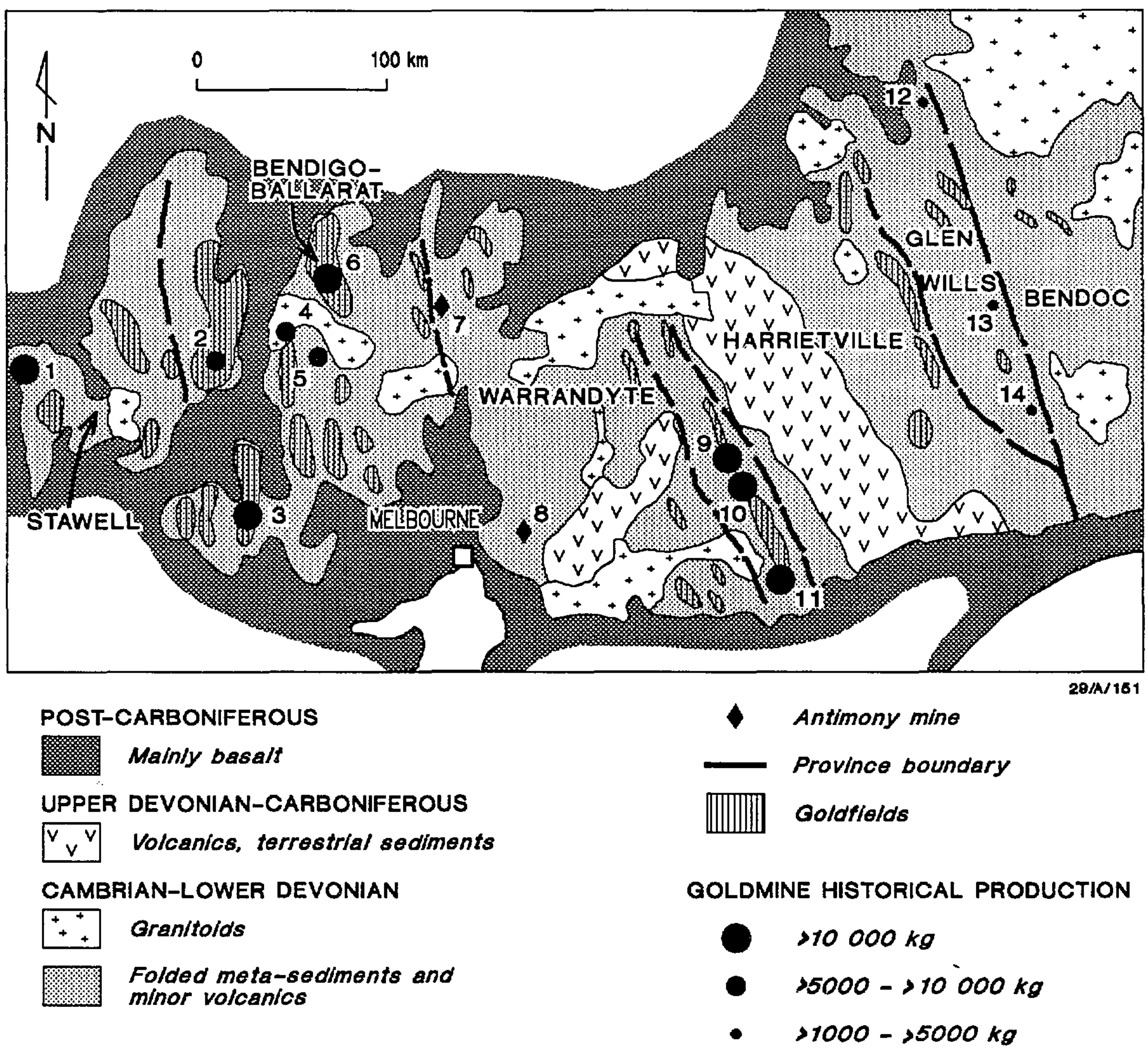


Fig. 2.1: Geological map of Victoria, based on McAndrew (1965) showing the distribution of major deposits and provinces of Bowen and Whiting (1975). 1 - Stawell, 2 - Maryborough, 3 - Ballarat, 4 - Maldon, 5 - Chewton, 6 - Bendigo, 7 - Costerfield, 8 - Warrandyte, 9 - Gaffneys Creek, 10 - Woods Point, 11 - Walhalla, 12 - Bethanga, 13 - Glen Wills, 14 - Cassilis.

2.1) were recognised by Bowen and Whiting (1975). It was postulated that within each province the deposits could be grouped together on the basis of ore mineral assemblage, age of host-rocks, inferred age of ore-deposition and K-Ar age of nearby granitoids (Table 2.1). Since the age of the mineralization is poorly defined in nearly every case, detailed mineralogical studies are few, and the significance of the granitoids to mineralization is in doubt, the justification for these sub-provinces must also be in some doubt. They are retained in this report as they provide a useful geographic framework for the following discussion. By far the greatest production came from the Bendigo-Ballarat, Stawell and Woods Point-Walhalla sub-provinces (Fig. 2.2), with negligible gold won from the sub-provinces of Bendoc, Warrandyte, Harrietville and Glenn Wills. The concentration of goldfields in the Bendigo-Ballarat area is extremely high, and over 20% of the exposed Lower Palaeozoic in this area can be classed as a goldfield. Although Bendigo was responsible for the bulk of Victoria's gold production the richest individual deposits were found in the Woods Point Walhalla province (Fig. 2.3). Production figures for the most significant Victorian deposits are given in Bowen and Whiting (1975).

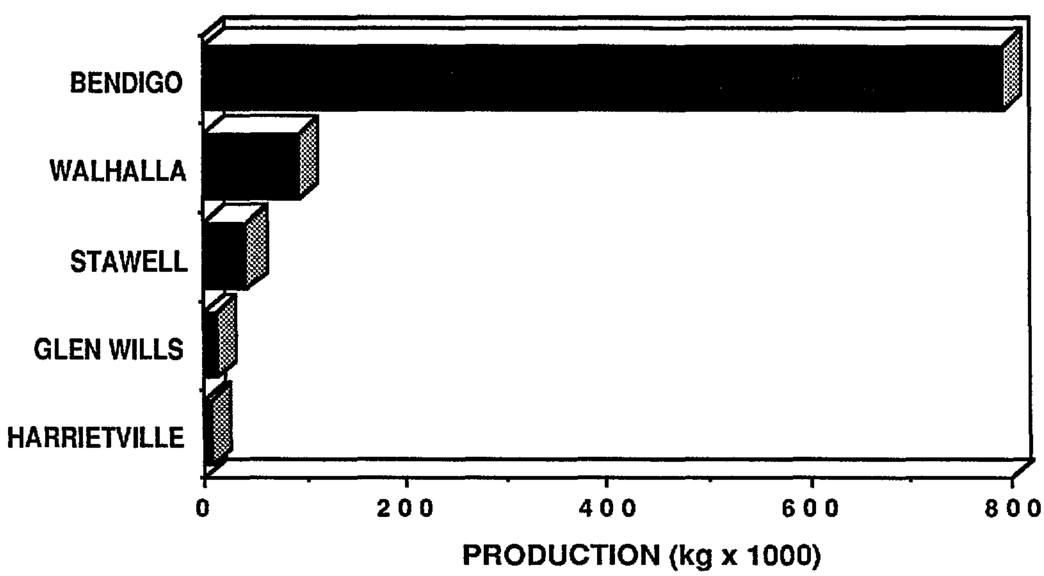


FIG. 2.2: Production of five of the seven "sub-provinces" recognized by Bowen and Whiting (1975). Production from Bendoc and Warrandyte did not exceed 5,000 Kg.

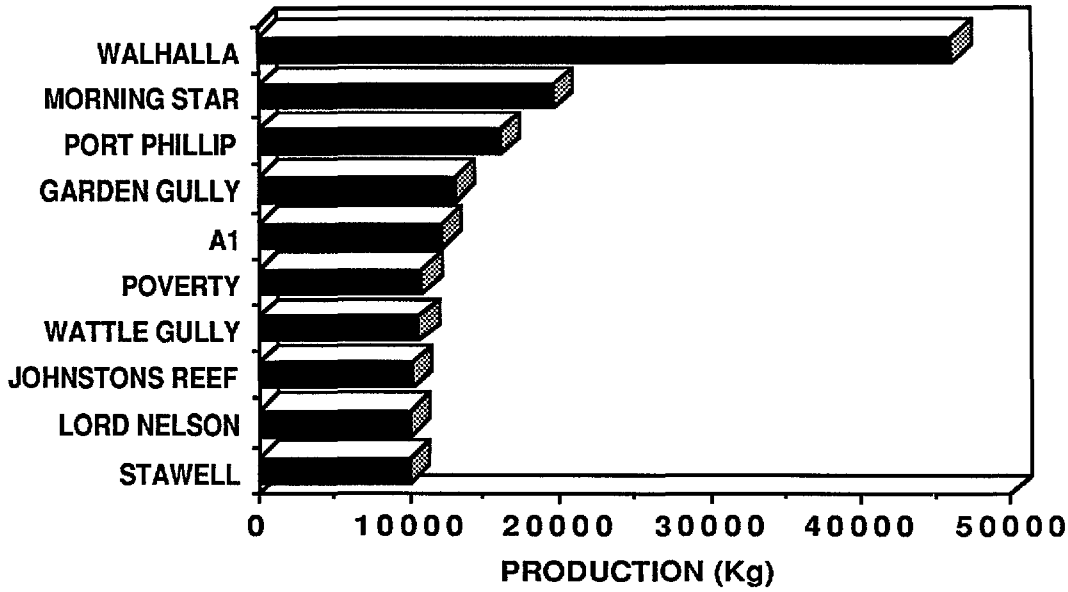


Fig. 2.3: Victorian gold mines which produced in excess of 10,000 kg gold (data from Bowen and Whiting, 1975). "Walhalla" includes Long Tunnel and Long Tunnel Extended mines. Lord Nelson and Stawell are from the Stawell province, Walhallla, A1 and Morning Star from the Walhalla-Woods Point province and the others from Bendigo-Ballarat.

2.3: LOCAL STRUCTURAL SETTING

The deposits occur in quartz veins (or "reefs" as they are called locally) which are located in post-D_1 (main cleavage) fault zones, often showing reverse movement. It is commonly held that these faults were formed during the cooling stage of the Tabberaberan orogeny, and were associated with the same stress system. Sandiford and Keays (1986) have suggested that they are associated with movement along major structures such as the Avoca fault (a possible strike-slip fault during at least part of its development).

In most of the deposits the quartz veins which host the ore show geometries which suggest that mechanical inhomogeneities in the host-rocks have played an important role in localizing dilantant structures. Veins often occur at, or close to, boundaries of rocks with contrasting mechanical properties. The deposits of the Woods Point - Walhalla province are spatially associated with dykes which have evidently exerted a strong mechanical control on the dispositon of the ore-bearing veins. Cohen's reef

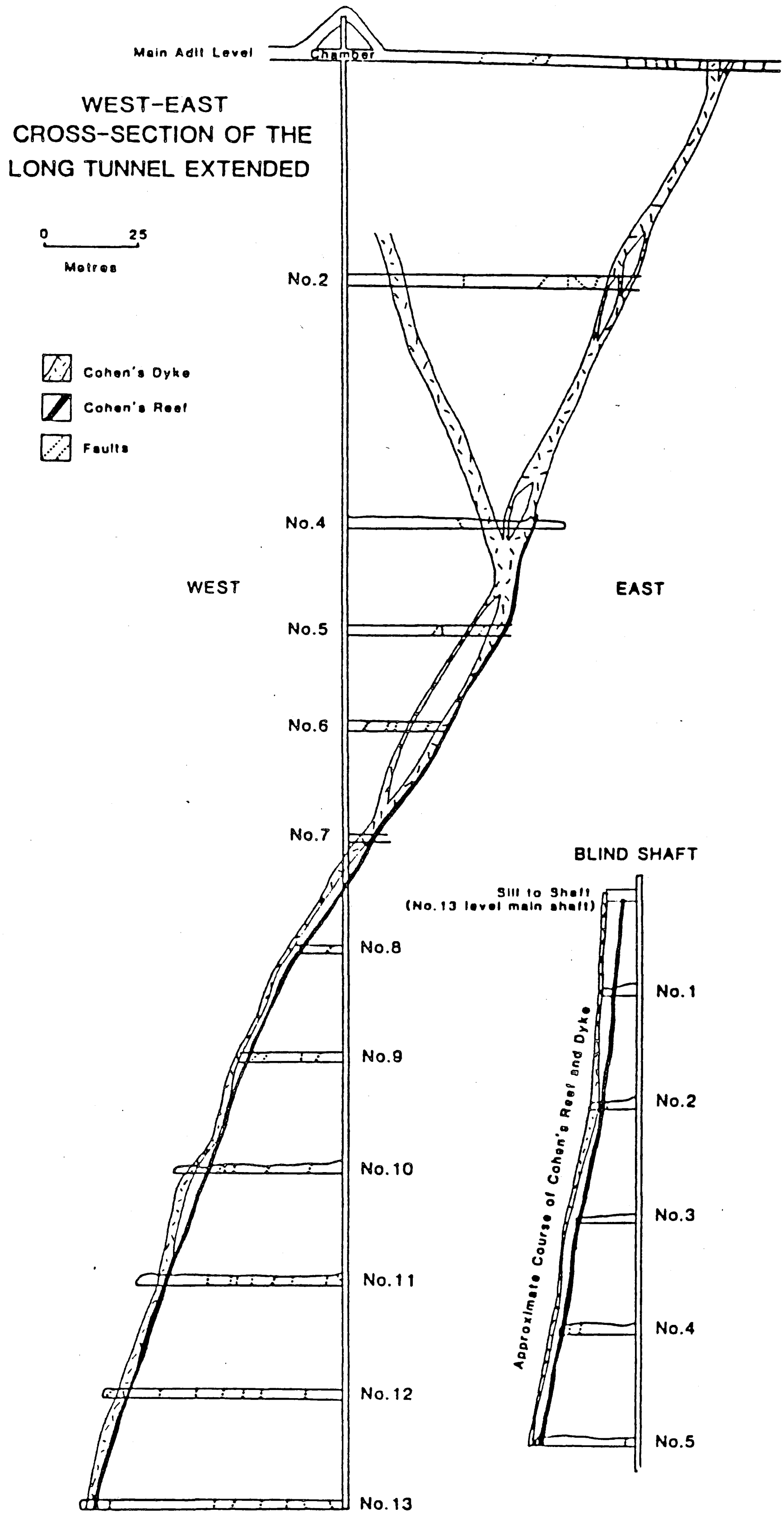


Fig. 2.4: Cross-section of the Long Tunnel Extended Mine, Walhalla, showing the relationship of the mineralized quartz vein (Cohen's Reef) to the diorite dyke. The dyke appears to have been an important mechanical influence on lode development.

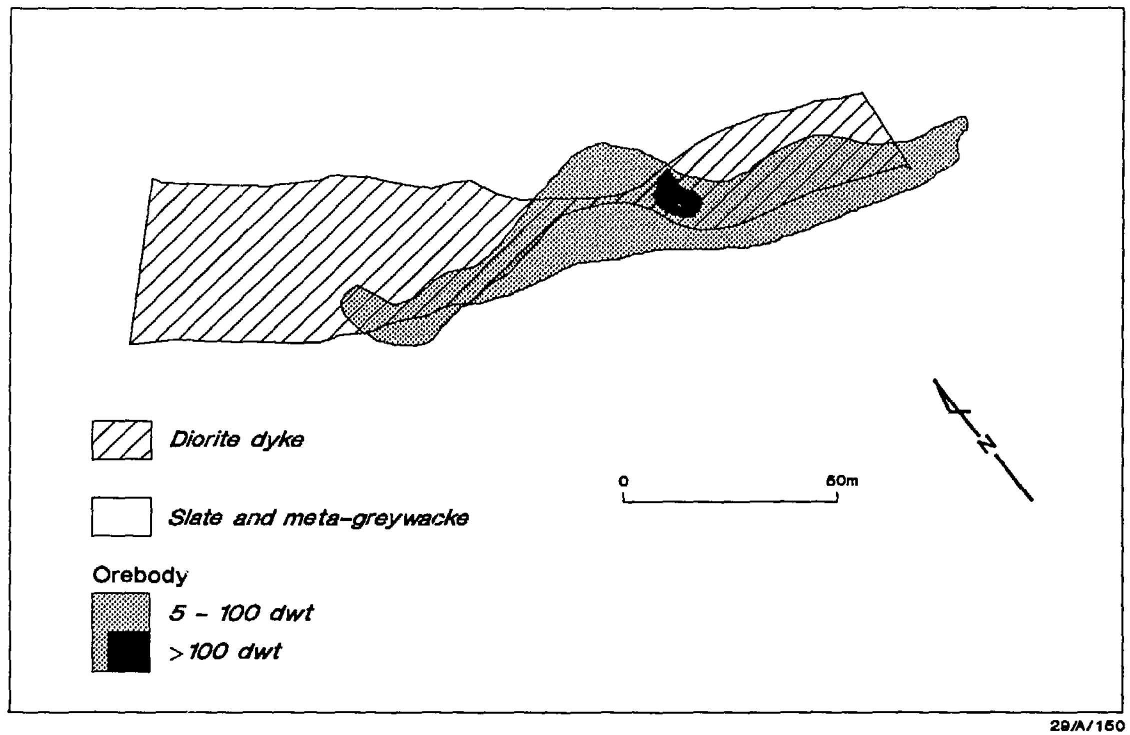


Fig. 2.5: The "dyke bulge" at the Morning Star mine (Woods Point) and its relationship to high grade ore (Threadgold, 1958).

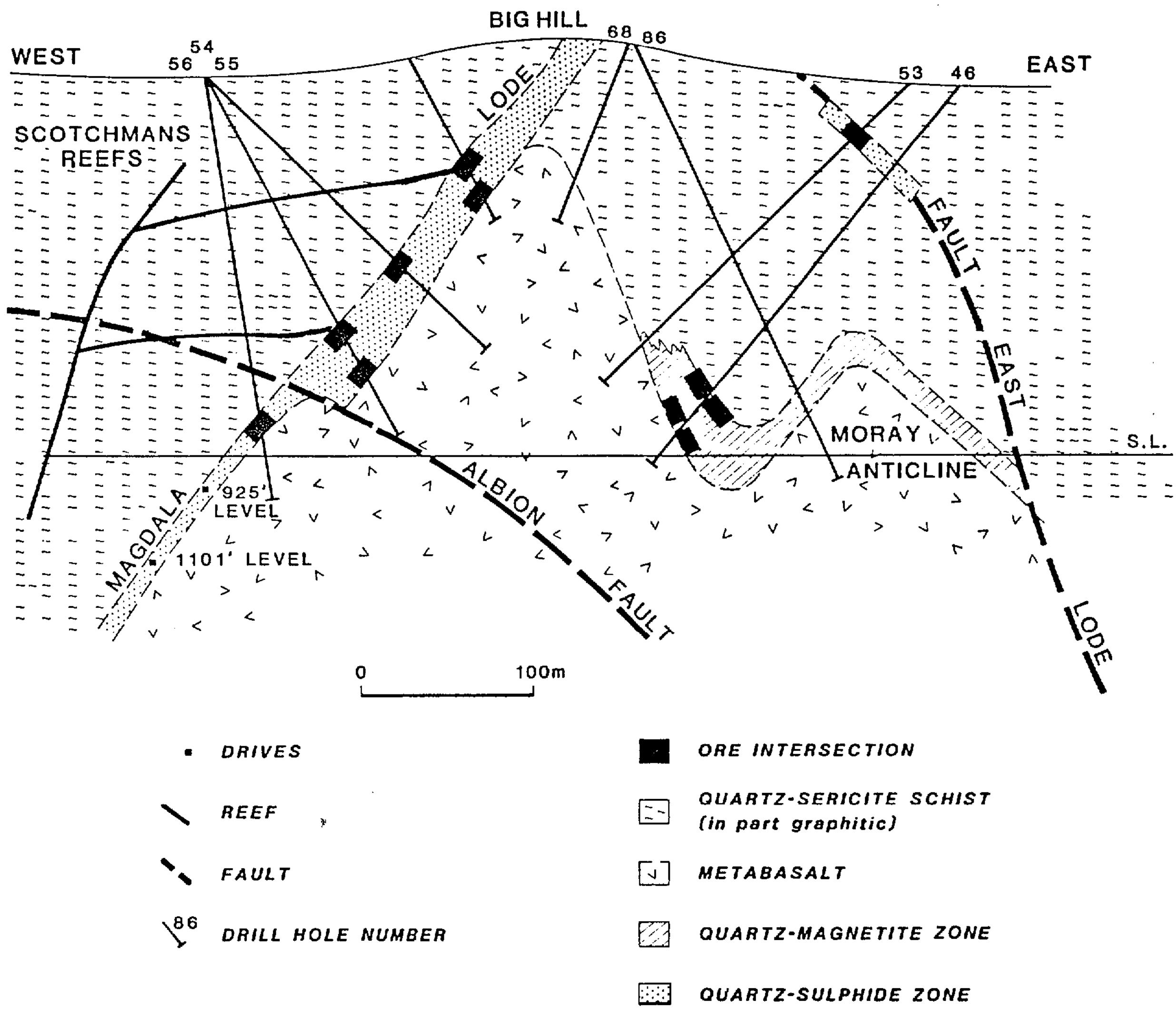


Fig. 2.6: Magdala lode and Scotchman's reef, Stawell deposit, Eastern Victoria (from Ramsay and VandenBerg, 1986). Note that the Magdala lode preferentially follows the contact between altered mafic volcanic rocks and meta-sediments.

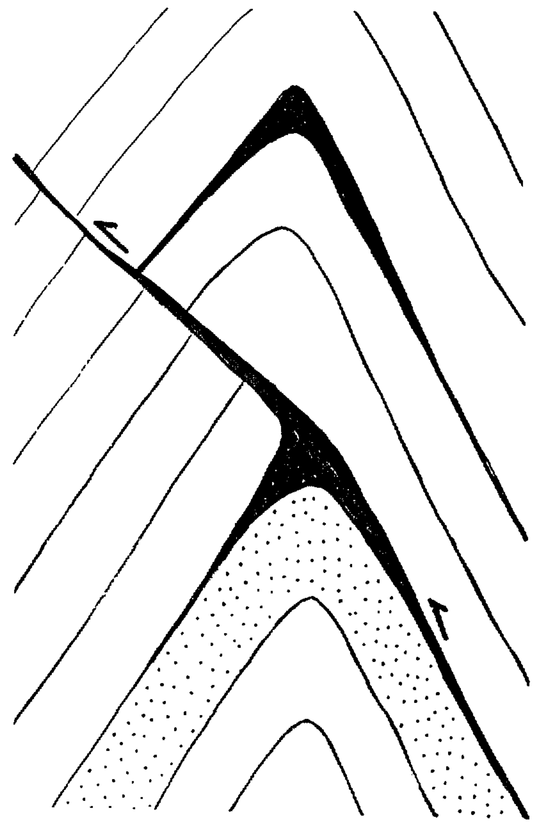


Fig. 2.7a: *Generalized form of reefs at Bendigo. Saddle reefs (in black) are typically located beneath reverse faults where they change orientation at the intersection with an anticline. Psammitic lithologies are stippled (Sandiford and Keays, 1986).*

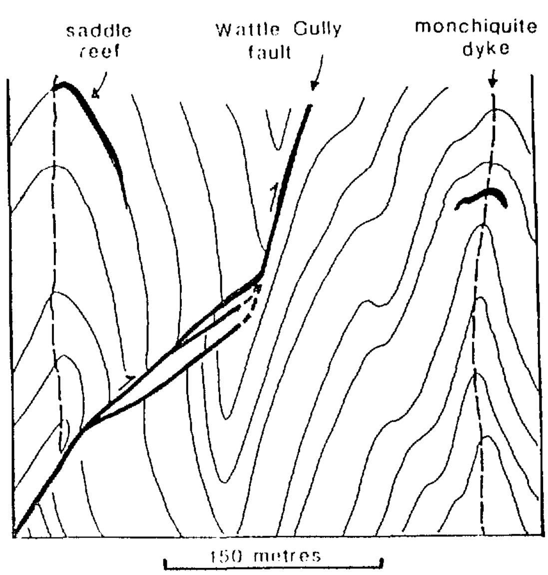


Fig. 2.7b: *Cross-section of the Wattle Gully Mine. Ore is hosted by the Wattle Gully reverse fault. Note the displacement of fold axial planes by the reverse faults. Saddle reefs are associated with bedding plane faults (Sandiford and Keays, 1986).*

at the Long Tunnel mine (Walhalla) follows closely a dyke country-rock contact (Fig. 2.4). At other deposits in this area, ore is concentrated in flat-lying thrust faults (termed "floors" by the old miners), particularly where the dyke is faulted over the country-rocks (greywackes and slates) forming "ledges". Also ore tends to be richest where constrictions occur in the dyke, forming what were known as "dyke bulges" (boudin-like structures) and these were regarded as favorable indicators of high-grade ore. (Fig. 2.5).

The Magdala lode at Stawell occurs at the junction of slate or schist and metavolcanics (Fig. 2.6). Stawell has undergone a complex structural evolution. The main structural event (D_2) resulted in the formation of tight upright north-south trending folds, with an axial planar cleavage. Superimposed on this event is the an S_3 crenulation cleavage and quartz veining (Promnitz, 1987). The deposit occurs at the margin of a Lower Devonian intrusive body which ranges from quartz diorite to leucogranite in compostion. The thermal aureole around this granite has affected the rocks in the deposit, which show the effects of hornfelsing. It is not clear whether the ore-bearing structures are of the same age as the intrusive.

In the Ballarat area three types of quartz vein have been identified (Ransom and Hunt, 1986). These have been termed:

LEATHER JACKETS
BREACHED FOLD AXIS VEINS
SPURS

Leather jackets occur on the east limbs of tilted anticlines, dip 45°W and are associated with pug-filled faults. Fold axis veins are west-dipping "stockwork-like" veins, which lie along the axial planes of folds, and usually terminate at a leather jacket. Spurs are narrow, east dipping and contain high grade ore where they intersect graphitic indicators.

In the Bendigo area classic saddle reefs are developed, and the structure here seems to be primarily influenced by the orientation of folded bedding in the interbedded greywacke/slate sequence (Sandiford and Keays, 1986). Fig. 2.7 illustrates typical structures at Bendigo and the Wattle Gully mine (near Castlemaine). Veins at Wattle Gully can record several hundred episodes of cracking and sealing (Cox et al. 1986) but also show evidence for stylolitic dissolution (Sandiford and Keays, 1986) attesting to a complex genesis. The sheer volume of quartz deposited suggests that large volumes of fluid were involved in vein formation (Wall, 1987), although recent experimental data (Goffe et al., 1987) suggests that equilibrium calculations substantially *overestimate* the volume of silica which can be carried by hydrothermal solutions.

Unfortunately mining records are not sufficiently detailed for the geometry of mined out orebodies to be reconstructed with confidence. Ore is frequently described as "patchy". Recent experience at Stawell suggests that the ore grades are often high where sub-horizontal and sub-vertical reefs intersect, and thus high grade orebodies might be expected to be cylindrical with a sub-horizontal plunge.

2.4: AGE OF THE MINERALIZATION

A lower limit on the age of mineralization is set by the age of the host-rocks, which ranges from Cambrian to Middle Devonian. A ubiquitous feature of the orebodies is that they post-date the regional S_1 cleavage (often slaty) and associated folds regardless of the sub-province in which they occur. Sandiford and Keays (1986) propose that this cleavage is Tabbaraberan (i.e. Lower to Middle Devonian) in Western Victoria at least. MacLennan (1987), however, attributes the cleavage in rocks of the Cassilis area to a Benambran (Silurian) event. Deposits in the Woods Point -Walhalla sub-province occur in dykes which post-date the regional folding and cleavage formation, but which are themselves truncated by overlying Upper Devonian sediments. Primary mineralization has not been described from within these sediments, but "alluvial gold is known from two localities in the basal Upper Devonian in Gippsland" (Singleton, 1965).

In the Bendigo-Ballarat sub-province some quartz reefs are cut by felsic dykes which are evidently associated with Upper Devonian granites (Maldon is a good example), tending to suggest a Pre-Upper Devonian age for the ore. These dykes have not, however, been dated by radiometric methods. This report assumes as a working hypothesis that the Victorian deposits (of types 1-3) are *all* pre-Upper Devonian (*cf.* Sandiford and Keays, 1986). There is a distinct possibility that mineralization throughout Victoria is diachronous. Comparable mineralization at Gympie (Queensland), for example, is demonstrably Permian or later. Radiometric dating of alteration and mineralization at some of the better characterized deposits from different sub-provinces would appear to be justified.

2.5: MINERALIZATION AND ALTERATION

2.5.1: MINERALOGY AND PARAGENESIS

Gold mineralization is mainly restricted to quartz-rich veins or "reefs"

DEPOSIT	PY	PO	ASP	GN	SPH	CPR	Sb	OTHERS
STAWELL	X	X	X			X	X	(bournonite)
St. ARNAUD	X		X	X	X	X		silver
MARYBOROUGH	X	X	X	X	X	X	X	
CLUNES	X		X	X	X			
BALLARAT W.	X		X	X	X	X	X	
BALLARAT E.	X	X	X	X	X	X	X	marcasite
MALDON	X		X	X	X	X	X	maldonite, molybdenite, Bi
BENDIGO	X	X	X	X	X	X	X	
CHEWTON	X	X	X	X	X		X	(boulangerite) tetrahedrite
WOODS POINT	X	X	X	X	X	X	X	(bourn., boul.) tetrahedrite
BETHANGA	X		X			X		
GLEN WILLS	X		X	X	X	X	X	
CASSILIS	X		X	X	X	X		

Table 2.2: *Sulphide assemblages at thirteen of Victoria's major gold mines (modifed after Bowen and Whiting, 1975). Note the absence of some phases may be due to the fact that sufficiently detailed studies were not carried out at some of the deposits. PY - pyrite, PO- pyrrhotite, ASP - arsenopyrite, GN -galena, SPH - sphalerite, CPR - chalcopyrite. Sb includes all antimony-bearing minerals, minerals other than stibnite are shown in brackets.*

although the immediate wall-rocks may also contain gold. Grades are highly variable, and spectacular nuggets were found in the Bendigo field where mineralized quartz reefs intersect graphitic "indicator" beds (which are often no more than a few centimetres thick). Bowen and Whiting (1975) estimate that the average ore grade for Victoria is 15 gms/tonne. Gangue minerals in the veins besides quartz are: sulphides, antimonides, ankerite (or other carbonates), albite, rutile (possibly anatase?) and zircon. The volume percentage of sulphides varies from approximately 2% (common) of the reef to as much as 60% (rare). The "mundic" lodes at Stawell are good examples of sulphide-rich veins (Clappison, 1965). At the Bethanga deposit (Glenn Wills sub-province) ores averaged 60% by volume sulphide and assayed at 3% Cu, 6% As and 30g/tonne Au (Bowen and Whiting, 1975). At Cassilis sulphide comprises as much as 40% of the ore (MacLennan, 1987). Bowen and Whiting (1975) have suggested that the abundance of "mundic" lodes is a characteristic of different sub-provinces, with deposits of the Stawell and Glenn Wills provinces showing a tendency to have higher sulphide content.

Victorian gold is nearly always present as the native metal, but the bismuthinide, maldonite (Au_2Bi) occurs at Maldon, near Castlemaine. In most of the deposits gold is free milling but a significant portion of the ore may be contained in sulphides, particularly arsenopyrite and pyrite. The silver content of Victorian gold (electrum) is evidently low, but documentation is poor. Microprobe analyses of gold from the A1 mine (Woods Point) show that silver ranges from 2 to 6% by weight (Jahnke, 1976). Stawell gold may contain as much as 34% Ag (Western Mining Corp. pers. comm.). Sulphide concentrates from the Morning Star Mine were analysed by Threadgold (1958) who found that silver was in excess of gold in some samples. Particularly silver-rich gold (32% Ag) occurred at the Meerschaum mine associated with rich silver mineralization, grading at 2800 oz/tonne Ag and 40 oz/tonne gold (Birch, 1981). This was apparently a rare occurrence for Victorian gold deposits (Birch, 1981). Silver occurs as various sulph-antimonides (andorite - $AgPbSb_3S_6$, miargyrite - $AgSbS_2$, owyheeite - $Ag_2Pb_5Sb_6S_{15}$) and tetrahedrite. Tetrahedrite has been described from several other deposits although silver was not apparently recovered economically.

Table 2.2 shows typical sulphide assemblages at some of the better known deposits. Bowen and Whiting (1975) emphasize that " mineralogical studies of the associated minerals are very few and the absence of certain minerals from some of the sub-provinces may be due to lack of recording rather than lack of the mineral". Few detailed studies have been completed in the intervening years. Pyrite and arsenopyrite are the most abundant sulphides present and are also ubiquitous in their occurrence. Galena, sphalerite and chalcopyrite are present at most deposits but are volumetrically less significant. Galena is often cited as being a good indicator of the presence of gold. Pyrrhotite and antimonides are apparently erratically distributed, but this may because they are present in low modal abundance and have hence escaped recognition. Bismuth minerals are found in the Maldon area (Haupt, 1982).

It is generally agreed that arsenopyrite and pyrite precipitation preceded that of gold (Junner, 1920; Tomlinson, 1987; Bedford, 1986; Jahnke, 1976; MacLennan, 1987) which often occurs in fractures in these minerals. S. Cox (pers. comm. 1988) however suggests that this oversimplifies the paragenesis and that mineral deposition was quite complex and possibly cyclic. There is often good correlation between whole-rock As and Au. At the A1 mine (Woods Point-Walhalla sub-province) Junner (1920) has suggested that arsenopyrite dies out with decreasing depth. No other authors have mentioned the possibility of vertical mineral zonation, but again this may be due to lack of sufficiently detailed studies.

Galena, sphalerite and chalcopyrite postdate (early) pyrite and aresenopyrite (Tomlinson, 1987; MacLennan, 1987). At the A1 mine gold is believed to postdate all three base metal sulphides (Jahnke, 1976). Junner (1920) has suggested the possibility of two generations of [hydrothermal] pyrite in deposits of the Woods Point area. Both pre- and post-gold pyrite have been recognized at the Cassilis deposit (MacLennan, 1987). Also there is a pre-foliation pyrite in host-rocks, at least in the Chewton area, where it is deformed by the cleavage and has quartz-mica "beards" (Bedford, 1986). The relationship of these sulphides to the gangue and alteration minerals is, in general, poorly defined.

Stibnite (Sb_2S_3) is a common and sometimes abundant phase in mineralized quartz reefs of the Warrandyte sub-province. Figure 2.1 shows some of the known antimony occurrences. There is a suggestion of regional scale metal zonation, in that antimony associated with gold is common (but not apparently ubiquitous) in the Warrandyte sub-province, but is less common elsewhere, particularly to the east. Antimony, as stibnite, was mined at Costerfield and Ringwood (Hill, 1975). Since 1966, the Brunswick Reef at Costerfield yielded 300 tonnes of ore grading 33% Sb and 70g/tonne gold. With this exception, high Sb does not appear to be necessarily associated with high Au (Hill, 1975). Bournonite ($Pb_2Cu_2Sb_2S_6$) and/or boulangerite ($Pb_5Sb_4S_{11}$) occur sporadically in the Woods Point deposits and elsewhere. Boulangerite at the Morning Star Mine (Woods Point) occurs as hair-like crystals projecting into quartz vugs and is included in gold (Threadgold, 1958). This is evidence that gold and Sb were deposited during the same mineralizing event. Jamesonite (Pb_4FeSbS_{14}) has been reported from Maldon and the Wattle Gully deposits (Haupt, 1982).

Platinum and palladium mineralization occurs at the Thompson River (or Cooper's Creek) deposit, where 311 oz of platinum group elements were produced during 1911 to 1914 (Edwards, 1942). Recent assays of drillcore from the deposit have shown that Pt can exceed 0.5 ppm and correlates well with Ni (Payne, 1982). It is likely that these metals were originally enriched in the igneous host-rock as a magmatic deposit and remobilized during gold-vein formation (Keays and Kirkland, 1972). Pt occurs as the arsenide sperrylite ($PtAs_2$) and palladium as the telluride merenskyite ($PdTe_2$) (Edwards, 1942; Keays and Kirkland, 1972). Ni-Co sulph-arsenides (pentlandite, cubanite, gersdorffite, and millerite) occur at the Morning Star and A1 mines, and it is likely that these too were derived from the local host-rocks (Keays and Kirkland, 1972).

2.5.2: HYDROTHERMAL ALTERATION

Rocks in the vicinity of gold-bearing quartz reefs are hydrothermally altered, but few studies have been considered the alteration in detail. The three-dimensional extent of the alteration with respect to the gold orebodies is poorly understood, and the paragenesis of the alteration phases poorly defined.

At the Wattle Gully deposit, Bowen (1975) has identified an arsenic halo which extends for up to 100m from individual mineralized veins. This suggests that hydrothermal fluids penetrated at least this far into the wall-rocks, but if any mineralogical changes accompanied this incursion, they have not been described. At many of the mines *visible* alteration extends for up to 10m from the veins (e.g. Cassilis - MacLennan, 1987), although it is commonly of the order of centimeters. Such alteration is often referred to as "bleaching". It is defined in thin-section by the presence of fine-grained white-mica (referred to as "sericite") and carbonate (ankerite, siderite and rarely dolomite) which replace on a mole for mole basis the host-rocks. Such alteration is developed regardless of the lithology of the host-rock (slate, sandstone or mafic igneous rocks for example). Bulk rock analyses of the host-rocks and altered equivalents are uncommon, but some presented by Clappison (1965) suggest (assuming negligible volume change) that alteration was accompanied by desilicification.

Although mica and carbonate are the dominant alteration phases, chlorite, epidote-group minerals, albite, rutile (?anatase) and phlogopitic biotite have been described. X-ray diffraction studies reveal evidence for "normal" 14 angstrom chlorite, but 7 angstrom chlorite (amesite) has also been observed at Wattle Gully and Stawell (Ceplecha, 1974; Clappison, 1965). Pyrite, arsenopyrite and pyrrhotite are commonly disseminated in the altered host-rocks.

Paragenesis is not well established. At the A1 mine ankerite is thought to have been deposited at a relatively early stage and overlaps formation of later white-mica, which also postdates albite (Junner, 1920; Jahnke, 1976). Concentrations of ankerite at the margins of veins also suggest that carbonate is quite early, in terms of vein evolution. There is, however, evidence that carbonate may also be quite late. MacLennan (1987) describes calcite occupying late fractures in pyrite, arsenopyrite and vein quartz. Bedford (1986) has noted a similar temporal relationship at Wattle Gully.

2.6: FLUID INCLUSION STUDIES

2.6.1: A1 MINE

Jahnke (1976) identified four different types of fluid inclusions in reef quartz and sphalerite on the basis of phase assemblage. Types A and B contain liquid and vapour only, with vapour comprising between 10 and 15 vol% in the former, and 6% in the latter. Types C and D are three phase, with liquid CO_2 visible. Type D is distinguished by the occurrence of solid inclusions thought to be dawsonite. A similar mineral was observed in fluid inclusions from the Wattle Gully mine, but laser Raman probe, while unable to provide a positive identification, did show that this mineral was not in fact dawsonite (S. Cox, pers. comm., 1988). The inclusions in any one group show a consistent liquid to vapour ratio, *suggesting that "boiling" or phase immiscibility had not occurred prior to entrapment.* The presence of both CO_2-present and CO_2-poor inclusions may indicate that (at least) two discrete solutions participated in mineralization.

Some inclusions were identified as primary, pseudosecondary or secondary but most could not be unambiguously described. CO_2 -bearing inclusions occur in sphalerite where at least some are secondary. This suggests that these fluids pertain to a post-sphalerite paragenetic stage, possibly syn-gold, or later.

Type A and B inclusions have a range in vapour disappearance (homogenization) temperature from 145 to 325°C. There is no statistical difference between inclusions classified as primary, pseudosecondary or secondary, all of which have a mean temperature of ~246°C. Because these inclusions represent trapping of a single phase fluid this temperature needs to be corrected for pressure to estimate trapping temperature. Two salinity groups were found: 2%wt. NaCl equiv. (4 inclusions, T_h not recorded) and 5 - 9%wt. NaCl equiv. (50 inclusions) . Bulk leachate analyses for Na, Ca and K reveal that Na/K of the bulk leachate (by weight) is ~65 and Na/Ca ~10.

2.6.2: CASSILIS

MacLennan (1987) also recognized CO_2-rich and CO_2-poor inclusions in vein quartz from the Cassilis deposit. CO_2-rich (three-phase, type 3) inclusions are found in quartz from the centre of the veins, which would tend to suggest like at A1, that these fluids are relatively late. Inclusions were also found which contained liquid and vapour and an unidentifed isotropic daughter phase thought to be halite (type 1 inclusions). These inclusions are found in quartz interstitial to pyrite and arsenopyrite implying that they are relatively early, and contain 10% vapour by volume. Type 2 inclusions are two-phase liquid and vapour with the vapour phase comprising between 1 and 20% by volume of the inclusion. They are thus comparable to types A and B of Jahnke (1976).

If the daughter mineral in type 1 inclusions is indeed halite (no dissolution was observed) then these inclusions are quite saline. Assuming a 400°C temperature of entrapment the inclusion fluid is hypersaline; containing 40wt% NaCl equiv. (MacLennan, 1987). This is quite unlike the composition expected of a metamorphic fluid, which is likely to be only weakly saline according to Wall (1987). Type 2 inclusions have salinity which varies from 1 to 20%, and no correlation with temperature was observed. Primary type 2 inclusions homogenize by vapour disappearance in the range 230-390°C and secondary at 140-200°C. MacLennan (1987) interprets this as indicating that the fluids cooled during the later stages of deposit formation.

2.6.3: DIFFERENT ORIGINS FOR A1 AND CASSILIS?

There are substantial differences between the studies of Jahnke (1976) and MacLennan (1987). In the former no evidence was found for a systematic change in temperature with paragenetic evolution, which may bear on the efficacy of cooling as a depositional mechanism. The range of salinity seen at Cassilis is much larger than that at A1, and inclusion fluid at Cassilis is often considerably more saline. The possible presence of hyper-saline inclusions at Cassilis may correlate with the relative abundance of sulphide at this deposit compared to the A1 mine (base-metals being more readily transported in this chloride-rich solution). Both deposits have evidence for distinct CO_2-rich and CO_2-poor fluids, although neither author apparently recognized this evidence for two fluids. Trapping temperatures at each deposit exceeded 325°C. The range in vapour disappearance temperature may indicate a range in trapping temperature, two fluids of contrasting temperature or a variable pressure correction. This limited fluid inclusion data might lend credence to a model which envisages polyphase mineralization in the Lachlan Terrane of Victoria (see also Section 5).

2.7: STABLE ISOTOPE DATA

2.7.1 QUARTZ

Stable isotopic data for reef quartzes from various deposits in the Victorian gold province have been presented by Golding and Wilson (1981 & 1984) and for the A1 mine by Green et al. (1982). These data suggest that isotopic values are constant for a particular region. The data tabulated below, with sub-province in brackets, suggests that the isotopic composition does not correspond particularly well to the sub-provinces defined by Bowen and Whiting (1975):

DEPOSIT (province)	$d^{18}O$ (‰)
BENDIGO-BALLARAT (Bendigo-Ballarat)	17.4 - 17.6
BEAUFORT-DAYLESFORD (Bendigo-Ballarat)	19.1
STAWELL-St. ARNAUD-DONNELLY (Stawell)	15.8
STAWELL DEPOSIT (Stawell)	14.5 - 15.5
WALHALLA-GAFFNEY'S Ck.-MARYSVILLE (Walhalla-Woods Pt.)	20.2
A1 DEPOSIT (Walhalla-Woods Pt.)	18.5 - 19.0

This geographic variation in isotopic signature has recently been confirmed by R.T. Gregory (pers. comm., 1988). If it is assumed that the deposits formed at similar temperatures, and there is no evidence that this is not the case, the mineralizing solutions at different deposits evidently had different oxygen isotopic signatures. It has been suggested (R.T. Gregory, pers. comm., 1988) that the isotopic signature is a reflection of the nature of the sediments in a given terrane or sub-province. Golding and Wilson (1984) interpret the data to indicate predominance of metamorphic fluids except for Stawell, which is thought to have been formed from magmatic fluid. While the isotopic data is not inconsistent with the involvement of magmatic fluid at Stawell it is not unambiguous proof that this was the case. A possible explanation for the apparent range in isotopic composition is that there are in fact two fluids of distinct isotopic composition (one may be magmatic in origin) and varying amounts are involved in mineralization. The lighter isotopic signature of the Stawell quartz may correlate with a conspicuously higher sulphide content at this deposit.

A possible explanation for the variation in isotopic composition is variation in depth of formation of the different analysed samples (see Golding and Wilson, 1981). This does not appear to have been considered.

2.7.2: CARBONATES

Isotopic analyses of carbonates are presented by Green et al. (1982) and MacLennan (1987). Ankerites from A1 mine have a spread in $d^{18}O$ from 14 to 18 ‰. Assuming that ankerite-fluid fractionation aproximates dolomite-fluid, and that the temperature is 300°C, the A1 fluid composition is 10±2.0 ‰. A temperature variation of ca. 100°C might account for the observed range in isotopic composition. Calcites from Cassilis give a much greater spread in $d^{18}O$ from 11 to 17 ‰. This range could also represent either a variation in temperature of 100°C or more during deposition. Alternatively a mixture of two fluids of contrasting isotopic composition may explain the data, although this is inconsistent with MacLennan's (1987) interpretation of the fluid inclusion data.

Calcite from Cassilis shows a range in $d^{13}C$ from -2.0 to -6.6 ‰ (5 samples) and from the A1 mine -6.7 to -7.5 (3 samples). Again if similar temperatures are envisaged for the two deposits during calcite deposition, isotopically distinct fluid is indicated at each deposit. Ankerite from A1 has a narrow range from -7.3 to -10.1. This might suggest that the isotopic composition of the fluid was different at different paragenetic stages of mineralization. Green et al. (1982) suggest that the isotopic composition of carbon in the carbonates is indicative of magmatic derivation (magmatic carbon = -5 ± 2.0). Since sedimentary organic carbon has a similar mean value, this interpretation is certainly not the only possible one. Since at 300 - 200°C the isotopic fractionation between carbonates and aqueous carbonate is neglible, cooling over this interval does not appear to explain the observed carbon isotopic variation.

2.7.3: SULPHUR ISOTOPES

Green et al. (1982) found that sulphides from veins and altered wallrocks at A1 had a narrow range in $d^{34}S$ with a mean value of +5.8 ‰. Galena from Cassilis has a very different composition: two samples give -4.48 and -4.50, and five other sulphides have a mean value of -1.70. Coexisting galena and sphalerite from A1 give a temperature of 309 ± 20°C, while pairs from Cassilis give temperatures of 248 to 212°C. The narrow range in sulphur isotopic compositions at both deposits suggests that the oxidation state of the fluid did not approach the oxidized/reduced sulphur species boundary and/or a constant isotopic composition.

2.8: LEAD ISOTOPES

The lead isotopic composition of gold and sulphides (particularly galena) from Victorian gold deposits is being studied by B. Gulson (CSIRO). His preliminary results show that lead isotopes from most Cambrian greenstones, thought by some to be the source of gold mineralization (e.g. Sandiford and Keays, 1986), plot on a Cambrian trend line. Lead isotopes in galena from the A1 mine lie along an upper Devonian line, but gold samples are different, suggesting that the lead in galena and in gold have different sources. Research is continuing on ore and host-rock samples from Stawell, Chewton, Clunes and Bendigo. Lead isotopes from Cassilis MacLennan (1987) are similar to those from the nearby Benambra massive sulphide deposit, which lead MacLennan (1987) to propose a common origin.

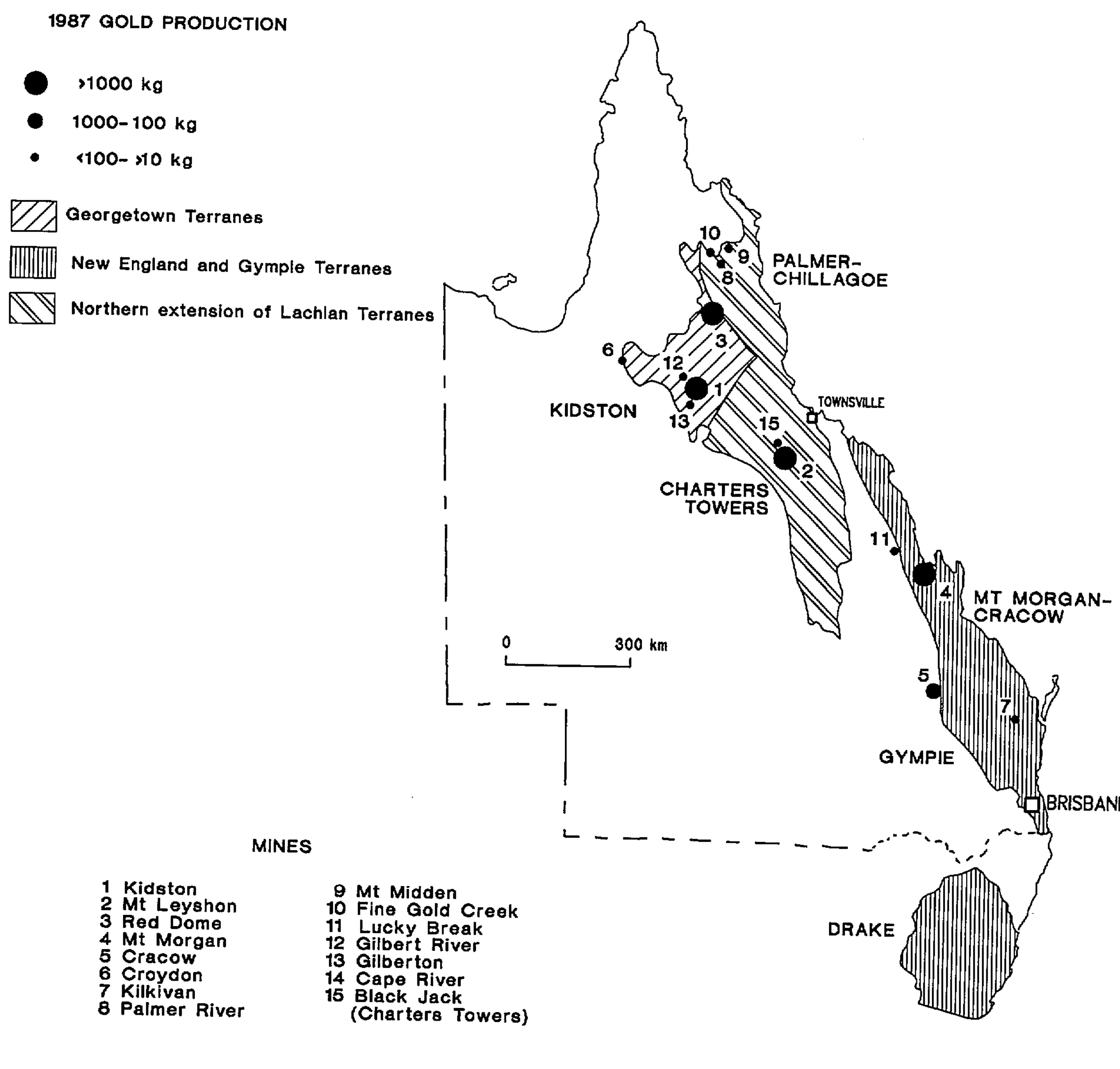


Fig. 3.1: Location of major ore deposits in Queensland and Northern New Souuth Wales and provinces cited in the text

3: QUEENSLAND

3.1: GOLD PROVINCES

Since the deposits of Queensland show a much greater diversity than their Victorian counterparts this section is arranged by gold province. The provinces as defined (geographically rather than genetically) in this report are, from south to north (Fig. 3.1):

GYMPIE
CRACOW - Mt. MORGAN
CHARTERS TOWERS
"KIDSTON"
CHILLAGOE - PALMER

This is not a complete coverage of all the goldfields in Queensland, but it is hoped that all major deposits are covered and representatives of each different deposit type (excepting alluvial deposits).

3.2: THE GYMPIE GOLD PROVINCE

3.2.1: DEPOSITS OF THE GYMPIE GOLDFIELD

Alluvial gold was found in the Gympie area in 1867 with reef production commencing in the following year. Collectively the "reef" deposits of this area produced 106,515 Kg of Au, making this field the fourth largest in Eastern Australia (Woodall, 1979). Production figures for the various mines (which number ca. 150) are given in Murphy et al. (1976). Twenty-eight deposits around the township of Gympie produced a total of over 60,000 Kg. of gold bullion. This remarkable concentration of ore is comparable to that at Bendigo in Victoria. Despite the importance of the field there is a remarkable dearth of modern work on the deposits. The top ten producers are listed below:

DEPOSIT	ORE CRUSHED	GOLD (Kg.)
Scottish Gympie	1,606,325	18,773
#2 South Great Western	432,893	10,472
South Glanmire and Monkland	258,007	6,276
1 North Phoenix	214,747	5,969
North Smithfield	67,732	5,563
4 North Phoenix	81,342	3,835
3 & 4 North Glanmire	55,417	3,769
1 North Glanmire	86,834	3,003
7 & 8 Monkland	57,353	2,909
North Glanmire	60,120	2,491

Host-rocks to the deposits are a sequence of deformed Permo- Triassic meta-sediments and volcanics of the Gympie Group. The Rammut Formation near the base of this group hosts all the mineralziation. This formation consists of volcanic conglomerate, andesite and basaltic lavas, tuffs, agglomerate, feldspathic arenites and carbonaceous shales (Phoenix slate) The latter host most of the mineralization. This sequence was intruded by a granite which outcrops 6 km away, and numerous N-NW trending Triassic dioritic dykes, associated with faults, the most significant being the Inglewood dyke. The metasedimentary rocks strike NNW and dip uniformly at 20 - 22° E throughout the Gympie area (Murphy et al., 1976). Several generations of faults have been recognized. Early bedding-parallel and strike faults are cut by dip (normal) faults which host the ore.

Two types of lode have been identified (Kitch and Murphy, unpub. manuscript): the Gympie type and the Inglewood type. Gympie-type lodes generally strike parallel to the country rocks but dip at 60 - 80°W and are evidently associated with normal displacement . Within these lodes ore was seemingly localised as flat-pitching shoots at the intersection of quartz-carbonate veins (in normal faults) with carbonaceous units in the sedimentary host-rocks (Murphy et al., 1976). The Ingelwood type lodes include the main producers of the area: the Scottish Gympie and #2 Great Western lodes. The lodes were evidently localized parallel to the microdiorite Inglewood dyke, which occupies a reverse fault zone. This structural control is strongly reminiscent of the Victorian Woods Point-Walhalla deposits.

The mineralized veins are filled with quartz and carbonate, and minor chlorite, tourmaline and brecciated country rock. The carbonate is either calcite or ankerite, the latter being more common (Golding et al.

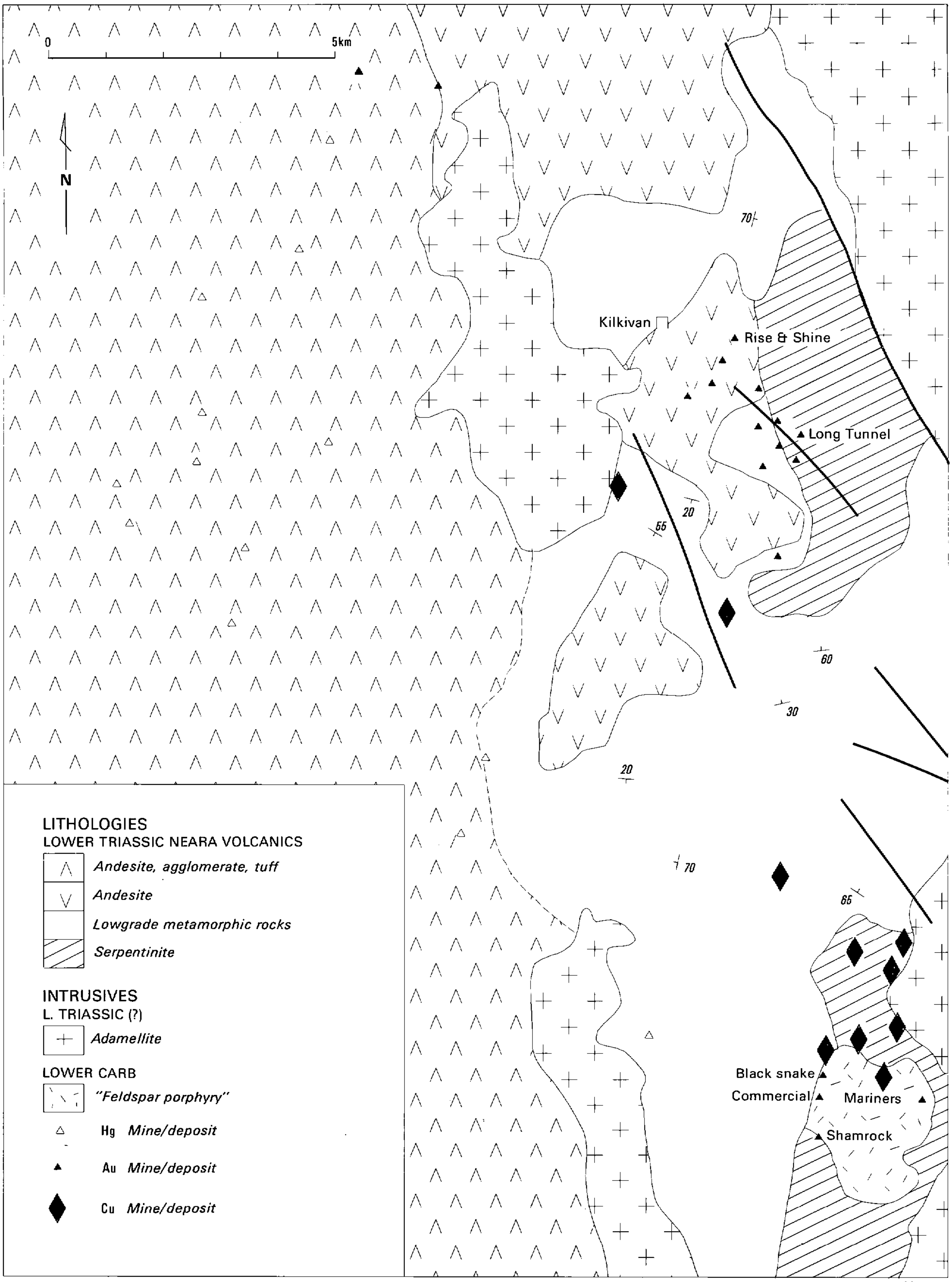


Fig. 3.2: Ore deposits of the Kilkivan area.

1987). Gold occurs free, with pyrite, galena, sphalerite, chalcopyrite, and locally hessite (Ag_2Te). Rare platinum (mineralogy unknown) has been described from the Lady Mary, and Alma reefs (Wilson, 1987). With the exception of the presence of hessite and absence of antimony-bearing minerals (which may be because there have been no detailed mineragraphic studies), the ore asssemblage appears to be remarkably similar to that observed in the Victorian reef quartz deposits, as are the gangue minerals. Lode quartzes give an oxygen isotope signature of 15.5 ± 0.9 ‰, similar to that seen at Stawell in Victoria (Golding and Wilson, 1984; Golding et al. 1987).

Since the Gympie deposits occur in post-peak deformation faults they must be at least Mid Triassic or younger (*cf.* Murray, 1986). It is not known if mineralization occurs in the overlying undeformed Late Triassic felsic volcanics, but if so a metamorphic vein model could be discounted. The main differences between deposits of the two areas appears to be the marked difference in age of the host-rocks and age of mineralization.

3.2.2. THE KILKIVAN DEPOSITS

The Kilkivan district is ca. 50 km from Gympie and alluvial gold was initially discovered here in 1852. The district has seen a resurgence in interest in alluvial gold mining and is now a significant alluvial gold producing area, with 1984-85 production of 64 Kg, 1.6% of Queensland's total (Ishaq, 1986). The most productive deposit is the Italian Gully claim, which has grades of 0.25 gm/m^3 to 0.85 gm/m^3 (Ishaq, 1986). The following however, concentrates on the primary reef deposits which are no doubt the source of the alluvial gold. Ore was won from over 17 primary reef deposits here, mainly in oxidized near-surface ore (Brooks et al., 1974). The largest deposit primary reef deposits of the area are: Rise and Shine, Shamrock and South Burnett (which occurs North-west of the area depicted in Fig. 3.2) but none of these produced over 125 Kg of gold. Thus the deposits are comparatively small, but there has been a disproportionate amount of contemporary research on the area.

The oldest unit in the area, possibly a correlative of the Gympie Group, consists of Lower Palaeozoic meta-sediments and meta-igenous rocks. These include: phyllite, mudstone, quartzite, jasper, schist, serpentinite, "greenschist" (or "greenstone") and gabbro (Bischoff, 1986). They are folded about NW trending axes and have a penetrative NW to NNW-trending cleavage or schistosity. The greenstones consist of tremolite-actinolite, epidote, calcic feldspar, clinozoisite, prehnite, chlorite and zeolite (Brooks, 1974). These rocks were intruded by granitoids of varying age. The oldest intrusives are Lower Carboniferous adamellite, granodiorite and granite. Next is an Early Triassic adamellite and ?co-eval volcanics of the Neara Volcanics which outcrop to the west of Kilkivan (Fig. 3.2). The Neara Volcanics are composed of porphyritic andesite and latite with minor lapilli tuffs and conglomerate (Bischoff, 1986). Overlying these are felsic volcanic rocks of the Aranbanga Beds. The Neara Volcanics are intruded by the Mudlo granite and other porphyry intrusives of Late Triassic age (Bischoff, 1986).

Shamrock is associated with NNW trending faults and ore occurs in what are possibly tension gashes associated with these faults. The mine produced 90 Kg of Ag in additon to 115 Kg Au and 57 tonnes Cu. South Burnett is hosted by Lower Triassic sediments (Gayndah Beds) which strike NNW and dip 65°W (Brooks, 1974). The host-rocks are predominantly conglomerate with graphitic mudstone. Ore occurs at the junction of an andesitic dyke and graphitic mudstones, in quartz-carbonate veins which transgress both dyke and mudstone. The ore is silver rich: early ore material had a Au/Ag of 0.13 although more recent assays demonstrate a lower silver content (Au/Ag 0.15 - 1.50; Brooks et al. 1974). Ore at the Long Tunnel mine (Fig. 3.3) was also found at the contact of dyke rocks (trachyte and diorite) with sediments rather like its Victorian namesake at Walhalla. Ore at the Rise and Shine deposit is hosted by greenstones (Golding et al. 1987). Many small deposits are hosted by granodiorite (and are apparently similar to the Charters Towers deposits described below) and others appear to be associated with porphyry-copper style alteration (e.g. Gibraltar Rock - Bischoff, 1986).

Quartz veins contain early K-feldspar (orthoclase, partially replaced by later chlorite) quartz, ankerite and late calcite (Scott, 1983) . Gold occurs with chalcopyrite, pyrite, galena, sphalerite, arsenopyrite, tetrahedrite and stibnite. Proustite (Ag_3AsS_2) has been identified at the South Burnett (Brooks et al., 1974) and bismuthinite occurs in the Kabunga area. Tourmaline veins ca. 5mm in width and selvages to quartz veins were noted at some deposits.

Study of the map presented by Brooks et al. (1974) suggests a possible broad-scale metal zonation, with Hg (as cinnabar) occurring to the west, and copper and/or gold to the east (Fig. 3.2). Mercury mineralization occurs in "tension veins, fissures and thrust faults" (Murphy et al. 1976) as cinnabar (or rarely native mercury - Denmead, 1945), with a gangue of chalcedonic silica, calcite, siderite, dolomite, ferroan ankerite, hematite, rare pyrite, tetrahedrite and baryte and limonite (a weathering product?). The veins commonly show layering of quartz and carbonate (Bischoff, 1986) and are enclosed by a narrow alteration zone of sericite, clay, chlorite and carbonate. Contemporaneity with the gold mineralization is suggested by the fact that the Shamrock lodes are enriched in Hg (Bischoff, 1986).

The Rise and Shine deposit contains quartz veins with a mean $d^{18}O$ of 15.2 ‰ and calcite with a mean $d^{18}O$ of 11.0 ‰ (Golding et al. 1987). Fluids coexisting with these minerals at 250 ± 50°C (although the temperature of formation is not well defined) would have a $d^{18}O$ of 6 ± 2 ‰ in the case of quartz and 3 ± 2 ‰ in the case of calcite. For quartz this is consistent with either magmatic or metamorphic water. Evidently the fluid depositing calcite had a significant non-magmatic component, particularly if a lower formation temperature is assumed (Golding et al. 1987).

Some ^{18}O enrichment of the host "greenstones" (probably originally submarine volcanics) was noted and Anderson (1982) suggested that enrichment occurred during sea-floor alteration. It is likely, however, that the presence of hydrothermal carbonate and white-mica related to gold mineralization would have caused the observed enrichment. The $\partial^{13}C$ of both host-rock and vein calcites is similar, with a mean of -2.7 ‰. Golding et al. (1987) concluded that this reflected derivation of carbon by dissolution of marine carbonates which are abundant in the altered submarine lavas, host to the deposits. This also suggests that the fluid during the calcite stage had a substantial non-magmatic component.

The Black Snake deposit preserves possible evidence for higher temperatures (400°C) with hydrothermal biotite and K-feldspar (Scott, 1983). Early potassic alteration is overprinted by fracture-controlled sericite and later chlorite-sericite alteration, reminiscent of a porphyry Cu system. Scott (1983) however, considers that the gold lodes are later, and were emplaced along the porphyry/host-rock margin, presumeably as a result of mechanical inhomogeneity there. Alteration is again characterized by an increase in whole-rock ^{18}O, probably due to sericite development. Gold lodes hosted by the porphyry range in composition from 4.1 - 13.7 ‰, with the lower values indicative of meteoric fluid (Golding et al. 1987).

At the Shamrock deposit, chlorite-water fractionation suggests a

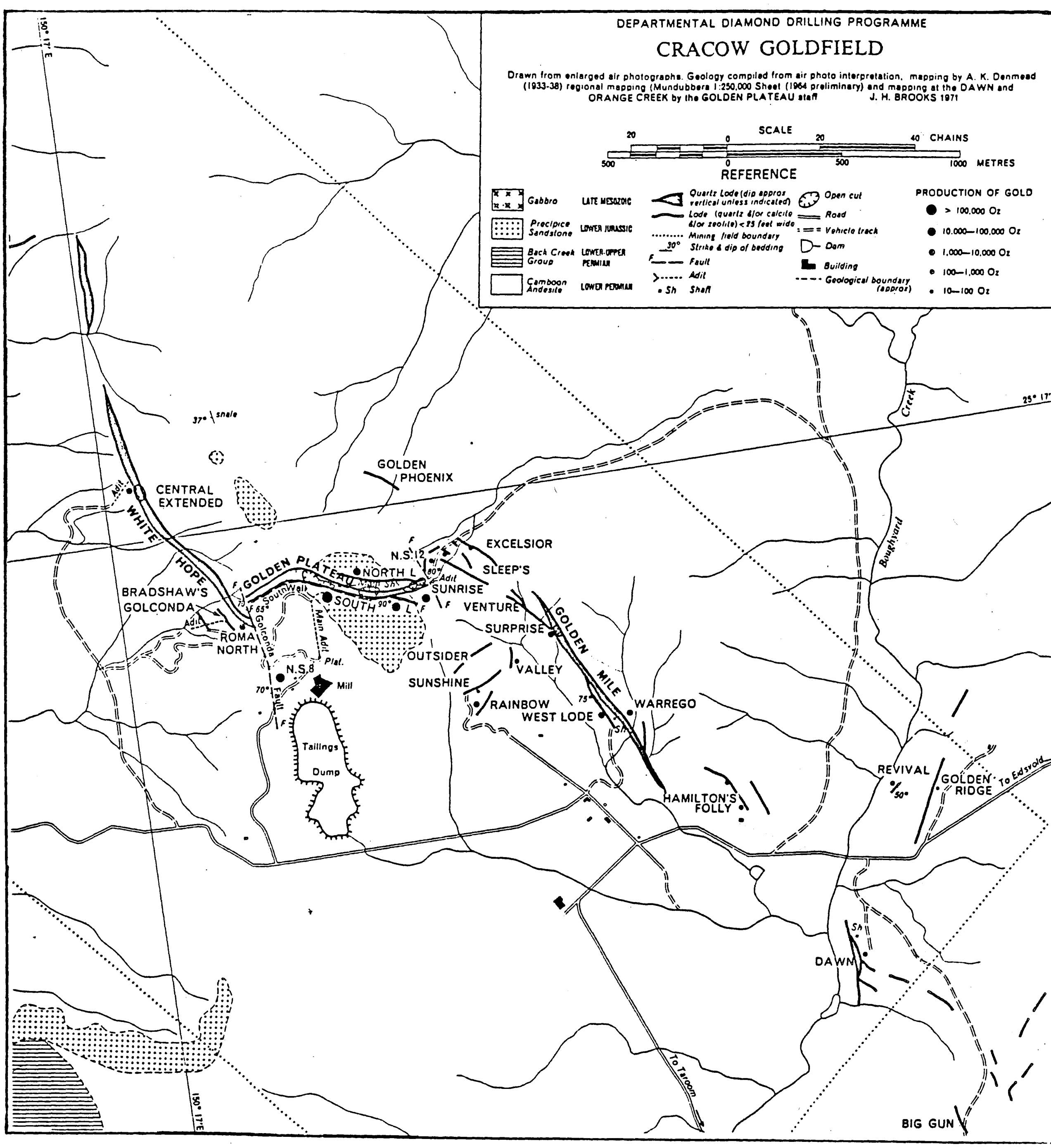


Fig. 3.3: The Golden Plateau fault zone and satellite deposits. The lode may represent a jog between two strike-slip faults, one of which is the Golconda Fault. Map from Brooks (1974).

non-magmatic fluid composition (4.5 ‰), assuming a temperature of 270 ± 10°C on the basis of Walshe's (1986) chlorite thermometer (Anderson, 1982). The calibration error for this thermometer is of the order of ± 50°C so this error limit seems a little liberal. The oxygen isotopic composition of water in equilibrium with ankerite (assuming dolomite-water fractionation?) is compatible with mixing of magmatic and meteoric waters. Calcites have a lighter composition, consistent with a fluid of distinct isotopic signature, possibly the result of a higher proportion of meteoric water or loss of CO_2 during retrograde boiling (Golding et al. 1987).

3.3: CRACOW - Mt MORGAN PROVINCE

3.3.1: THE GOLDEN PLATEAU DEPOSIT, CRACOW

Progressing north from the Gympie Province, the next major gold field is Cracow. This consists of a number of small deposits (Fig. 3.3), the most significant being the Golden Plateau; the only major producer in the field. The Golden Plateau produced 1.1 m tonnes of ore by 1963, for 14,100 Kg Au and 10,500 Kg Ag (average Au/Ag = 1.4). As of 1977 the mine had produced 19,910 Kg of gold making it Eastern Australia's 20th largest mine or gold-field (Woodall, 1979). Gold is currently being recovered from old tailings while further exploration work is aiming at establishing additional ore reserves in the old workings.

The deposit is hosted by the Early Permian Camboon andesite, a ~4 km thick sequence of andesitic lava, tuff and agglomerate, with minor dacite and rhyolite (Denmead, 1938). This unit is possibly a stratigraphic equivalent to the Neara Volcanics, host to the Kilkivan deposits. The Late Permian Auburn granodiorite intrudes these rocks. There are also "bosses" of gabbro, diorite, porphyry and rhyolite and trachyte dykes. Unconformably overlying these rocks are outliers of Triassic freshwater and marine sediments.

Gold at the Golden Plateau deposit is restricted to a major inflection in a complex quartz lode system which could be interpreted as a fault "jog" between two strike-slip faults (Fig. 3.3). In the eastern part of the Golden Plateau lode the veins show a tendency to occur at the junction of andesite lavas with rhyolite dykes (Denmead, 1938). To the west, the lodes are apparently unrelated to dykes. Here the hanging wall of the ore is a shear zone, up to 2 m wide, containing rounded fragments of the host andesite, but no quartz. Ore cuts out very sharply at this fault. Quartz veins which host the ore are not parallel to this fault zone, and may represent tensional structures (possibly en echelon tension gashes). This contention is supported by the common occurrence of vugs and cockade structure. Some ore occurs in flat-dipping structures referred to locally as "flatmakes", and the lodes are offset by sub-horizontal faults. Ore shoots in the eastern part of the ore body plunge almost vertically, but to the west plunge at a shallow angle. The reason for this geometry is not known. Veins in some instances trangress the overlying Triassic sandstone (Denmead, 1938), indicating that vein formation was post-Early Triassic.

Quartz dominates the lode mineral assemblage, with calcite, K-feldspar, laumontite, ankerite, rutile and sulphides. Radially arranged laumontite locally constitutes a major portion of the quartz veins and may itself form veinlets in the host-rocks. K-feldspar occurs as selvage to altered andesite fragments in the quartz, and also as euhedral crystals in vugs (Denmead, 1938). The sulphide and other opaque minerals include: sphalerite, galena, chalcopyrite, pyrite, minor bornite, hessite, free gold, altaite (PbTe), argentite (Ag_2S), arsenopyrite and phases which result from supergene alteration of the primary ore.

The host andesite is hydrothermally altered but the extent, nature, distribution and paragenesis is poorly known. Alteration of the andesite commonly involves pervasive silicification, and fragments of "jasper" recorded from within the mineralized veins may represent such silicified andesite. Other alteration minerals include: chlorite, epidote, calcite, zeolite (stilbite), pyrite and kaolinite. The latter is thought (on a unknown basis) to be a product of weathering (Denmead, 1938).

Lode quartzes have an unusually low $d^{18}O$ signature of -2.7 ± 0.7 (n=3) and calculated $d^{18}O_{fluid}$ of -12.0 ± 3 (assuming a temperature of 250°C ± 50 - Golding et al. 1986). Country rocks are depleted in $d^{18}O$ relative to normal volcanic rocks (Golding et al., 1986). Calcites from the ore zones give $d^{18}O$ of 4.3 - 9.3 interpreted to indicate lower depositional temperatures than for the quartz stage. Golding et al. (1986) conclude that " there is little doubt that the Cracow [Golden Plateau] ore fluids are meteoric in origin".

3.3.2: Mt. RAWDON

The Mt. Rawdon deposit occurs ca. 130 km ENE of Cracow, and is currently being developed by Placer Pacific (Table 1.3). It is hosted by pyroclastic rocks of the Lower Triassic Aranbunga beds, which also outcrop NW of Kilkivan. The sequence consists of subaerial rhyodacitic lapilli tuffs, which unconformably overlie quartzite, arkose and schist attributed to the Biggenden Beds (Mustard, 1986) and granitoids. These rocks are intruded by a series of igneous rocks. The earliest is a porphyritic dacite which is cut by a similar dacite having coarser phenocryst phases. These intrusives are cut by trachyandesite dykes, and all have been altered to some extent. East-west striking trachytic dykes are the last intrusive event, and are only weakly altered containing disseminated pyrite (Mustard, 1986).

Gold-silver mineralization occurs associated with sulphides in 1 - 2mm wide veinlets of quartz, carbonate and chlorite, and associated with pyrite, disseminated adjacent to these veins (Mustard, 1986). Lapilli tuffs host most of the mineralization, as the dacitic pyroclastics were evidently relatively impermeable to the mineralizing solutions. The mineralization is enveloped by a phyllic alteration zone, which overprints a pervasive chlorite-carbonate alteration zone (Mustard, 1986).

3.3.3 Mt. MORGAN AND Mt. CHALMERS

The Mt Morgan and Mt Chalmers deposits occur approximately 200 km north of Cracow (Fig. 3.1) . Mt Morgan was discovered in 1882 and has been a major gold producer, second to Bendigo in Eastern Australia and fourth largest in Australia. For many years Mt. Morgan was Queensland's only gold producer, and its output (to 1963) was 237,00 Kg Au and 360,616 tonnes of Cu at average grades of 4.75 gm/tonne Au and 0.72% Cu. Mt Chalmers has average grades of 1.7% Cu, 3.0 gm/tonne Au, 42 g/tonne Ag, 3.51% Zn and 1.01% Pb. Mt Morgan is again the scene of gold production, with gold currently being recovered from old tailings.

The host-rocks to Mt Morgan (mine corridor) resemble those typical of Kuroko-style masive sulphide deposits (Taube, 1986). There is a lower and an upper pyroclastic sequence, with intervening sediments consisting of tuffs, exhalites (jasper), turbidites and limestone. The limestone is dated as Middle Devonian (Eifelian) on the basis of a condont fauna. The upper sequence contains fragments of jasper, limestone and significantly sulphides. This implies that sulphide mineralization was Middle Devonian in age and probably syn-volcanic in a broad sense.

Minor stratiform pyrite and baryte occur in black shale but most of the mineralization occurs in what has been described as an hydrothermal crackle breccia (Cornelius, 1967) or a stringer zone (Taube, 1986) which cuts the lower pyroclastic sequence. The upper part of the orebody is distinctly pipe-like in shape (Cornelius, 1967). Mineralization is zoned, with high Cu and Au occurring in the core of the body, and high Zn on its margins (Taube, 1986). Early magnetite, pyrite, pyrrhotite, quartz, chalcopyrite, sphalerite and possibly gold are suceeded by pyrite, quartz chalcopyrite, sphalerite and gold according to Cornelius (1967). A third phase of mineralization consists of tellurobismuthinite, calaverite, gold, tetradymite (Bi_2Te_2S) and quartz. Taube (1986) maintains that this third phase was temporally separated from the other two, probably syngenetic massive sulphide-type ore, and associates it with intrusion of the Mt Morgan tonalite, which is Late Devonian in age.

Hydrothermal alteration associated with mineralization is most intense in the footwall (lower) pyroclastics manifested as replacement of feldspar by white-mica ("sericite") and quartz. A pyritic halo extends some 50m from ore (Taube, 1986). These altered rocks were originally described as quartz porphyries because quartz is the only phase to have escaped alteration. Chlorite and albite are locally present in low modal abundance (Gibbons, 1974).

A cursory fluid inclusion study was carried out by Eadington et al. (1974) who found saline inclusions (6-11 wt% NaCl equiv.) which homogenized (vapour disappearance) in the range 183-268°C. Far from being diagnostic this range overlaps the salinity-temperature range found for the Victorian A1 and Cassilis deposits. Eadington et al. (1974) interpreted sulphur isotope data to indicate magmatic sulphur. Ore quartzes analysed by Golding and Wilson (1981) give a range in $d^{18}O$ from 7.3 - 9.4 resulting in a calculated fluid composition of $0 \pm 3‰$ based on the fluid inclusion thermometry of Eadington et al. (1974). This suggests marine, meteoric or connate fluid (Golding and Wilson, 1981). The host-rock limestones are depleted in ^{18}O compared to normal marine carbonates, reflecting interaction with hydrothermal solutions (Golding and Wilson, 1981).

It seems probable that the Mt Morgan deposit is an example of a Kuroko-style massive sulphide deposit that has been disrupted by later faulting and erosion (Gibbons, 1974; Taube, 1986). Some gold was possibly introduced along with the primary copper ore (data of Cornelius, 1967) but a later magmatic origin for the some of the gold is also possible (Taube,

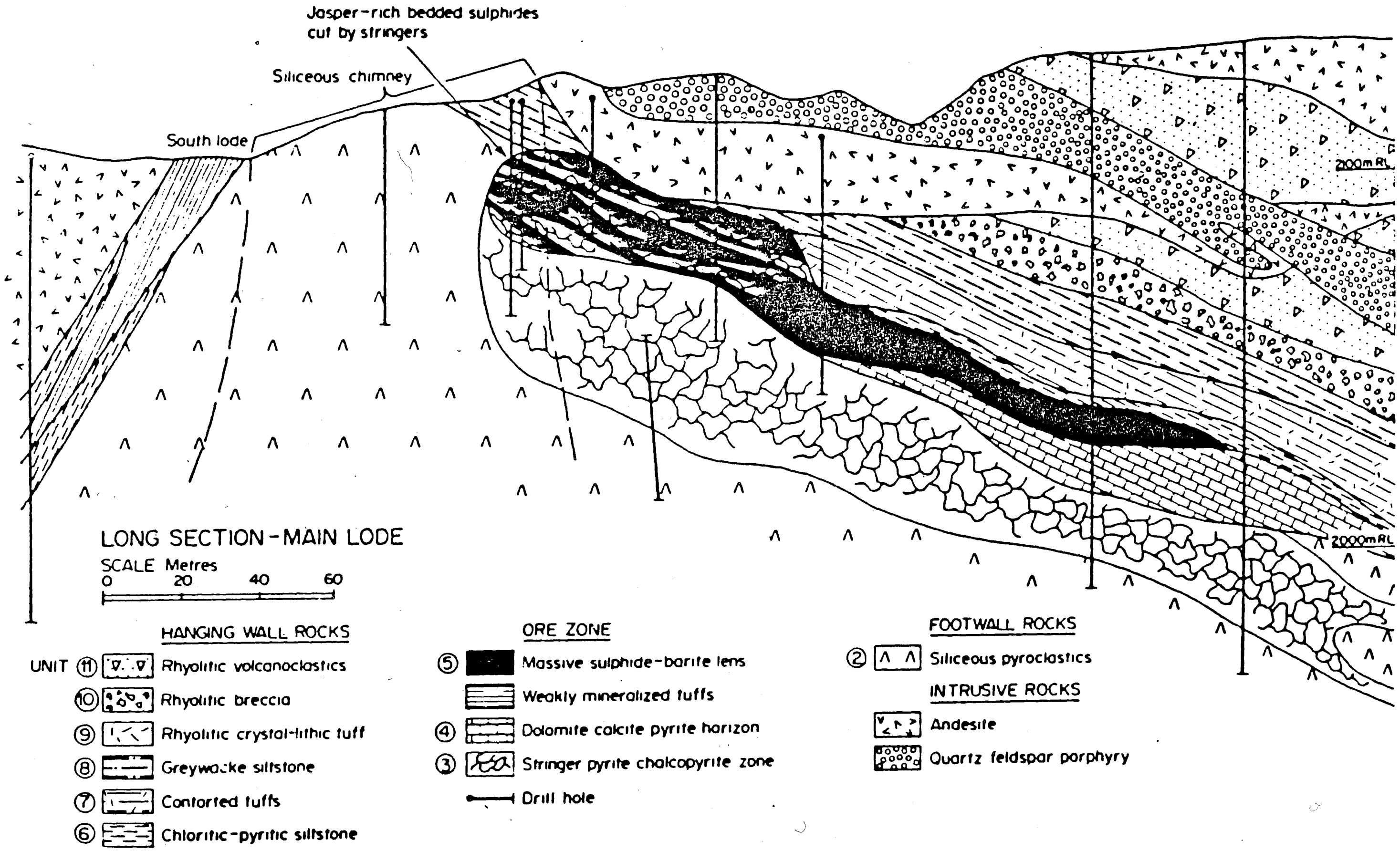


Fig. 3.4: An example of gold mineralization in a Kuroko-style massive sulphide deposit, the Mt. Chalmers deposit (Large and Both, 1980).

1986).

Mt. Chalmers also has many characteristics of Kuroko-style mineralization (Large and Both, 1980). Ore is hosted by pyroclastic and sedimentary rocks of the Beserker Beds of Lower Permian age. Thus the deposit is somewhat younger than the Mt Morgan deposit. The host rocks consist of a series of submarine rhyolites, rhyolites breccias, lithic tuffs, lapilli tuffs, silts and minor greywackes overlain by massive andesite lavas and andesitic tuffs of the "Andesite Series" (Fig. 3.4).

The footwall pyroclastic sequence defines a dome, at the summit of which is a "siliceous chimney". There are two orebodies each with a stratiform segment and an underlying stringer zone (Large and Both, 1980). The stratiform ore includes beds of baryte, pyrite and chalcopyrite and 1 - 5cm thick jasper beds, and is thus comparable to the Mt Morgan sequence. A pyrite halo surrounds the stringer zone, and may extend 50 m beyond ore. In the stringer zone, Cu dominates at the base and Cu-Au in the upper part. In the stratiform ore, Cu-Au are the dominant metals in the lower part, grading to Zn-Cu-Au-Ba in the middle to Pb-Zn-Cu-Ag-Ba in the upper and outer parts. Alteration is markedly different in the hanging wall and footwall. In the latter silicification is well-developed, and accompanied by chlorite and white-mica ("sericite"). In the hanging wall alteration is relatively restricted to "bleached zones" and carbonate veining.

3.4: THE CHARTERS TOWERS PROVINCE

There are several small deposits and mines immediately north of Mt Morgan (including the Clermont alluvial field) but the next field to be considered here is the Charters Towers Province - a province that hosts several major deposits including Mt Leyshon, the mines of Charters Towers and Ravenswood townships, plus Far Fanning and Pajingo. The province also hosts several significant prospects such as Disraeli, Wirralie, Mt Coolon and Highway. The province is part of the Thompson River fold belt, which was described earlier. Mt Leyshon is currently Queensland and Eastern Australia's second richest gold producer (Table 1.1). Charters Towers township and the surrounding area is historically Eastern Australia's third largest reef gold producer, having amassed 211,506 Kg of gold (Woodall, 1979). Ravenswood township is Eastern Australia's 15th most productive goldfield (Woodall, 1979). Despite the importance of the region there has

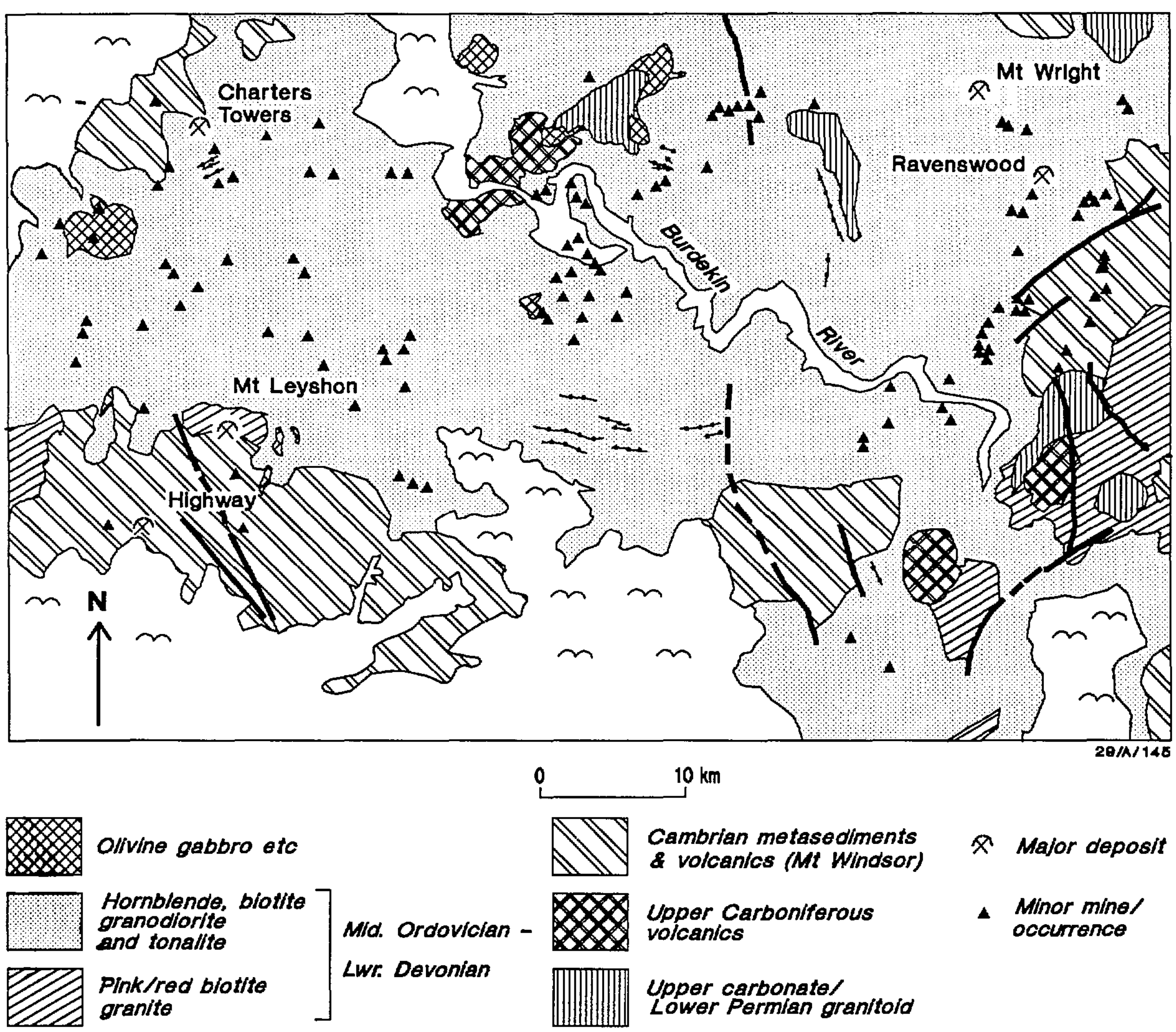


Fig. 3.5: Geology of the Charters Towers Province. Note the large number of small deposits.

been little recent work, and many aspects of the geology and genesis of the deposits remain obscure.

3.4.1: CHARTERS TOWERS AND RAVENSWOOD GOLDFIELDS

The goldfields of Charters Towers and Ravenswood occur within 50 km of each other and share a similar geological setting and are thus described together. The geology of the area is depicted in Fig. 3.5. Although there are a large number of gold occurrences and mines outside the township areas these produced a comparatively small amount (<25%) in comparison with the lodes in the town areas, and documentation of their geology is virtually non-existent.

A major proportion of the deposits of this area are, or were, hosted by granodiorite of the (predominantly Ordovician) Ravenswood granodiorite complex (or Ravenswood batholith) but others occur in Cambro-Ordovician meta-sediments and volcanic rocks (Mt. Windsor volcanics) which it intrudes. The granitoids are foliated and mylonitized (Peters and Golding, 1987), with the foliation striking NW parallel to major NW-trending faults and lineaments (one of which is associated with the Mt. Leyshon deposit - Morrison et al. 1987). The mylonite is pre-Devonian in age since it is not developed in the Devonian Millchester Creek granodiorite and Alabama diorite (Peters and Golding, 1987).

The top ten lodes are:

DEPOSIT	**ORE (tons)**	**Au (Kg)**
Day Dawn/Wyndham	589,500	17,090
Mills Day Dawn Utd.	507,430	13,390
Brilliant & St. George	371,100	14,450
Brilliant P.C.	340,600	12,600
Day Dawn P.C.	275,128	11,870
Queens Cross	138,125	8,970
Brilliant Extended	567,500	6,318
Brilliant Central	245,500	6,735
Victory	98,800	6,761
Victoria	70,900	4,593

In the township areas ore occurs in lodes which have two distinct orientations (Reid, 1917). Most strike approximately north-south and dip eastwards at angles of between 20 - 45°. The Shemalier and Buck Reefs at Ravenswood trend east-west and also dip shallowly (Clarke, 1969). The lodes average 1 m in thickness, although they may be up to 20 m (Reid, 1917). Most of the richest mines in the Charters Towers township exploited the Day Dawn, Brilliant and Queen lodes, which together produced 75% of the fields production. The Day Dawn lode is composed of two sub-parallel quartz veins at depth which coalesced nearer the surface to produce a rich "bulge". Peters and Golding (1987) suggest that the Day Dawn lode occupies the site of a reactivated mylonite.

Shoots within the lodes were irregular, but tended to be elongate in a vertical direction (Reid, 1917). Peters and Golding (1987) interpret the shoot geometry to be a reflection of the presence of "mullions" on former mylonite surfaces which were dilated during later reverse movement. Also boundaries between different rock types appear to have influenced shoot geometry. The lode walls were well-defined and often slickensided. Comb structure within the veins was common. Late faults displace the lodes by up to 12m and these are defined by a "gouge" of chlorite, smectite, quartz and laumontite (Peters and Golding, 1987).

The lodes typically consisted of single or mutiple (sheeted) quartz veins, surrounded by a zone of altered country rock which extended for up to 2.5 m from the central vein zone (Peters and Golding, 1987). The hanging wall and footwall contacts were generally sharp and marked by slickensided clay seams. Gold mineralization was usually confined to the central quartz veins and gold values evidently decreased with depth. Typical grades are: 30g/tonne Au, 2% Pb and 1% Zn. In the main field gold fineness is ca. 825 but decreases to 780 on the periphery (Peters and Golding, 1987).

A characteristic of the lodes was their "mundic" nature (high sulphide content) which made processing of the unweathered ore difficult with the technology avaliable at the turn of the century. Sulphide constituted as much as 75% by volume of the lodes in some instances (Reid, 1917). High gold grades were usually associated with particularly "mundic" lodes. Sulphides included pyrite, chalcopyrite and arsenopyrite, galena and sphalerite except in the Shemalier and Buck Reefs which lacked arsenopyrite and sphalerite. Galena and sphalerite were regarded as favourable indicators of the presence of payable gold. The volumetric percentage of galena in the ore showed a good correlation with gold grades, but not so sphalerite. Native arsenic, tetrahedrite and tellurides of Au and Ag (including possible petzite and/or hessite) were identified at some deposits. There have been no detailed published studies of the mineralogy

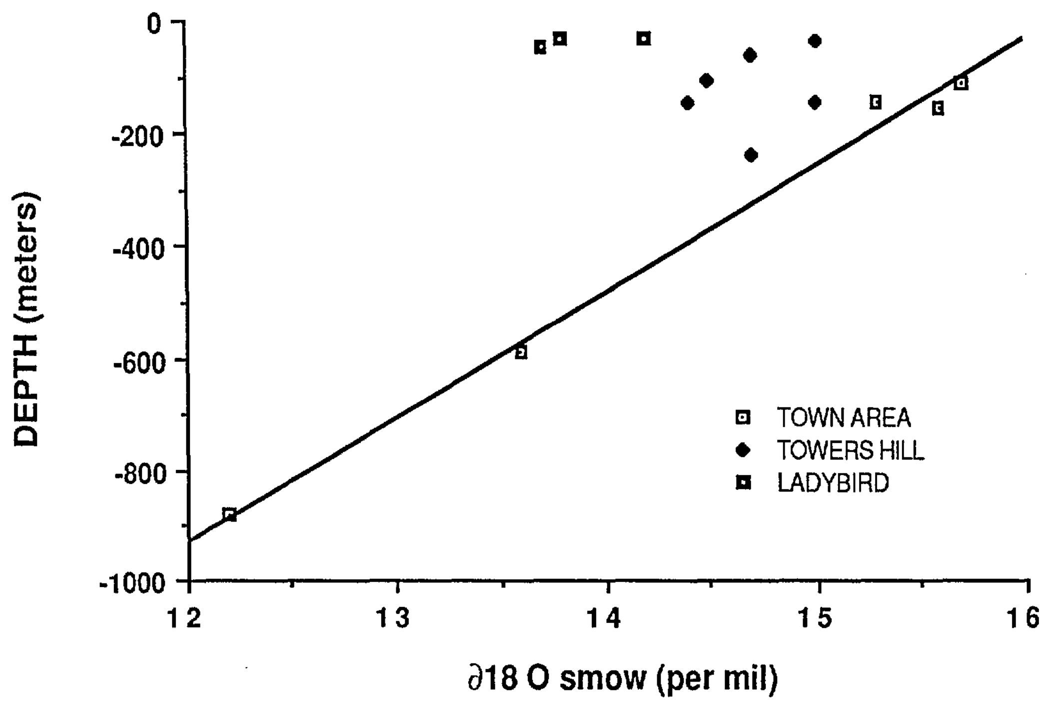


FIG. 3.6: Diagram showing the relationship of isotopic composition of vein quartzes to depth (Golding and Wilson, 1981). Note that each deposit is characterised by a different signature for a given depth, and second, there is an apparent depth dependence of $\delta^{18}O$ in deposits of the town area.

of these deposits, so tellurides and other minerals may be more common than hitherto supposed. Sphalerite is more abundant with depth, and comprised as much as 9% by volume of the lode (Reid, 1917).

Gangue minerals in the lodes consist of quartz and minor calcite, and rarely baryte and gypsum (Wyatt et al. 1971). The sulphates may be of supergene origin, as the paragenesis of ore and alteration minerals is undefined. Apatite and zircon were noted as accessories in Ravenswood lodes (Clarke, 1969). Peters and Golding (1987) describe alteration selvages around the mineralized veins of fine-grained white-mica ("muscovite") and ankerite grading outwards to montmorillonite and white-mica ("illite") with silicification adjacent to the vein. Pre-gold epidote-quartz and post-gold laumontite-calcite mineralization were noted.

Unpublished fluid inclusion data suggests mineralization at ca. 300°C (Peters and Golding, 1987). Oxygen isotopic ratios of lode quartz from several of the deposits at Charters Towers have been determined by Golding and Wilson (1981). Veins from different deposits are characterized by a distinctive isotopic ratio (Fig. 3.6). This may mean either that the mineralization at different deposits ocurred at slightly different temperatures at a given depth, that the fluid isotopic composition of the ore-forming solution varied somewhat or a combination of both situations. There appears to be a systematic decrease in the $d^{18}O$ with depth at the Ladybird deposit and Golding and Wilson (1981) interpreted this as being due to a temperature gradient of some 100°C/km and constant fluid composition. Whole-rocks from the Ladybird mine show an increase in $d^{18}O$ concomitant with alteration (from 7.5 to 10.5‰). More recent work has shown a correlation between the isotopic signature of the lode quartz and the composition of the wall-rocks which Peters and Golding (1987) interpret to be the result of fluid-rock interaction and modification of the original solution.

3.4.2: Mt. LEYSHON

Mt. Leyshon is currently Queenland's and Eastern Australia's fourth biggest gold mine and ranks in Australia's top twenty. The deposit is located 24 km south of Charters Towers (Fig. 3.5) and was originally discovered in 1872.

Mineralization is associated with a Permian diatreme complex, the Mt. Leyshon Complex, which is situated at the junction of

Cambro-Ordovician sediments and the south margin of the Ordovician Ravenswood batholith, where the junction is also intersected by a prominent NW-trending lineament (Morrison et al., 1987). Within the complex is a central zone of porphyrytic to trachytic plugs mantled by brecciated meta-sediments, lapilli tuff and other coarse pyroclastics. Radial dykes emanate from the core. Much of the ore is spatially associated with a dyke of "milled breccia" (i.e. a "pebble" dyke), which contains rounded fragments of the wall-rocks up to 5cm in diameter. It is interpreted as a phreatomagmatic product (Morrison et al., 1987).

Gold mineralization occurs with disseminated sulphide and irregular veinlets in the milled breccia and adjacent rocks. Ore grading at >2 g/tonne outlines a NW-trending mineralized zone, roughly coincident with the milled breccia dyke. Three paragenetic stages have been defined (Morrison et al., 1987):

> Stage 1: On the basis of (unpublished) fluid inclusion data this stage is thought to have occurred at 500 - 450°C . It is manifested as stockwork molybdenite-quartz veins with K-feldpsar alteration and gold-pyrite veins with biotite alteration. Pyrrhotite and chlacopyrite are also present.
>
> Stage 2: Fluid inclusion data suggests that this stage occurred at 400-350°C. It is manifested as chlorite and pyrite matrix replacement and gold & base-metal sulphide veins (which include pyrite, chalcopyrite, sphalerite amd galena). There is a gangue of quartz, siderite and calcite. White-mica ("sericite") occurs in cavities. (N.B. There is a very similar assemblage in the deposits of Charters Towers and it is tempting to correlate the two).
>
> Stage 3: Fluid inclusion data suggests that this stage also occurred at 400-350°C. This is a quartz, base-metal sulphide and bismuth-rich stage. It is also the stage which resulted in the highest gold grades. Siderite and calcite are gangue minerals and the ore minerals include: pyrite, molybdenite, chalcopyrite, sphalerite, aikinite ($PbCuBiS_3$), bismuthinite (Bi_2S_3), matildite ($AgBiS_2$), cosalite ($Pb_2 Bi_2S_3$), wittichenite (Cu_3BiS_3) and argentiferous galena (Morrison et al., 1987).

In summary, the complex is suggested to be a multi-stage breccia pipe formed by explosive interaction of local groundwaters with trachytic to rhyolitic magma (Morrison et al., 1987). There seems little doubt that the deposit is related to this magmatic activity, and there is some evidence that high temperature magmatic fluid was involved in ore genesis.

3.4.3: FAR FANNING

Far Fanning is situated 70 km NE of Charters Towers township and has seen historical production of ca. 50 Kg Au from 3,756 tonnes of ore. A re-evaluation of the old mine by the Northern Queensland Co. Ltd. established a resource of 500,000 tonnes of ore at 2.3 g/t using a cut-off grade of 0.5 g/t (Elliot and Houtgraf, 1986). Gold was poured at the new mine in 1987. As with most deposits in this area, there is a singular dearth of published information.

The deposit is hosted by Upper Devonian clastic red-bed sediments of continental to shallow marine origin (Dotswood Formation) which are folded into open NNW trending structures and overlie the Ravenswood granodiorite. Ore-bearing tensional quartz veins and breccias, ranging from 2 to 20 m thick, are preferentially located along bedding planes in the folded sandstone, and dip shallowly, concordant with bedding (Elliot and Houtgraf, 1986). The ore zone is evidently elongate along strike (1.7 km long) while individual ore-bearing lenses are between 10 - 200m in length. The folding is thought to be related to movement on a prominent lineament. This sequence is intruded by a diorite plug (Mt Kitty O'Shea) and associated dacitic to andesitic dykes.

Gold occurs in quartz veins and breccias which are from 10 to 20 m long, are 5 - 10 m deep and have an average width of 15 cm. These veins are associated with an east-west striking tectonite (shear zone) with associated reverse movement. Three veins stages have been identified (Dunham and Skrzeczynski, unpub. manuscript):

1. (Earliest) K-feldspar, quartz and minor gold

2. Quartz, pyrite, chlorite, sulphides, native bismuth, calcite (dolomite and siderite are also present) and gold.

3. (Latest) sparry calcite.

Sulphides include: pyrite, chalcopyrite, arsenopyrite, galena and sphalerite. Cu values range from 200 - 500 ppm and Zn can be up to 2%. Gold shows a good correlation with Zn and Cu values. High Zn evidently forms a halo around the gold mineralization (Dunham and Skrzeczynski, unpub. manuscript). Hydrothermal alteration consists of silicification and pervasive white- mica (*i.e.* is phyllic). The silica is chalcedonic (Dunham and Skrzeczynski, unpub. manuscript). Chlorite is also present. The spatial distribution and extent of this alteration is not described.

Elliot and Houtgraf (1986) suggest that the deposit is epithermal and associated with nearby Permo-Carboniferous granitoids, but provide no evidence for this model.

3.4.4 Mt. COOLON

The Mt. Coolon gold mine is situated 100 km SE of Ravenswood. It is relatively small, ranking as Eastern Australia's 40th largest historical gold producer as of 1979 (Woodall, 1979). It is being evaluated by RGC/Crusader and is a promising prospect (Table 1.3). The deposit is hosted by andesite of the Mt. Coolon Formation, correlated to the Camboon andesite host to the Golden Plateau deposit. The Mt. Coolon Formation was intruded by a tonalite and contact metamorphic effects include the production of skarn-like rocks in sediments underlying the Mt. Coolon Formation which include magnetite rock, massive garnetite and garnet quartzite (Morton, 1935). Contact metamorphism of the andesites also resulted in the development of epidote, garnet and "iron-ore concentrations" according to Morton (1935) although hydrothermal processes could be reponsible.

The Mt. Coolon lode is a single quartz vein over much of its length but splits into several branching structures at its eastern end. The lodes dip at between 75 and 85° SW, and parallel a fracture plane known locally as "the indicator". The indicator, which is usually ca. 0.5 m wide, is defined by "pug" or pyrite seams. Minor displacement (8 - 10 m) of the lode occurred. The lode consists of a "siliceous core", dominated by fine-grained quartz ("chert") which grades into highly silicified andesite. The andesite is differentiated on account of the presence of disseminated chlorite (after igneous ferromagnesian minerals) which gives it a darker and mottled appearance (Morton, 1935). The siliceous core may be layered, due to alternating quartz and adularia. Disseminated pyrite is present and although assays reveal minor Cu and Zn there is no evidence of sphalerite and chalcopyrite (Morton, 1953). It is again stressed that modern mineralogical studies (i.e. post 1935) are non-existent. Other minerals identified in the lodes include: epidote, andradite garnet, specular hematite, calcite, chlorite and zeolites. Zeolites are in fact quite common, and both stilbite and laumontite have been identified. The ore has a gold to silver ratio of ca. 5.

The deposit thus strongly resembles the Golden Plateau deposit, except that garnet has not apparently been identified at Golden Plateau and base-metal sulphides have not been identified at Mt. Coolon.

3.4.5: HIGHWAY

The Highway deposit is situated approximately 30m km south of Charters Towers (Fig. 3.5). It yielded 1 Kg of gold in 1954 and recent evaluation by Aberfoyle Exploration Pty. Ltd. has shown the deposit to be sub-economic under present conditions.

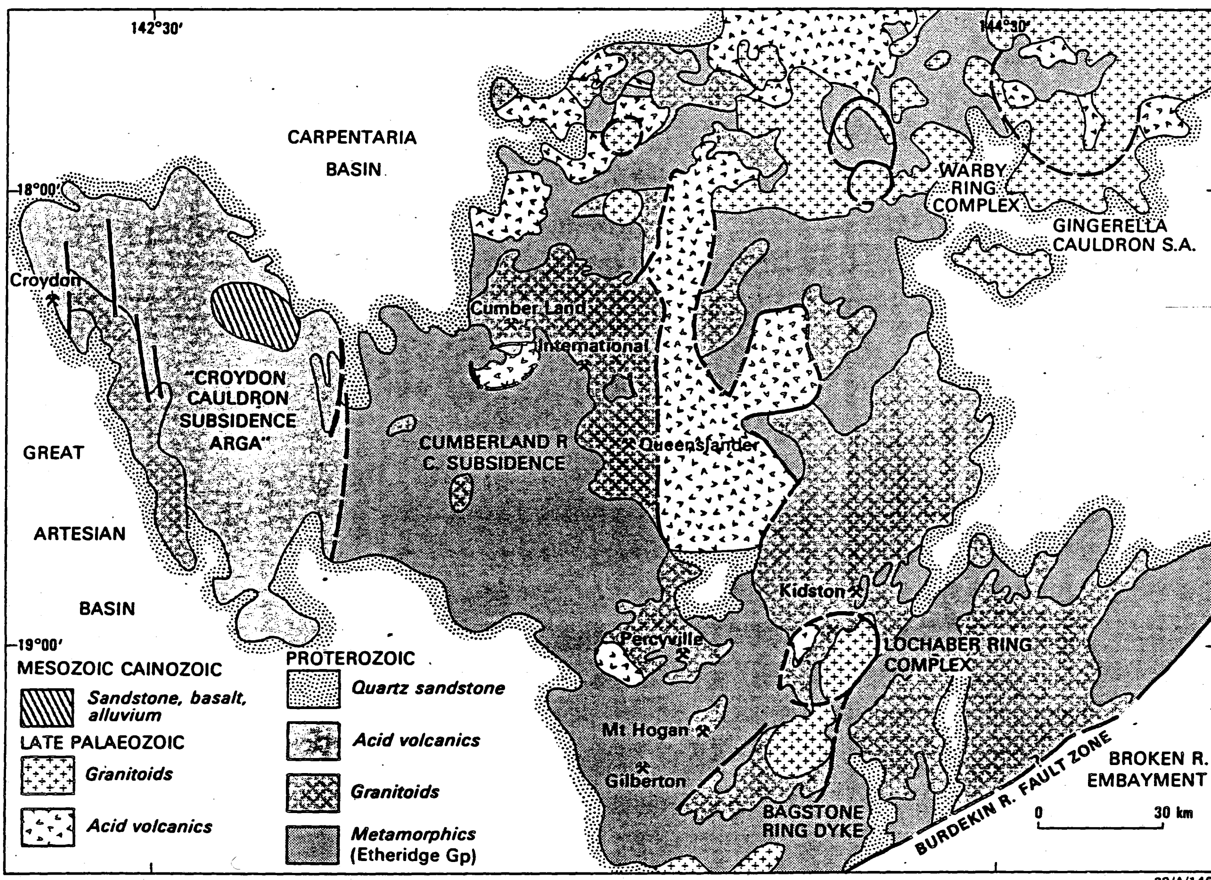
Mineralization at Highway is hosted by the Cambro-Ordovician Mt. Windsor volcanics (which also hosts deposits in the vicinity of Charters Towers), part of the Seventy Mile Range Group (Kay, 1987). The Mt. Windsor volcanics, are a sequence of rhyolites, rhyodacite flows and pyroclastics, folded into a series of tight to isoclinal upright structures, and dips are steep. A NE-trending cleavage is developed in the deposit area which has obliterated volcanic textures (Kay, 1987).

Lateritic weathering has obliterated primary mineralogy in the deposit for some depth, but a banded ironstone (hematite, geothite and quartz) grades downwards into massive stratiform pyrite unit, interpreted to be exhalative (Kay, 1987). This unit contains high Ba (1-1.5%) attributed to veinlets of baryte. High gold values are found in the banded ironstones and in a siliceous and quartz-veined zone in the footwall volcanics (? a stringer zone). Kay (1987) concluded that the mineralization occurred during Cambro-Ordovician time at the site of a small submarine volcanic vent. The deposit is thus comparable to Mt. Morgan and Mt. Chalmers.

3.4.6: PAJINGO

Pajingo is located 50 km south-east of Charters Towers (Fig. 3.5), near the northern end of the continental Lower Devonian to Carbonifeorous Drummond Basin. Outcrop in the area is poor, but the deposit is associated with outcropping rocks of the Janet Range Volcanic Complex, which is probably Lower Carboniferous in age and intrudes sandstone and mudstone (containing plant fossils) of the Raymond Formation.

Mineralization occurs in NW-SE trending quartz veins, some of which can be traced for 2.5 km. The veins are hosted by altered andesitic tuffs and lavas. The veins are evidently multiphase (Etminan et al., 1988) and are cemented by chalcedonic quartz which is often layered. Both the wall-rocks and the lode may be brecciated. Three stages of alteration have been identified (Etminan et al., 1988):



Fig, 3.7. Geology of the Georgetown area, after Bain et al. (1988).

Stage 1: Phyllic alteration (quartz, phengitic white-mica, chlorite and pyrite). Two white-mica K-Ar determinations give ages of 319 and 329 m.y. (Etminan et al., 1988) i.e. the deposit is Mid Carboniferous in age.

Stage 2: Argillic alteration, with mixed layer illite and kaolinite. This overprints alteration of the first stage.

Stage 3: Siderite, dolomite and ankerite, both pervasive and as veins.

Fluid inclusions from late quartz veins have a salinity of ca. 6 wt% NaCl equiv. and homogenize in the range 230 - 270°C (Etminan et al., 1988). Analysis of the inclusion fluids by mass spectrometer reveals that water is dominant with rare CO_2 and no CH_4 or H_2S. The oxygen isotopic signature of quartz is between 5.0 and 7.0 ‰, which corrected for a temperature of 250°C indicates a fluid composition of -3 ± 1, or predominantly meteoric water (Etminan et al., 1988). A depth of formation of 250 - 600m was estimated "from boiling/depth relationships". The fluids are believed to have boiled, at least transiently, and the resultant cooling of the fluid was thought to be responsible for the deposition of chalcedony, rather than quartz.

3.5: THE "KIDSTON" GOLD PROVINCE

This informal province name covers the goldfields of Croydon, Etheridge and Oaks, and other small fields such as Gilberton, which can be logically considered together on account of common geological setting (in the Proterozoic Georgetown inlier - Fig. 3.7). As with most deposits of Eastern Australia detailed knowledge of the vast majority of the several hundred known gold deposits is not available. Even "production data and mine plans are either incomplete or totally lacking for most mines" (Bain and Withnall, 1980). The region produced some 70,000 Kg of gold-silver bullion from reef mines and 5,000 to 6,000 from alluvial workings, as of 1980.

3.5.1: CROYDON GOLDFIELD

The Croydon field, discovered in 1885, was the most productive in the "Kidston" province. Barrack Mines are currently mining the old Federation deposit (Table 1.2), and the area is likely to see a major development by

Pancontinental Mining Ltd. Few geological studies have been made of the area for forty years.

The "Croydon sub-province" of the Georgetown inlier is dominated by a sequence of Mid Proterozoic felsic pyroclastics and lavas of the Croydon Volcanic Group, intruded by co-genetic granites (Esmeralda Granite). These rocks postdate Proterozoic metamorphism. The Croydon Volcanics are dominated by ignimbrite and rhyolitic lavas, but minor basalt and intercalated sediments also occur. Black (1973) gives a Rb-Sr age of 1429 ± 75 m.y. for the volcanics, similar to that for the Esmeralda Granite. These rocks are uncomformably overlain by Mesozoic and Cainozoic sediments. East of Croydon the Iorunie Group overlies the volcanics and is intruded by Upper Palaeozoic rocks (Shelton, 1987). There are major NNW-SSE trending faults of probable normal displacement (Shelton, 1987). The volcanic rocks are folded about NW-trending axes.

Volcanic and intrusive rocks of Permian age (on the basis of K-Ar and Rb-Sr ages) have recently been identified within 50 Km of Croydon township, but these rocks have not been identified from the vicinity of the deposits. Carboniferous felsic ignimbrites, related to sag-type cauldron structures also occur in the region, but not close to any ore deposit (MacKenzie, 1987).

A feature of the Esmeralda granite and its co-genetic volcanic rocks is the abundance of graphite. Ignimbrites (formerly described as "felsite") frequently contain abundant graphite (strictly, disordered carbon) as "rounded, lustrous particles up to 0.5" [1cm] in diameter" (Reid, 1935). The contact between the granite and volcanics is shallow dipping, and is marked in the Croydon township area by a "belt of graphitic granite" 3 km long and 500 m wide (Shelton, 1987; Reid, 1935). This belt represents the presence of abundant xenoliths many of which are graphitic but also include gneisses and schists (Shelton,1987). Gold deposits are often associated with this belt, but there is no detailed correlation between graphite and gold (Shelton, 1987).

Ore in the Croydon township area is mainly (but not exclusively) restricted to lodes in the granite and ignimbrite, no mineralization has been recorded in the overlying sediments (Reid, 1935). The lodes are " vertical fissures or overthrust faults" which strike NS and dip 15-45°E, in some cases they extend for as much as 3 Km (Reid, 1935). Typically, the lodes reach 10 m in thickness. Reid (1935) presents a photograph of a lode, which

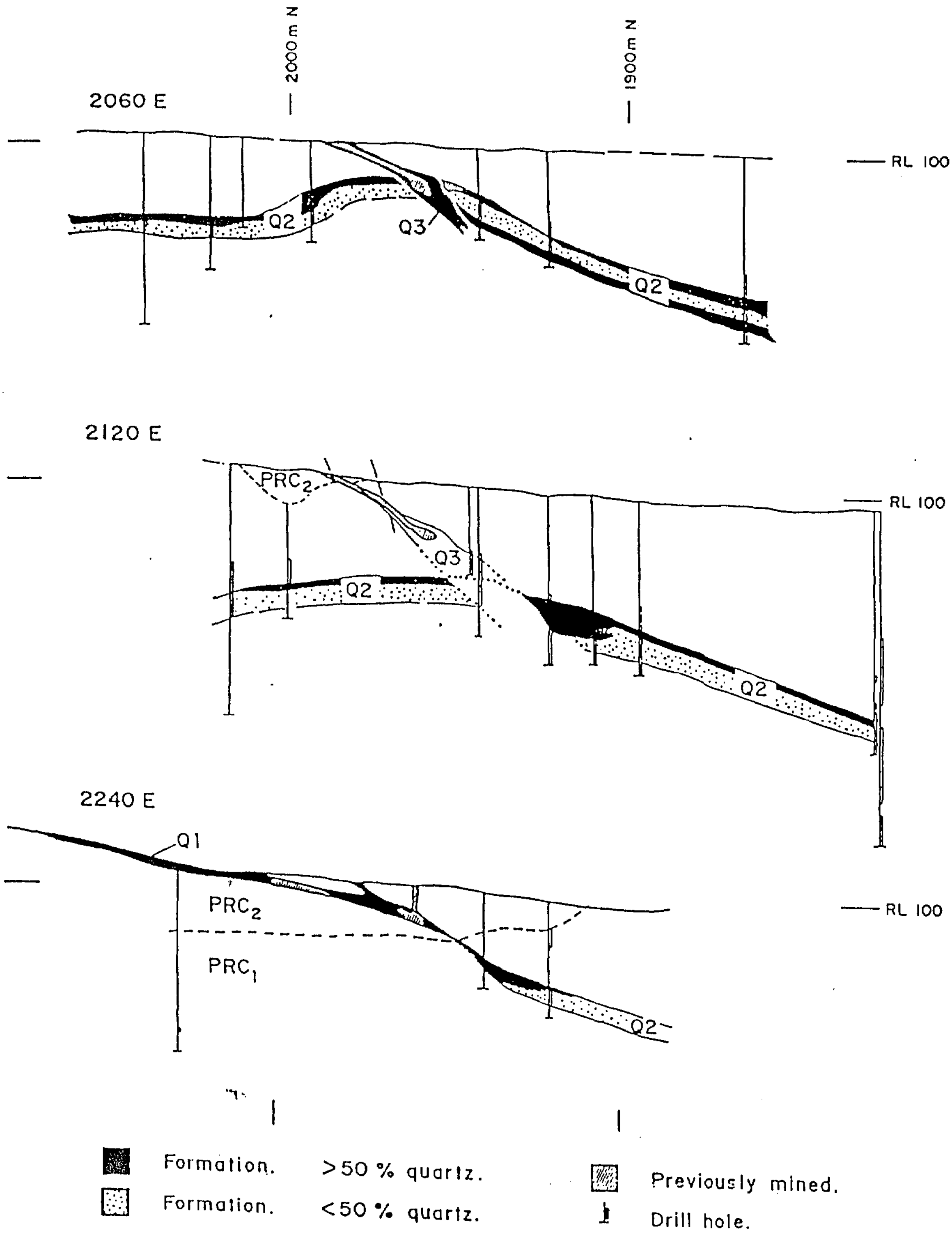


Fig. 3.8: Cross-sections through the Federal Mine, Croydon, showing th e geometry of the mineralized vein system. See text for explanation of Q1, Q2 and Q3.

is ca. 5 m wide and has the appearance of a breccia, in which angular fragments of host granite remain more or less in situ as would be expected if the mechanism of formation was hydraulic fracture. Individual quartz veins in the lode range from a few centimetres to 0.5m in thickness. Within the quartz veins vugs are common, and are filled by euhedral quartz and calcite. The lodes are offset by late faults (locally termed "breaks"), and high-grade ore is seemingly localized at the lode/late fault intersection (Reid, 1935). Orebodies also tend to be situated where there are abundant graphitic xenoliths in the wall-rocks (Reid, 1935). The Golden Gate lode was the most productive in the field having yielded 33% of the total production.

The ore minerals include arsenopyrite as the main sulphide and pyrite, with only minor chalcopyrite, galena and sphalerite. In general the sulphide contents of the ore were low, and the bulk Au/Ag low (in fact the field produced slightly more Ag than Au). Gold is presumeably present as the native metal. Native silver was seen at several of the deposits and Reid (1935) speculates that it is present in other lodes also. The Croydon lodes are unique in Australia for their high graphite content, and nodular masses or films of graphite were noted in most lodes (Reid, 1935).

The Federation mine (open cut mining commenced in 1984) has been the subject of research by S. Shelton. The following is based on his work. The Federation vein system is part of the Tabletop group of reefs, and originally yielded 400 Kg of gold bullion. Mineralization is hosted by a complex vein system in the Carron and Federation rhyolites (of the Croydon Volcanics). Shelton describes three vein types (Fig. 3.8):

Q1: A shallow dipping vein which occurs only in the Federation Rhyolite.

Q2: A folded, flat-dipping antiformal vein with a shallow plunge.

Q3: "Axial planar" to Q2, which offsets it by ca. 6m.

The Tabletop fault terminates the vein system to the west. The Q3 vein evidently postdates the other two, and averages 2 m in thickness. The quartz within it is often sheared and its sulphide content oxidized. Gold occurs in all three veins. In the Q1 vein it is preferentially located at the vein margin. Gold is also enriched where the veins "bulge" presumeably in response to folding of the host-rock. Gold shows a good correlation with sulphide content. In addition to the ore minerals which occur in the Croydon township area, Shelton (1987) has identified covellite, marcasite, greenockite, baryte and iodyrite.

Fluid inclusion data of Dowling, cited by Shelton (1987) suggest ore formation at 300 to 500°C, from a fluid of moderate salinity (5 - 10 wt% NaCl equiv.). The inclusions are interpreted to represent condensate from a magmatic steam phase. Oxygen isotope data on quartz give a range in dO^{18} of 9.3 to 16.3‰. Thus Shelton (1987) favours a model whereby mineral- ization is entirely of magmatic origin.

3.5.2: ETHERIDGE GOLDFIELD

The Etheridge field is second to Croydon in terms of its production. As of 1965, 20,013 Kg of gold had been won (White, 1965) and so the field is quite small in terms of Eastern Australia as a whole. As in other fields there are a large number of gold occurrences and mines but production was concentrated in a relatively few mines. Only six deposits produced over 500 Kg:

Cumberland	2,053
Big reef	774
Durham	710
International	595
Nil desperandum	560
Queenslander	536

A major proportion of the productive reefs in this field were situated at the margin of the Proterozoic Forsayth granite which intrudes Proterozoic amphibolite facies metamorphic rocks (Fig. 3.7). The deposits are located close to a regional greenschist to amphibolite facies transition described as a "regional greenschist facies retrograde metamorphic front" associated with the intrusion of Siluro-Devonian batholiths (Bain et al., 1988).

Most lodes were hosted by granite and "occupy fissures with well-developed walls and have regular trends" for up to 600m (Ball, 1914). They were 1 m thick on average. Lodes in the metamorphic rocks adjacent to the granite were less continuous and lenticular (Ball, 1914). In some instances the lodes were composed of "solid masses of pyrite and galena, or both, with smaller admixtures of chalcopyrite and blende [sphalerite]" (Ball 1914). Sulphide, however, usually comprised only 5% by volume of the ore. There was a good correlation between gold and the abundance of galena and pyrite, but not apparently with the abundance of blende (sphalerite). Siderite was noted as a gangue mineral in addition to quartz. Hydrothermal alteration consists of argillic and sericitic facies (Bain et al., 1988).

Alteration has been dated at 398 - 426 m.y. using the K-Ar method (error margins not quoted) and sericite yields a Rb - Sr isochron age of 407 m.y. (again no error limits quoted). Thus mineralization evidently took place during the Late Silurian to Middle Devonian, and correlates with the important mineralizing episode in the Lachlan Terrane at this time.

Fluid inclusion studies indicate saline fluids (up to 10wt% NaCl equiv.) of unspecified temperature, containing appreciable CO_2. Some inclusions are three phase, containing an aqueous liquid plus liquid and gaseous CO_2 (J. Bain, pers. comm., 1988).Oxygen isotope data for several of the deposits is given in Golding et al. (1987, and below). A mean value of 14.6 ‰ for vein quartzes was found. This data is interpreted to indicate the participation of "highly modified meteoric water", with or without a substantial magmatic component, having a composition of 5 - 9 ‰. The possibility, however, of metamorphic fluid is certainly not ruled out by this data, although the light isotopic composition of the Havelock quartz, together with a fluid inclusion homogenization temperature of 230°C, does however suggest strongly the involvement of meteoric water (Bain et al., 1988).

DEPOSIT	$d^{18}O$ (‰)
Cumberland	15.7
International	15.4
Spero Meliora	15.7
Dairymaid	15.5
Havelock	10.8
Jubilee Plunger	14.8 (±0.7)
Dividend Gully	15.5
Knights of Malta	13.9
New Zealand	14.0

Bain et al. (1988) compare the Etheridge deposits to the "Mother Lode" type of the Sierra Nevada, California and suggest that mineralization is in response to mobilization of meteoric fluids attendent on intrusion of large quantities of felsic magma during the Siluro-Devonian period.

3.5.3: KIDSTON DEPOSIT (OAKS GOLDFIELD)

The Kidston deposit is Eastern Australia's largest current gold producer and Australia's second largest. Like so many of Eastern Australia's currently producing goldmines, Kidston was discovered originally in the previous century, and its lodes were mined extensively during the

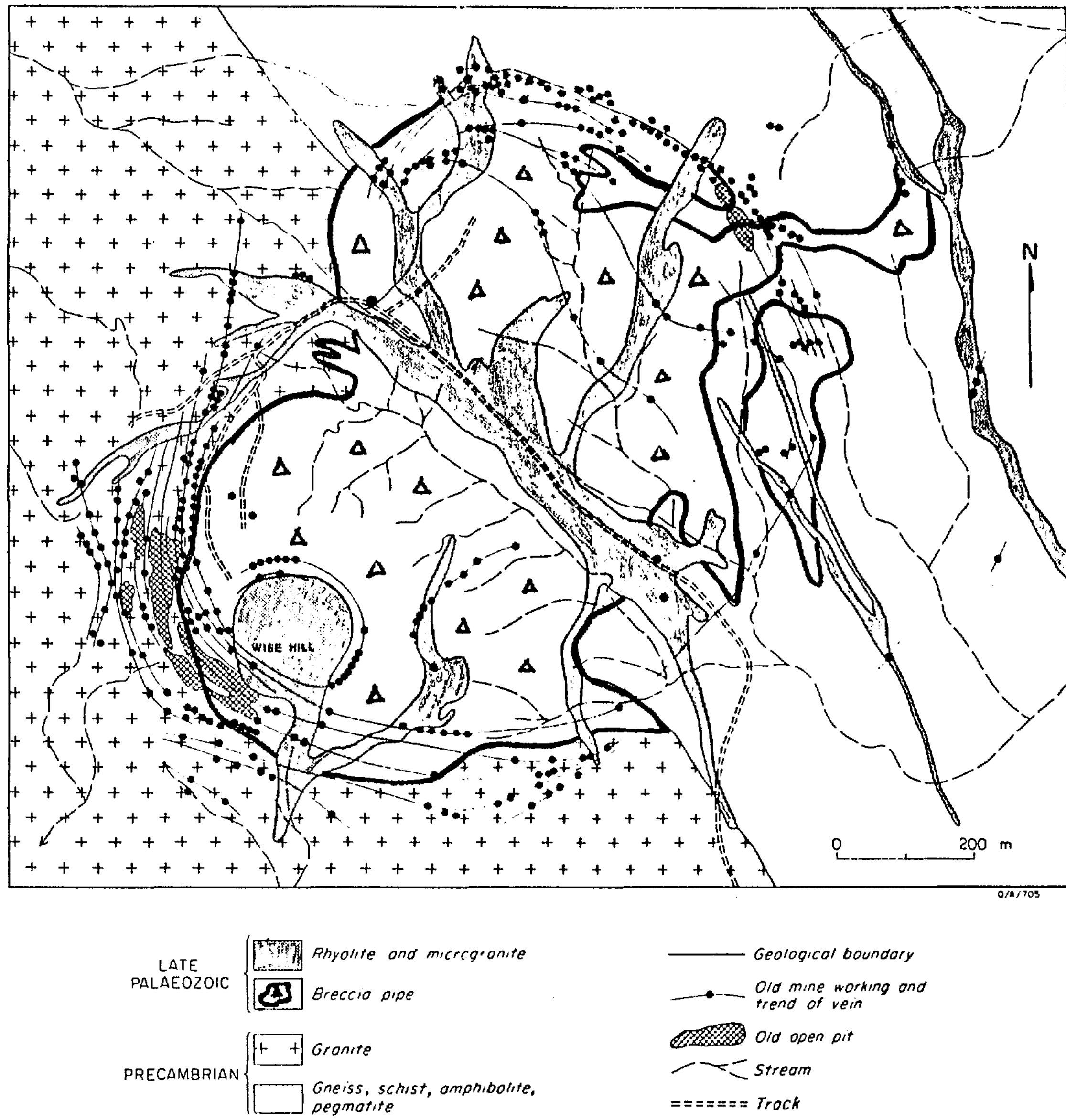


Fig. 3.9: Plan showing the Kidston breccia pipe (from Bain and Withnall, 1980). Note that the pipe occurs at the junction of granite and its host-rocks, a similar relationship to the Mt. Leyshon deposit.

1907-1948 period (when the field was known as the Oaks goldfield). Production during this time was, however, relatively insignificant.

Kidston is hosted by a breccia pipe of presumed Permo-Carboniferous age (Mustard, 1984; Baker, 1987), which occurs at the junction of Proterozoic metamorphic rocks (predominantly gneisses) of the Einasleigh metamorphics and granodiorite and tonalite of the Oak River Granodiorite (Fig. 3.9). The age of the granodiorite is uncertain; it could be Proterozoic to Devonian. This mode of occurrence is very similar to that of Mt. Leyshon described earlier, although the host-rocks are apparently of different ages.

Overall, the breccia body is ovoid in shape, but is in detail quite irregular (Fig. 3.9), and is 1.1 km long and 900 m wide at the surface (Baker, 1987). Its margins are sharp and dip inwards at 80°. Fragments within the breccia seem to be in situ, and have a mean diameter of 5 cm. The breccia is cut by rhyolite dykes and a series of sub-parallel sheeted quartz veins which host a significant portion of the ore. These veins parallel the breccia margins (Fig. 3.9). There are also some dykes with rounded fragments in the centre of the body, possibly equivalent to the "milled breccia dykes" which occur at Mt. Leyshon. Unlike Mt. Leyshon, these dykes do not seem to have influenced the distribution of ore.

Baker (1987) defines three distinct paragenetic stages:

> Stage 1: Predates brecciation. Two vein types are recognized which occur as laminated stockworks. Quartz, pyrite, ±, molybdenite, arsenopyrite, and chalcopyrite associated with quartz and white-mica ("muscovite") alteration. Silicification can be quite intense. Also quartz, magnetite and pyrite veins associated with K-felspar, epidote and chlorite alteration.
>
> Stage 2 (Early): Postdates brecciation. Quartz and epidote-filled cavities around the periphery of the pipe and calcite ± pyrite and pyrrhotite in the core. Locally patches of biotite, siderite and pyrite. Associated with a weakly developed potassic alteration (K-feldspar, albite, muscovite calcite and chlorite).
>
> Stage 2 (Late): Quartz, ankerite and calcite cavity fill and sheeted veins. Sulphides (in order of abundance): pyrite > pyrrhotite > sphalerite > chalcopyrite > molybdenite > galena > bismuthinite and a BiTe mineral (? tetradymite?). Most of the gold is associated with this phase. Some discrete silver minerals are probably present. Associated with a creamy-white phyllic alteration (quartz, white-mica, carbonate).

Thus there are considerable similarities between this deposit and Mt. Leyshon, and a common genetic mechanism seems probable.

Fluid inclusion data suggests the presence of a high temperature (>500°C) hypersaline (40 - 55wt% NaCl equiv.) at >1000 bars during the early stages of ore formation (Andrew and Baker, 1987). Boiling occurred they concluded, in response to a pressure drop due to faulting or brecciation. Scanning electron microscopy of daughter minerals in fluid inclusions in pre-brecciation "brain rock" (crenulated quartz rock) reveals the presence of halite, sylvite and Fe chloride plus Ca, K, Fe and Mn mixed chlorides and carbonates. Condensation of steam is recorded as low salinity (10 - 20 wt%) fluids at 400°C (*c.f.* Croydon) and 300 bars (the evidence for this interpretation is not given). Secondary biotite and K-feldspar alteration is related to 20 - 30 wt% fluids thought to have been trapped at 340 - 500°C. Late phyllic alteration is associated with low salinity (2 _ 10wt%) inclusions trapped at 340 - 400°C. Finally, inclusions in sheeted veins contain ca. 10 mol. CO_2 and have a salinity of 0.5 - 0.7 wt%, trapped at 320°C. The significance of this fluid is not discussed.

Isotopic data is available on alteration phases and hydrothermal precipitates. Samples of unaltered granodiorite give a range of 8.3 - 10‰, while altered equivalents show values of 10.9, due to the development of chlorite and white-mica. Andrew and Baker (1987) conclude that low fluid rock ratios are required (ca. 1:1) and that the fluid causing the alteration had the same isotopic characteristics as that in equilibrium with pre- and early post-brecciation precipitates at 250 - 400°C. Computed $d^{18}O$ values of the pre- and early post-brecciation fluids are consistent with magmatic fluid.

MINERAL	$d^{18}O$ (‰)	dD (‰)	$d^{13}C$(‰)
PRE-BRECCIATION:			
"Brain rock" quartz	9.4 - 9.8		
EARLY POST-BRECCIATION:			
Quartz	10.3 - 10.5		
Epidote		-51 - -57	
Orthoclase	10.8		
Calcite	11.3 - 13.6		
Muscovite		-68 - -71	
LATE POST BRECCIATION:			
Quartz	10.5 - 13.3		

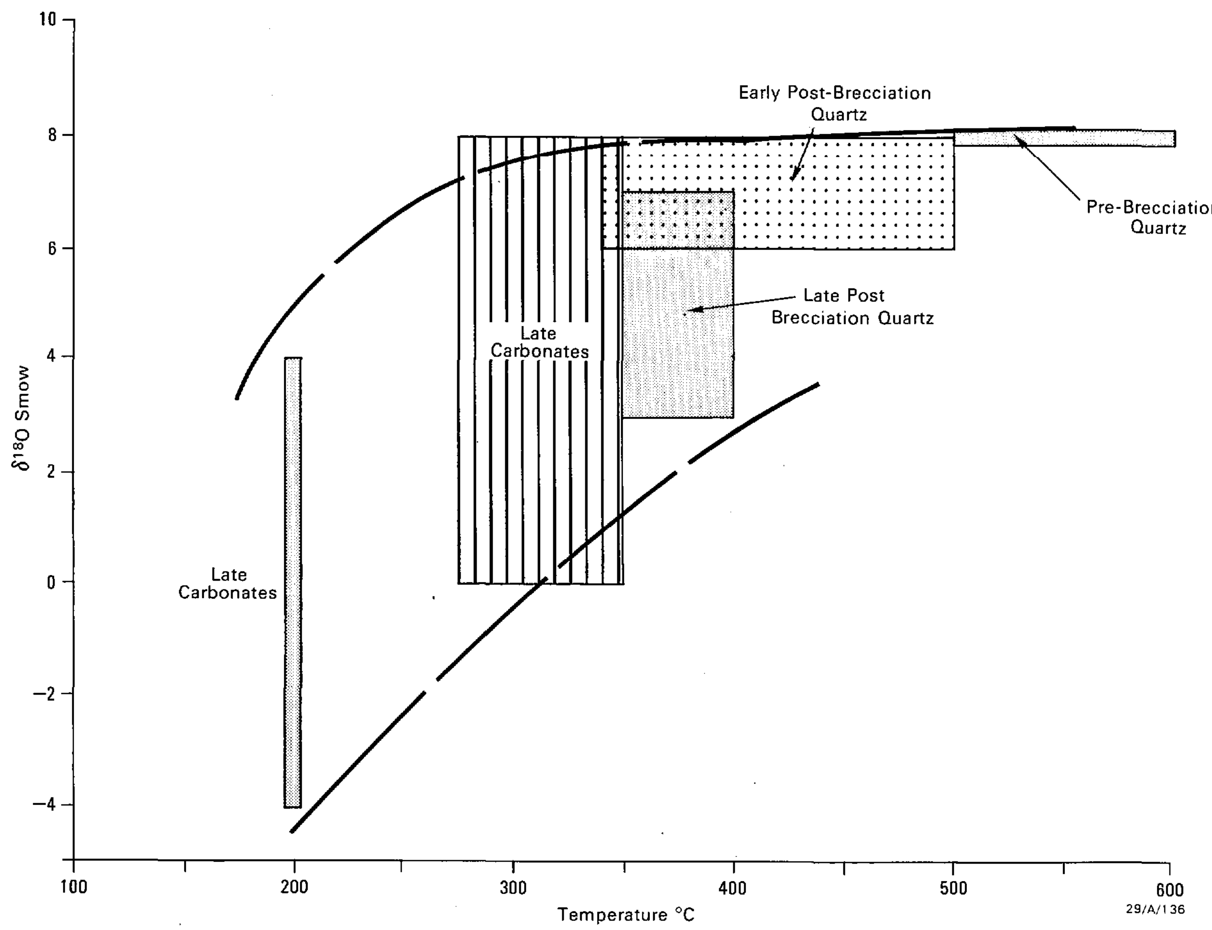


Fig. 3.10: *Evolution of the fluid isotopic composition with declining temperature and paragenetic evolution at the Kidston deposit (Baker, 1987). Note the wide range in isotopic composition at low temperature reflecting the influx of meteoric fluid.*

Quartz (in ankerite veins)	11.8 - 13.7	
Calcite	6.7 - 11.5	-7.1 - -5.7
Ankerite	9.8 - 14.8	-6.0 - -6.7

The carbonates, however, suggest the introduction of meteoric water (Fig. 3.10). Sulphur isotopic values for pyrite, pyrrhotite, galena and sphalerite fall in a narrow range between 1.1 and 4.2 ‰. The sulphides are in isotopic equilibrium and suggest deposition at 350 ± 50 °C. Pyrrhotite in the host granite is quite different to that in the mineralization suggesting that the source of sulphur was not the granite.

3.5.4: GILBERTON (ALLUVIAL) FIELD

Gilberton is situated ca. 60 km S.W. of Kidston. It was a mainly alluvial field (80% or 4,000 Kg) with minor production from a handful of small reefs (900 Kg). Portman produced 27 Kg in 1987, presumeably from an alluvial operation. Reef mines are hosted by Lower Proterozoic slate and quartzite of the Etheridge Formation, which also includes meta-dolerite and meta-basalt. The veins strike NNW to NNE and dip east or west . They possibly represent tension gashes (Withnall, 1981). The veins are thin (cm to 50 cm) but provided some spectacularly high-grade ore (e.g. one crushing of 71t yielded 982 g/t of bullion). Gold is associated with pyrite and galena, and is contains tetrahedrite (Withnall, 1981). The age of mineralization is uncertain. It has not been observed in the early Carboniferous to late Devonian Gilberton Formation, but this does not preclude a younger age (Withnall, 1981).

3.5.5 Mt. HOGAN

Mt. Hogan was mined from 1885 from numerous shallow (<10m) workings. The deposit was tested extensively by Central Coast Exploration N.L. and Urangeschellscahft Australia P.L. and some of their results published in O'Rourke and Bennell (1977). The deposit is hosted by Lower Proterozoic coasre-grained, pink biotite granite which intrudes the Lower Proterozoic Bernecker beds. Mineralization is asociated with "quartz veined alteration zones" which dip shallowly (<40°) to the south and are less than 30 m thick. It is not clear if any displacement is associated with these zones. Quartz veins within these zones are of the order of 2 - 6 mm.

Gold ore is associated with the quartz veins and occurs with pyrite, chalcopyrite, galena and sphalerite. A reasonable correlation between the volumetric abundance of galena and gold grades was noted. Discrete silver grains (tetrahedrite) are present locally. Uranium mineralization (both primary uraninite and secondary minerals) is spatially associated with fluorite. Fluorite is disseminated in alteration zones as well as in veins.

3.6: THE CHILLAGOE-PALMER PROVINCE

This area has not been a significant gold producer in the past, rather it was exploited primarily for its base-metals, Pb and Cu and also Ag. The area was mined during the period 1880 to 1930. The Red Dome deposit is located in this area, and is currently Eastern Australia's third richest producer, and ranks in Australia's top twenty.

3.6.1: THE RED DOME DEPOSIT

The Red Dome deposit occurs in Siluro-Devonian sediments close to the Palmerville fault, which divides them from Archaean metamorphics (schist, gneiss, quartzite and amphibolite). The Siluro-Devonian sequence comprises three units: the Chillagoe Formation (fossiliferous limetsones, cherts, arkosic sandstones, quartzite and minor basalts), the Mt Garnet Formation (dominantly clastic rocks) and the Lower Devonian Hodgkinson Formation (flysche-like sediments). After folding into tight NW-N trending structures these rocks were intruded by Permo-Carboniferous rhyolites (of which two generations have been identified - Ewers and Sun, 1988) which resulted in skarn formation in some of the host-rocks. A breccia which occurs at the surface is interpreted as a karstic alteration of calcitic skarns. There are erosional remants (mesas) of a once extensive Mesozoic sandstone and grit cover.

Ewers and Sun (1988) have identified four phases of skarn formation:

1. Hedenbergite-quartz stockwork veining in early rhyolite and andradite-rich exoskarn which overprints this. At the skarn marble contact massive magnetite rocks occur and these contain minor chalcopyrite, bornite and chalcocite.

2. Wollastonite skarn which replaces type 1 skarn. Gold is associated with this phase. Minor components of this skarn include: garnet, ferrobustamite, calcite, fluorite and opaques.

3. Retrograde skarn, Fe-chlorite, quartz, calcite, sericite, epidote, fluorite, amphibole, minor gold, arsenopyrite, pyrite and sphalerite.

4. Similar to 1, but associated with late rhyolite and includes

remnants of other skarn types.

Gold occurs native and as an alloy with up to 50% Ag. Silver also occurs as hessite (Ag_2Te) with altaite and tellurobismuthinite.

Fluid inclusions in garnet, fluorite and quartz phenocrysts were studied. Inclusions in garnet and fluorite are two phase liquid and vapour (10-20 vol%) often with accidental solid inclusions of calcite. Inclusions in garnet have a salinity of 2 - 24 wt% and homogenize in the range 250 ± 50°C. Fluorite contains less saline fluid (5.7 ± 2.8 wt%) at lower temperature. No CO_2 was detected by Raman laser probe, but minor CH_4 was found. In the quartz crystals halite daughters are present and these inclusions have a salinity of 30 - 50 wt%. Sphalerite geobarometry indicates pressures of formation of ca. 1.5 Kb (*i.e.* a depth of over 6 Km) Corrected for this pressure the fluid inclusion data indicates formation of the skarns at 400°C, consistent with stable isotope thermometry (350 - 480°C).

Sulphur isotope data was taken to indicate mixing of magmatic sulphur and country rock sulphur. Conversion of limestone to marble evidently was accompanied by a reduction in $d^{13}C$, due to decarbonation and reaction with the ore-fluid. A range in $d^{18}O$ of skarn calcites was interpreted as the result of a progressive increase in ^{18}O due to reaction of the ore-fuids with the limestone (which has a high $d^{18}O$ of 22‰). The calculated $d^{18}O$ of fluids in equilibrium with alteration silicates is ca. 9, indicative of magmatic (or metamorphic) fluid.

A model is proposed (Ewers and Sun, 1988) whereby ore was precipitated from magmatic fluid either "by an increase in pH through solution wall-rock interaction, declining temperatures, the effects of dilution, or some combination of these".

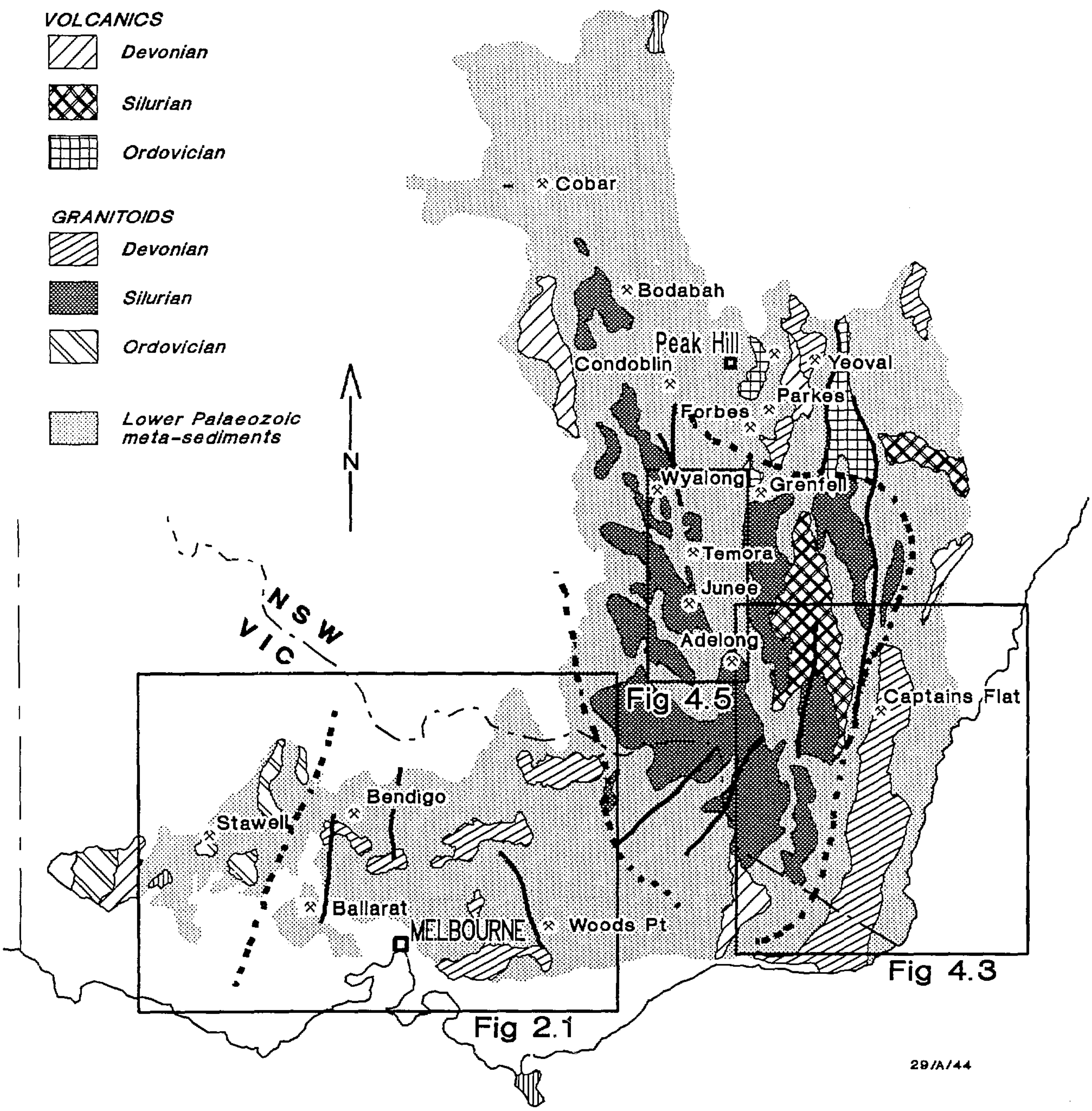


Fig. 4.1: Deposits of the Lachlan fold belt (terrane) showing the location of maps in following text.

4 NEW SOUTH WALES

4.1: INTRODUCTION

Gold deposits occur in two different tectonostratigraphic terranes in New South Wales: the Lachlan (Fig. 4.1) and New England (Fig. 3.1). New South Wales has been the least important of the Eastern States in terms of its historical gold production (Table 1.1). The most productive goldfields and deposits, and their historical production (to 1979) are shown in Fig. 4.2:

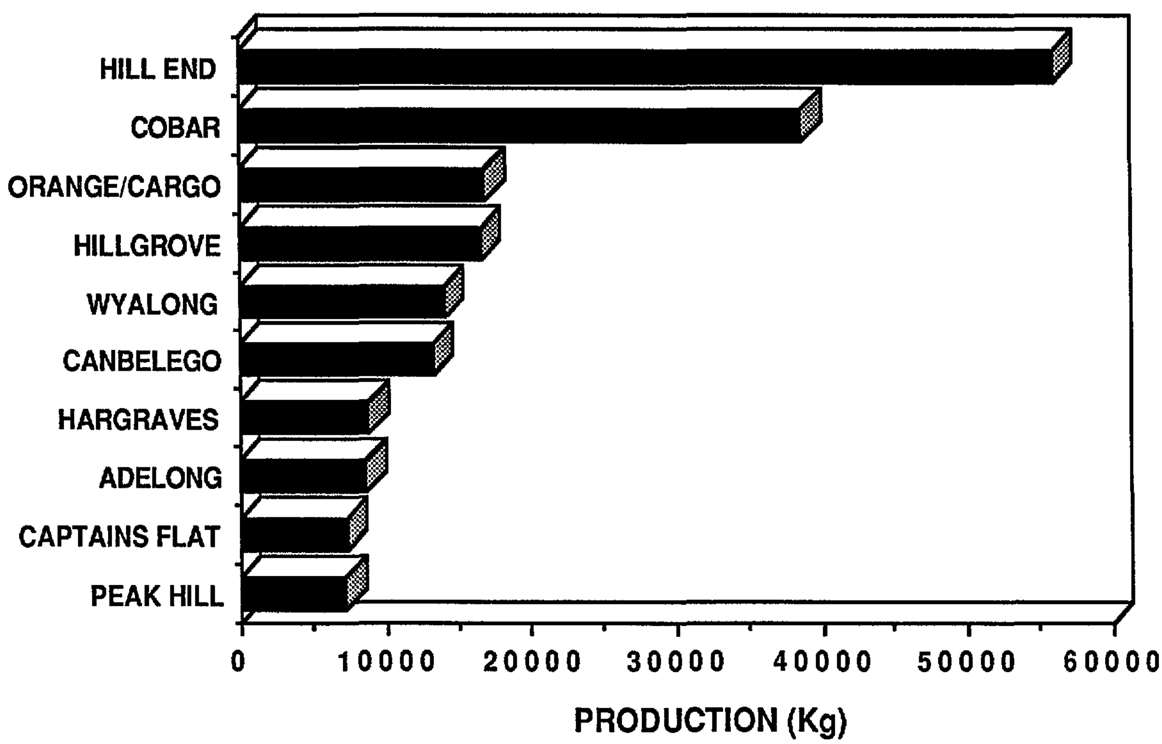


FIG. 4.2: Production from the top ten goldfields in New South Wales to 1979 (figures from Woodall, 1979).

4.2: DEPOSITS OF SOUTH-EASTERN NEW SOUTH WALES

South-Eastern New South Wales encompasses the so-called Eden-Yalwal-Comerong rift zone and parts of the Captain's Flat-Goulbourn, Cowra-Yass synclinorial zones as defined by the Geological Survey of New South Wales (Fig. 4.3). The geology of the area is dominated by north-south trending folded Siluro-Ordovician meta-sediments, Silurian and Devonian

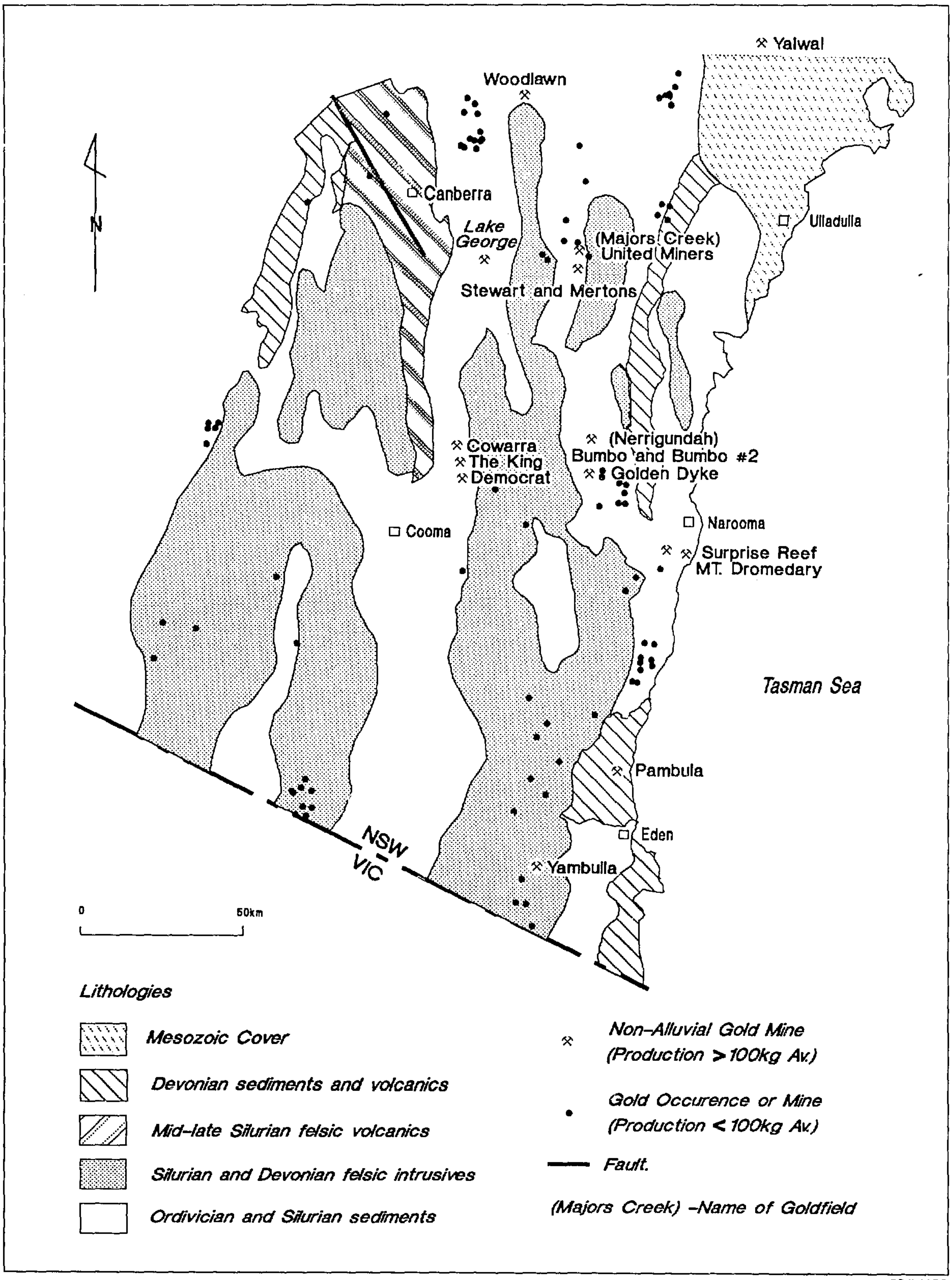


Fig. 4.3: Geology of South Eastern New South Wales (after the Geological Survey of New South Wales).

felsic volcanics and granitoids. There are numerous small gold deposits (Fig. 4.3) but production from most of them has been insignificant. Today, only the Woodlawn and Cowarra deposits are being mined.

4.2.1: LAKE GEORGE (CAPTAIN'S FLAT) AND WOODLAWN

The deposit at Lake George (Captain's Flat) has been the region's main producer, and ninth in New South Wales, since commencement of mining in 1882. During the period 1937 to 1962 Lake George Mines Pty. Ltd. processed over 4 million tonnes of ore grading at 10% Zn, 6% Pb, 0.7% Cu, 56 g/t Ag and 1.7 g/t Au (Davis, 1975). The deposit is hosted by coarse tuffs and shale of the Silurian Kohinoor Volcanics. The volcanics consist of tuff, agglomerate, rhyolitic lavas, exhalites ("cherts") and sinters. Ore occurs as a massive sulphide body in a shale horizon between two tuff units, and was apparently stratiform, although now folded. The volcanics are altered to a greenschist facies metamorphic assemblage consisting of quartz, albite, sericite and chlorite, sphene, epidote, and calcite (Davis, 1975).

The orebody, consisted of pyrite > sphalerite > galena > chacopyrite > tennanite (tetrahedrite) > arsenopyrite > gold > pyrrhotite with very rare stannite and was enveloped in a pyritic envelope. Gangue minerals include: quartz and "chert", calcite and lesser dolomite, chlorite and sericite. The sulphides are commonly layered. A metal zonation is apparent and the highest gold grades occurred to the east of the orebody, and high copper to the west. Baryte occurs in some of the footwall rocks, and in "shale" of the mineralized sequence. Davis (1975) suggests a volcanogenic (exhalative) origin for the massive sulphides and hence for the gold, although the nature of the gold occurrence in this deposit is poorly documented.

Woodlawn is a recent discovery, having been located in 1969. It was recently acquired by Denehurst who are recovering gold and base-metals from oxidized ores and old tailings while continuing underground mining. Gold production currently amounts to over 50 Kg per annum. Recent estimates put the reserves of *tailings* at: 6.3m tonnes at 2.7% Zn, 1.3% Pb, 0.4% Cu and 34 g/t Ag. Gold grades are not given but are likely to be less than those of silver.

Host rocks to the deposit are rhyolitic tuffs and flows, tuffaceous and graphitic shales and "chert". Chlorite and talc schists occur in the footwall. The rocks are dated as Mid to Late Silurian on the basis of a graptolite fauna. The Hanging Wall sequence consists of rhyolites with dolerite sillls, volcanic breccia, tuff and shale. A quartz-sericite "shale" (10m thick) forms a distinctive unit at the immediate Hangingwall contact of the orebody. The Footwall is extensively altered, with chlorite, talc and silification facies developed. The orebody itself has two distinct ore-types: "complex ore" which makes up the main stratiform ore lens and "footwall copper ore". Contacts between complex ore and both hanging and footwalls are sharp. It contains > 75% sulphide and is well-layered, the layers paralleling those in the overlying rocks (except where kinked and folded). Ore minerals include pyrite > sphalerite > galena > chalcopyrite and 1% tertahedrite-tennantite, arsenopyrite, pyrrhotite and rare stannite. Layers are often monomineralIic. A Kuroko-style volcanogenic origin for the deposit is generally accepted.

4.2.2: PANBULA & YALWAL GOLDFIELDS

These goldfields are described seperately because they are apparently unique in South Eastern Australia. Also included in this category are the Sugarloaf and Grassy Gully goldfields and the prospects of Narooma and Wagonga. They occur in the so-called Eden-Comerong-Yalwal rift zone, along New South Wales' east coast (Fig. 4.3). Production from the four fields was comparatively minor:

YALWAL (1871-1938)	2,513 Kg
PANBULA (1890-1928)	1,252 Kg
GRASSY GULLY (?)	66 Kg
SUGARLOAF (1927-1969)	10 Kg

The oldest rocks present are a sequence of deformed Ordovician flyschoid sediments overlain by an Upper Devonian bimodal volcanic suite (Boyd Volcanics) and overlying arkosic red-bed sediments. Host-rocks to the deposits are mainly rhyolitic volcanics. Vesicular basalts within the sequence have a mineral assemblage indicative of low grade burial metamorphism: prehnite, pumpellyite, carbonate, white-mica, K-feldpsar, hematite and tremolite -actinolite (J.R. Taylor, in prep.). These rocks are folded into open, large wavelength structures probably during the Kanimblan event.

The deposits are associated with north-south trending faults, and the orebodies are elliptical, elongate parallel to the host fault zone. Ore commonly occurs in brecciated rhyolite cemented by chalcedony, although the Pinnacle deposit is hosted by what was described as a "crushed conglomerate" (Andrews, 1901). Gold occurs in, or disseminated adjacent to chalcedonic veins and stringers or in kaolinite fracture fill. Lodes in the Grassy Gully field varied from 1 to 1.5 m wide and contained disseminated mineralization grading at up to 17 g/tonne. Intense hydrothermal alteration surrounds the deposits and is characterized by the presence of pyrophyllite (possibly of metamorphic origin - J.R. Taylor, pers. comm., 1988) and kaolinite with disseminated pyrite, and further from ore an envelope of white-mica (J.R. Taylor, in prep.). Apart from pyrite, sulphide mineralization was evidently uncommon although Love (1965) describes sphalerite and arsenopyrite. Metastibnite and paratellurite (TeO_2) have been tentatively identified in deposits from the Panbula field. Jarosite and native sulphur have been identifed in the "oxidized zone" above Yalwal deposits (Kesson, 1968). Absence of the faults which host mineralization in the overlying Devonian sediments suggests that the age of mineralization was close to that of extrusion of the host volcanics.

A fumarolic hot spring origin has been proposed for these deposits (Kesson, 1968). The Al-rich alteration and chalcedonic breccia fill would indicate low temperature and/or acidic alteration such as would be expected in the upper parts of a terrestrial epithermal system. The native sulphur and jarosite zone may represent a very near-surface environment, such as a hot spring.

4.2.3: OTHER DEPOSITS

There are a large number of other deposits in this region, which can be grouped into two main types. These are: deposits hosted by granitoid batholiths and those hosted by folded Siluro-Ordovician meta-sediments. None of these deposits produced over 500 Kg of Au, and very little is known of their geology. Deposits which produced over 200 Kg are given below:

DEPOSIT	**PRODUCTION (Kg)**	**GRADE (g/t)**
COWARRA (1938-1942)	457	8
Mt DROMEDARY (1878-1910)	319	30-60
YAMBULLA (1900-1912)	234	22
MAJORS CREEK (1876-1910)	231	30-62
DEMOCRAT (not recorded)	210	30

The former type includes the gold fields of Yambulla and Major's Creek (Fig. 4.3). At Major's Creek ore occurs in quartz veins which are ≤ 9m in width. Veins are apparently associated with aplites, but it is not clear if they provided a structural inhomogeneity in the otherwise homogeneous granitoid, facilitating vein formation, or some other control was important. Gilligan (1974) has identified three paragenetic stages here:

Gold-pyrite ± magnetite and ilmenite
Cu-Pb-Zn-tennantite-tetrahedrite
Pyrite-gold and silver telluride (and calcite)

A zonation from base-metal rich to gold rich veins was noted from the centre of the field to the periphery. Kennedy (1962) commented that gold mineralization was associated with "griesen alteration" (possibly white-mica and quartz stable alteration, *i.e.* phyllic) and base-metals with propylitic alteration. Sulphide minerals which occur in the veins include: pyrite, arsenopyrite, chalcopyrite, galena, cubanite, pyrrhotite, covellite, marcasite, mackinawite. Silver and molybdenum have been reported (Gilligan, 1974) but the mode of occurrence of these metals is not stated. The Yambulla field contains further examples of granitoid hosted deposits. Ore occurs in a series of sub-parallel quartz veins which strike east-west and which are less than 6 cm in width (although they reach 2m in some instances). Beneath the oxidized zone gold is associated with pyrite and galena, sphalerite and chalcopyrite. Granite around the mineralized veins is altered (to white-mica and quartz) and contains low grade gold mineralization. The ore is silver-rich with Au/Ag typically of the order of 2.

Cowarra, a currently active mine, represents the latter deposit type. Little is known of the deposit. It occurs in a shear zone in folded Silurian sandstones, slates and quartzites (Canavan, 1965). Ore is restricted to quartz veins which are on average 1 m thick, and contain pyrite, pyrrhotite and sometimes arsenopyrite and bornite. The volume of gold is closely correlated to the volume of sulphide (Canavan, 1965). In the Nerrigundah goldfield (Fig. 4.3) gold occurs in sulphide quartz veins in Ordovician metasediments adjacent to the Bega batholith. Sulphides include: pyrite, chalcopyrite, galena, arsenopyrite and sphalerite. Gilligan (1974) mentions that silver (of unknown mineralogy) occurs in the veins.

4.3: DEPOSITS OF CENTRAL NEW SOUTH WALES

4.3.1: HILL END AREA

Three major goldfields occur within the so-called Hill-end synclinorial zone of Central New South Wales, bounded by a triangle connecting Orange, Wellington and Mudgee. These are the Hill End, Stuart Town and Hargraves fields. Hill-End is New South Wales historically most productive goldfield (Fig. 4.2, Table 1.1). Hargraves is New South Wales seventh most productive goldfield.

Most of the production from the Hill End goldfield came from

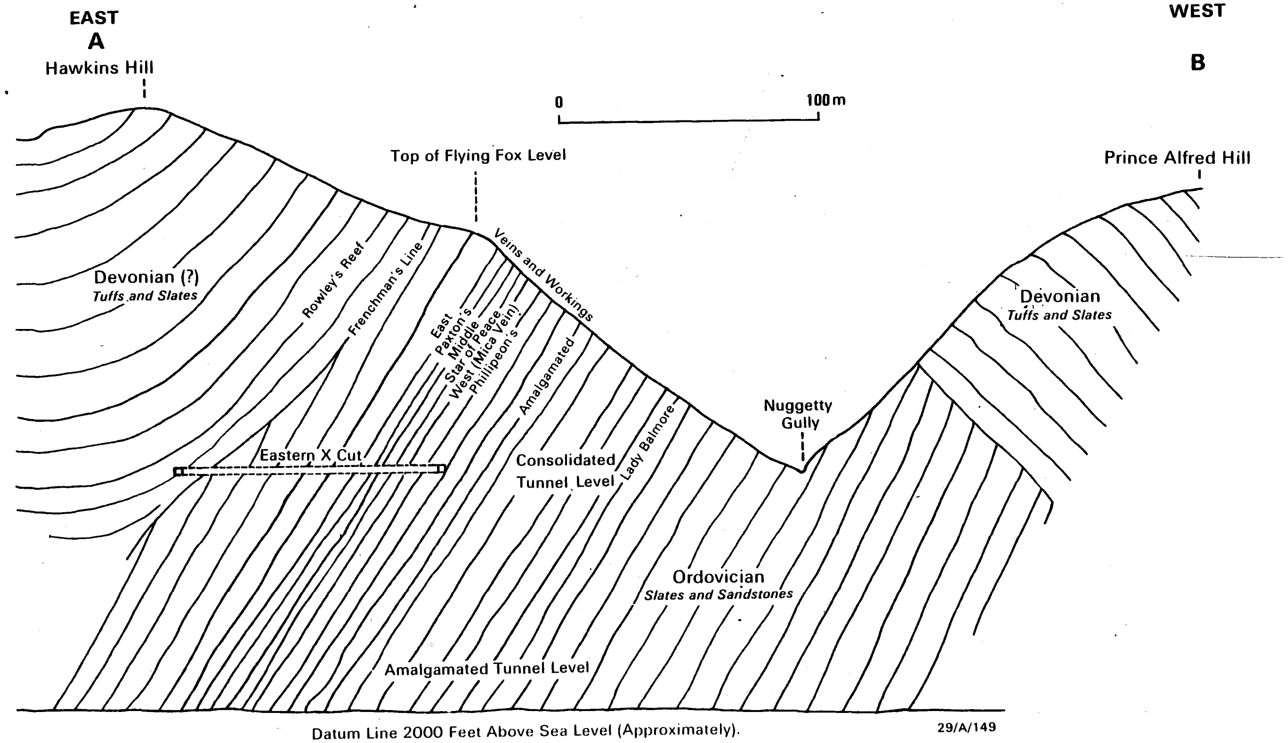


***Fig. 4.4:** Cross-section through the deposits of Hawkins Hill, Hill End goldfield. Although saddle reefs are rare, the deposits otherwise resemble those of Bendigo-Ballarat.*

Hawkin's Hill (12.78t according to the Geological Survey of New South Wales) where several gold-bearing veins were exploited. Again, there has been little published modern work on the deposits of this goldfield; Carne (1918) has presented the most complete account of the geology. The ore is hosted by ?Ordovician slates and sandstone, folded into tight upright structures, so that dips are steep (60 - 70°). These rocks are unconformably overlain by presumed Devonian slate, tuff and sandstone, which are also folded, but apparently during a second event. This sequence was intruded by Pre-Carboniferous granitoid dykes and sills of "porphyry" (Fig. 4.4). The ore-bearing veins are bedding-parallel, strike north and dip at 60 to 70° east. A few veins were described as "inverted saddle reefs". Veins are apparently preferentially developed in carbonaceous slates ("follow carbonaceous slate beds"). Rich gold values were obtained in the vicinity of "cross-courses" (late faults) "droppers or indicators" (joints) or "kindly" (carbonaceous slate). A layered structure in the veins was observed in some areas, where calcite alternated with quartz. Calcite was, in general, not abundant. A photograph in Carne (1918) shows four thin sub-parallel veins, each no more than 5 - 10 cm wide. One vein has an offshoot which is displaced by another vein, suggesting polyphase vein development. Individual veins sometimes coalesce to form "blows". Vein margins vary from gradational (due to silicification of the wall-rocks) to sharp and slickensided. Often intense slickensiding was correlated with high gold values. The presence of "indicators" may have influenced ore deposition by providing localized dilation. Ore was sometimes very rich; a nugget weighing 285 Kg was found at a depth of 31m (Beyer and Hettermann's nugget).

Mineralization in the Hargrave field occurs in Lower Silurian to Mid Devonian slate, sandstone, tuff and andesite. The rocks have a strongly developed axial planar cleavage, and quartz veining is well develpoed in the hinge regions of tight upright folds. Ore occurs in saddle and non-saddle reefs. Watt (1899) commented " reefs at Hargraves resemble in every essential feature the famous saddle reefs of Bendigo". Like Bendigo ore was also concentrated at the intersection of the lode with "marks", a mark being a thin layer of dark brown to green slate 3 - 13 mm thick, presumeably containing carbonaceous material. The "marks" of Hargraves evidently correlate with the "indicators" of Bendigo. Gold occurs with pyrite, arsenopyrite and sometimes galena, with grades from 3 to 100 g/t.

At Stuart Town gold is hosted by siltstone and slate and to a lesser extent by andesite and andesitic tuff (Stevens, 1974). Gold occurs in quartz reefs which strike N-NW (rarely east-west) and dip steeply east or west.

Matson (cited in Stevens, 1974) suggests that ore formation is related to the development of thrusts and to andesitic volcanism, but there is little evidence for this other than occurrence of *some* of the ore in andesites and the mere presence of thrust faults nearby.

4.3.2: PARKES-FORBES GOLDFIELDS

The Parkes-Forbes goldfields include the Peak Hill deposit and the Yeoval and Goonumbla porphyry-style copper (-gold-Mo) deposits (Jones, 1985). Together with the smaller fields of Tomingly and Alectown, this area produced 29 tonnes of gold. The area also includes the London-Victoria prospect.

Peak Hill is historically New South Wales' tenth major gold producer, having yielded 2,338 Kg Au and 25 tonnes Cu during 1889 - 1919. Mineralization occurs in Silurian north-striking moderately dipping dacitic tuffs and lesser lavas and related intrusions. Clarke (1987) regards the volcanic rocks as Ordovician in age (see discussion in Section 1). Drilling has established a reserve of 8 m tonnes at 2.3 g/t Au and 0.2% Cu.

Disseminated copper occurs in an altered dacitic volcanics, containing quartz, sericite, pyrite and pyrophyllite (Bowman and Richardson, 1985). Primary ore grades at up to 6 g/t Au and between 0.2 and 1.0% Cu. The ore minerals include: pyrite, tennantite, tetrahedrite, enargite, chalcopyrite, sphalerite and galena. The richest Cu zone is partly concordant with the richest Au zone. Besides Au and Cu the ore zone contains anomalous Ag, Pb, Ba, As and Zn (not surprising given the ore mineral assemblage). Rare jarosite has been observed at outcrop (Bowman and Richardson, 1985). According to (Bowman and Richardson, 1985) pyrophyllite is a conspicuous feature of the deposit and defines a linear SE-trending zone. A peripheral kaolinite-illite zone has been tentatively identified. Bowman and Richardson (1985) attribute the mineralization to solfataric activity during the Late Silurian.

Yeoval (the Goodrich mine) produced 144 Kg Au and 294 tonnes of Cu. It is hosted by a high K diorite similar to those seen in modern island arc settings, and is early Devonian or younger. Mineralization consists of chalcopyrite, bornite and molybdenite, with associated potassic alteration. It lacks pyrite, and is probably the root of a porphyry copper system.

4.4: DEPOSITS OF THE WYALONG-ADELONG BELT

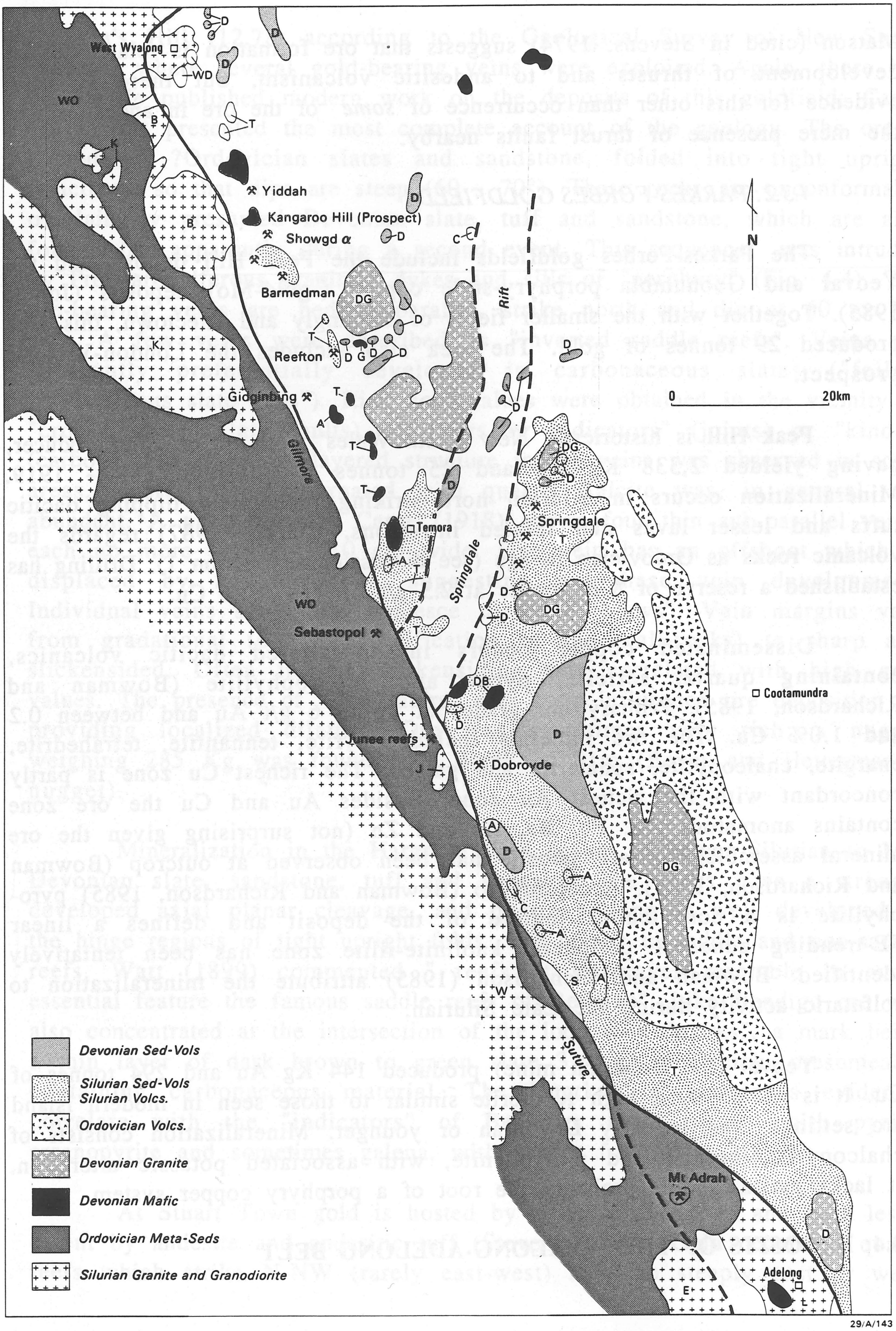


Fig. 4.5: *Geology of the Wyalong-Adelong belt, after Suppel et al. (1986).*

The Wyalong-Adelong belt has been the subject of recent research by the Geological Survey of New South Wales (Suppel et al., 1986). The belt is elongate in a direction north-west to south-east (Fig. 4.5) and contains several historically important goldfields (Adelong and West Wyalong) and several recently discovered prospects. It is also host to New South Wales current major gold producer: the Gidginbung deposit. The ore deposits are spatially associated with a prominent NNW-SSE trending lineament, the Gilmore Suture, which is postulated terrane boundary (Suppel et al., 1986). To the west of the suture the rocks are dominantly Ordovician slates and greywackes (turbidites) while to the east volcanic rocks (from andesitic to silicic compositions) predominate.

4.4.1: TEMORA, SEBASTOPOL & JUNEE REEFS

The Temora, Sebastopol and Junee Reefs goldfields apparently occur in the same lithological sequence. Nearly 75% of the production from the Temora region (3,200 Kg) was from the Temora lead placer, a Late Tertiary stream channel (gravel and finer sediments) which extends for 7 km. The Sebastopol and Junee Reefs fields were primarily reef producers.

The reef deposits at Temora occur in a sequence of Upper Silurian rocks (shale, sandstone, siltstone, slate, conglomerate, corallian limestone and minor volcanics) overlain by Devonian sandstones, siltstones, conglomerate and shale and intruded by Devonian granite and diorite. The reefs strike ESE to SSE, dip steeply and range in thickness from a few centimetres to 5 m. Gold is associated with minor pyrite, arsenopyrite, galena and rare bismutite ($(BiO)_2CO_3$). Mineralized reefs occur only in Devonian diorite. Reef gold occurred in some instances as coarse nuggets: one nugget of 258 oz (8 Kg) was recorded.

At Sebastopol and Junee reefs ore was hosted by "knotted" (i.e. porphyroblastic) schist and quartz mica schist possibly of Ordovician age (Raggat, 1972), overlain by a sequence similar to that at Temora. The most productive mine at Sebastopol was the Morning Star (930 Kg) but production from other mines was negligible. Twenty five individual veins were worked. The main veins trended NW and dipped SW at 60°, parallel to bedding. There were also offshoot veins striking EW and dipping 60° south. From the sketch section in Raggat (1972) it appears that these offshoot veins truncate bedding and schistosity. Evidently the two vein types were of the same age (Raggat, 1972) and post-dated the regional deformation. The veins had a sheeted structure parallel to the vein walls, and sulphides occurred in thin seams also parallel to the walls. Sulphides included pyrite, galena, chalcopyrite and minor sphalerite. The gold to silver ratio of the ore was typically of the order of 1. Tourmaline was locally present. The Morning Star vein was 400 m long and had an average width of 60 cm, although it was locally greater than 3 m wide. "Knots" in the host schist are masses of white-mica with residual grains of sillimanite (?ex-andalusite).

Gneissic (*i.e.* deformed?) granite hosts the reefs at Junee Reefs. They strike NW-SE or 055-070° (offshoot veins) and dip at greater than 60°. Ore distribution is irregular and shoots are developed which pitch parallel to the dip of offshoot veins. This tendency for rich ore to occur at the intersection of two vein orientations is quite common (see also Section 2) and may indicate greater dilational permeability at these sites.

Raggat (1972) noted that the reefs developed in granite (Junee Reefs) and in sediments (Sebastopol) are "strikingly similar in their structure and mineral content [and] there can be little doubt that they are all of the one geological age". Furthermore the nature of the reefs at Sebastopol is apparently very similar to those at Hill End, except for the higher metamorphic grade of the host-rocks at Sebastopol. The small deposits at Reefton (170 Kg) and Barmedman (254 Kg) are similar to those just described, occurring east of the Gilmore suture, and are quartz veins in Silurian meta-sediments. It is proposed that they are due to "mobilization of gold from the underlying sequences during the Benambran orogeny" (Suppel et al., 1986). Hence it is considered probable that all these deposits and those of the Bendigo-Ballarat region share a common genesis.

4.4.2: GIDGINBUNG (TEMORA PROJECT)

The Gidginbung deposit (Temora Project) was discovered in 1983 by BP minerals and Seltrust Gold Pty. Ltd. It is currently New South Wales major gold producer and ranks as Eastern Australia's fourth largest producer. The deposit contains a resource of 5.6 m tonnes at 2.5 g/t and 7 g/t Ag. The following is taken from Lessman (cited in Suppel et al., 1986).

The deposit occurs in highly altered volcanic and volcaniclastic rocks in which primary textures have been largely obliterated. The host-rocks dip shallowly to the east. Mineralization is associated with an argillic alteration zone which is 2 km by 1 km at the surface, enveloped by a propylitic zone. The latter is defined by a chlorite, calcite, pyrite and epidote assemblage, which could also be due to an earlier metamorphism as well as hydrothermal processes. The argillic zone consists of pyrophyllite with alunite, diaspore, pyrite and minor kaolinite. A poorly developed "intermediate" argillic alteration occurs on the north-western side of the deposit, defined by quartz, kaolinite, sericite, montmorillonite and pyrite. The argillic zone grades downwards and outwards into the propylitic zone.

Mineralization tends to be disseminated and defines an ore zone 500m x 300m x 100m thick. The main element is a chalcedonic lens, ca. 80 m long and which outcrops (where it contains secondary mineralization). To the east there is a possible chalcedonic feeder system, and the eastern margin of the orebody is defined by a fault. The bulk of the gold occurs in fractured and veined chalcedonic rock. The main ore mineral in the ore zone is pyrite (5-40 vol%) which occurs in chalcedony veins and also constitutes late sulphide veinlets. Other primary minerals include: covellite, tennantite, argentite, native gold and silver, loellingite, an unidentified gold telluride and cerargyrite. Copper grades range from 0.1 to 0.2%, As exceeds 1,000 ppm (up to 1%), Ba ranges from 500-3,000 ppm (there are some baryte veinlets) and Sb is generally low (< 15 ppm) as are Pb and Zn. Au/Ag ratios vary from 1:1 in the north to 1:10 in the south.

K-Ar dating of alteration alunite has yielded a model (?) age of 422 m.a. or Mid Silurian. This age coincides (error limits were not quoted) with the 431 and 435 m.y. ages of the Goonumbla porphyry copper deposit, which occurs nearby (Jones, 1985). According to Lessman, the Gidginbung deposit could represent the top of a porphyry copper system.

4.4.3: ADELONG &WEST WYALONG.

West Wyalong was the fifth largest producer in New South Wales and according to Suppel et al. (1986) produced 14 t Au. Adelong was New South Wales' eighth major producer, and also contained some of the State's largest individual gold deposits: Old Reef (4,053 Kg), Gibraltar (3,888 Kg) and the Victoria Reef (3,270 Kg). Adelong Creek Alluvials produced 7,465 Kg gold at an average grade of 0.3 g/m^3. Although the two goldfields occur at the extremities of the Wyalong-Adelong belt their geology is similar and indeed similar to that of the Temora group of deposits (previous section).

At West Wyalong lodes occupy "zones of intense crushing or shearing in the Wyalong granodiorite", a short distance to the north of where it intrudes meta-andesite and mafic to intermediate intrusives. The mineralized shear zones trend 020 - 030° and dip east. Gold distribution is irregular, but as seen elsewhere appears to richest at the intersection of two different structures. The reefs contain quartz, calcite, gypsum, pyrite, galena, sphalerite and chalcopyrite. Epidote, chlorite and secondary quartz occur in the host rocks (*i.e.* a propylitic assemblage).

Primary mineralization at Adelong is hosted by shear zones in the Wondalga granodiorite, particularly where these shear zones are occupied by mafic dykes (mica-lamprophyres - Harper, 1916). Mineral Management and Securites have proved 144,000 tonnes of ore grading at 8.5 g/tonne (with a 4 g/tonne cutoff). Shear zones are defined by gneissic granite or mica schists (Harper, 1916). There are several generations of dyke rocks but the lamprophyres appear to be the earliest and are extensively sheared and foliated, in fact the old miners referred to them as "slate". Relics of the original rock in the sheared matrix attest to this origin. Clearly the granodiorite was deformed in the ductile region prior to mineralization, and hence mineralization cannot be related to emanation of magmatic fluids related to this igneous rock. In this regard an analogy can be drawn to the deposits of Charters Towers (Peters and Golding, 1987). Granodiorite at the Gibraltar mine is aplitic (Harper, 1916), possibly comparable to that at the Major's Creek deposits.

The shear zones trend north-south and "moreorless coincide with the strike of the orebodies and primary igneous dykes of lamprophyre" (Harper, 1916). Quartz veins partly engulf the dykes, which are altered to biotite, chlorite (Degeling, 1972) and contain blebs of calcite, quartz, pyrite and sphalerite. Sphalerite was a good indicator of gold values (Harper, 1916). Other sulphides include: chalcopyrite, pyrrhotite, arsenopyrite and galena. There were at least two generations of quartz veins. Alteration minerals include: K-feldspar, ankerite, chlorite and white-mica (Morrison and Nanke, unpub. manuscript).

4.4.4: OTHER PROSPECTS

Recent exploration activity has located a number of prospects in the region. These include: Yiddah, Kangaroo Hill, Showground and Dobroyde (Fig. 4.5). The Yiddah prospect is hosted by a volcano-sedimentary sequence. Mineralization occurs in an altered zone, some 2.5 km x 500 m at surface. A central quartz, white mica, kaolinite and pyrite zone is surrounded by propylitically altered rocks (carbonate, chlorite and epidote). There are zones of discontinous silicification which contain no gold. Rather, gold is associated with an area of copper minmeralization grading at 0.1 to 0.2 % Cu. The best intersection yielded 0.64% Cu and 0.87 g/t gold. Anomalous Mo occurs in the Cu zone and patchy Pb-Zn mineralization occurs in veins peripheral to the main Cu zone. The deposit may be related to a porphyry copper system (Suppel et al., 1986). Kangaroo Hill is similar to Yiddah, but no continous zone of gold mineralization has been delineated and gold values are low (the best intersection being 18m at 0.8 g/t).

The Showground deposit is hosted by intensely altered andesitic to rhyolitic volcanic rocks. As seen at the Yiddah prospect, two distinct alteration zones are developed: a quartz, white-mica and pyrite zone and a marginal kaolinite zone with quartz veining. An elongate Cu and Au anomaly extends for 200 m in the quartz white-mica (i.e. phyllic) zone. The deposit has not been drilled but Suppel et al. (1986) contend that it "exhibits alteration typical of epithermal-type prospects". At Dobroyde an "advanced" alteration (quartz, gypsum, kaolinite, "sericite", pyrite, and minor "illite", alunite, pyrophyllite and adularia) has been identified. (The reason for differentiating between "sericite" and "illite" is not known). Outside this zone, alteration is propylitic (carbonate, chlorite, serpentinite and epidote). Gold values are associated with high Ba and As, in the "advanced" zone.

4.5: DEPOSITS OF THE ORANGE-CARGO AREA

This area encompasses several goldfields and deposits including: Lucknow, Junction Reefs, Brown's Creek and Cadia (Fig. 4.6). The area was a major historical producer (Fig. 4.2), and Browns Creek is currently being mined (Table 1.2). Examination of Fig. 4.5 suggests that the deposits are clustered around a group of dioritic to monzonitic intrusions some of which have characteristic porphyry style alteration. Indeed a feature of the deposits of this area is the high copper content.

4.5.1: JUNCTION REEFS GOLDFIELD

This field was worked during 1886 to 1938 and according to Wilson (1965) produced 1,500 Kg of gold. The main mines were: Frenchman's, Sulphide and Sheahan-Grants, the latter being two separate mines very close together. The deposits occur in low grade metamorphosed and folded Ordovician slate, siltstone, sandstone, tuff, agglomerate and andesitic flows. Mineralization is restricted to the "Ore Bed Series", a 20m thick sequence of siltstone, sandstone, marble, shale, cherty siltstone, and other calcareous sediments, which persists for at least 1 Km along strike. Folds trend north are open and rocks dip at 10 - 30° (except adjacent to fault zones). These were intruded by three phases of intermediate rocks (dykes, sills and irregular masses). A large hornblende diorite intruded north of Junction reefs and was evidently responsible for hornfelsing some of the rocks to a quartz, plagioclase, amphibole and mica assemblage. Ore is located close to

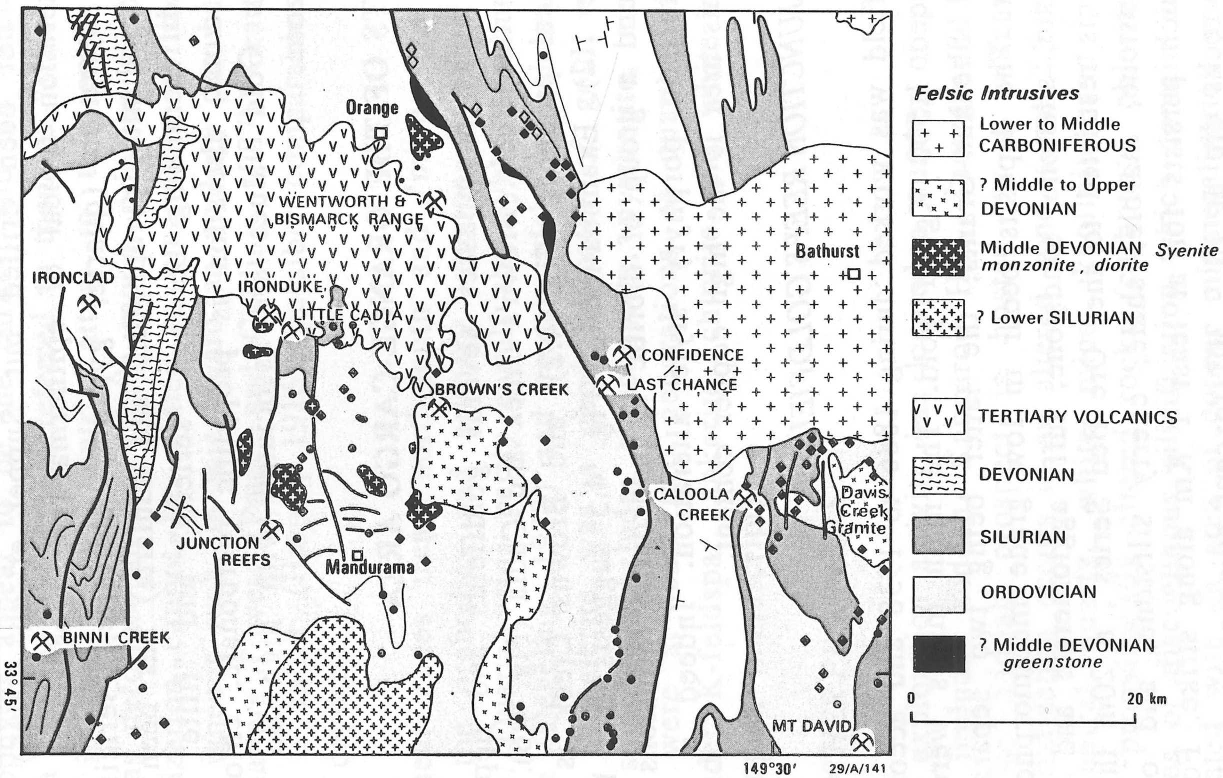


Fig. 4.6: Geology of the Orange-Cargo goldfields, after the Geological Survey of New South Wales.

the intersection of two major faults; the Belulula and Marangulla faults.

Ore is evidently located in skarn, although Wilson (1965) does not describe it as such. A gangue of quartz and calcite is developed and the mineralized beds consist of actinolite, epidote, calcite, chlorite, diopside, plagioclase and mica. The zeolite thompsonite was observed at Grant's mine. The ore minerals are: chalcopyrite (ubiquitous but not abundant), pyrrhotite, pyrite and arsenopyrite with rare bismuthinite. Gold occurs as inclusions in pyrrhotite.

4.5.2: CADIA COPPER GOLD DEPOSITS

The aptly named Iron Duke yielded 100,000 tonnes of copper ore grading at 5 - 7% Cu, and 1.5 m tonnes of iron ore. It was hosted by the Angullong tuff, a 200 m or thicker unit, of lavas, volcanic breccias, lahars and agglomerates (Welsh, 1965). This unit was intruded by a Lower Devonian diorite to monzonite stock and related dykes. To the east the stock consists of an orthoclase diorite with minor lateration and to the west a monzonite porphyry which is brecciated, altered and mineralized.

The Iron Duke orebody is essentially a magnetite-pyrite (?skarn) body with chalcopyrite and gold ore in its upper parts. The orebody is elongate east-west and offset by NE-trending faults. The west end of the deposit is folded. Controls on the geometry of the orebody are poorly understood. A modal analysis of typical ore reveals: 40% magnetite, 7% pyrite, 3% chalcopyrite, 20% calcite, 20% chlorite and 5% each of quartz and epidote. Again, although Welsh (1965) does not explicitly describe the miner- alization as being hosted by skarn, he concluded that that " the copper-gold orebodies at the Iron Duke and Little Cadia (Fig. 4.6) were developed by selective replacement and fracture filling of a sedimentary rock unit composed largely of calcareous tuff, calcareous shale and chemically precipitated or replacement iron oxide bands", and proposed that the gold mineralization derived from hydrothermal fluids from the neighbouring intermediate intrusive stock. The description of the stock is similar to that of typical porphyry copper systems.

4.5.3: BROWN'S CREEK MINE

This is the best described of the deposits of the Orange-Cargo area, having been the subject of a comprehensive work by Taylor (1983). 1,800 Kg of gold were extracted from the deposit in the period from 1871 to 1946 at an average grade of 5.2 g/t. Recent evaluation of the deposit has provided intersections of 3.25% Cu and 20 g/t Au over 2 m and variable Ag grades (up to 92 g/t). The mine produced 483 Kg in 1987.

Like the Iron Duke and Little Cadia deposits Brown's Creek is hosted by the Angullong tuff, less than 1 km from its contact with the ?Lower Devonian Carcoar "granite". Gold mineralization occurs in stratabound or vein skarns. The former occur at the boundary of marble with tuffaceous mudstone. Gold is most abundant in the thickest and highest grade skarns (type 3 of Taylor, 1983) which consist of: quartz, calcite, idocrase (vesuvianite), wollastonite, epidote, chlorite amd sulphides, with minor garnet, diopside and siderite. The sulphides in the high grade massive skarns include pyrrhotite, pyrite, chalcopyrite, arsenopyrite and tennantite. Vein skarns have a different mineral assemblage, with garnet being more prominent, and radiating wollastonite fibres common.

Taylor (1983) concluded that the mineral assemblages indicated temperatures of formation of at least 650°C, poosibly considerably higher. This strongly implicates magmatic fluid in the formation, at least in the early stages of skarn formation. As yet there are no fluid inclusion data to substantiate this, but it is consistent with the occurrence of this and other deposits around a series of monzonite to diorite intrusions (Fig. 4.6).

4.5.4: CARGO DEPOSITS (IRONCLAD MINE)

Cargo is an old gold mining area, which contains a recently discovered major copper deposit of 27 m tonnes of 0.2% Cu. Old gold deposits around the periphery of this deposit were mined from 1870 to 1904 and yielded 318 Kg Au, the major deposit being the Ironclad mine (178 Kg Au, 10.7t Cu, 280g Ag at 30-60 g/t Au).

The deposit is hosted by Early Ordovician andesite, trachyandesite, basalt, tuff and minor breccia overlain by Mid to Lower Proterozoic limestones. In the Cargo area these rocks are overlain by Early Devonian dacitic tuffs, and intruded by porphyritic dacites. There are also Early to Mid Devonian stocks of monzonite porphyry and late mafic dykes. Two distinct alteration types are well developed (as seen in some deposits of the Wyalong-Adelong belt which occurs 100 km to the south-west). Propylitic alteration is widely distributed, particularly in the andesites (chlorite, calcite, epidote and minor montmorillonite; with actinolite replacing mafics). Disseminated pyrite is common in this zone. Phyllic alteration (quartz and white-mica) is best developed in dacitic rocks. There is no evidence of a K-feldspar and biotite (*i.e.* high temperature magmatic) alteration zone.

Primary ore occurs as chalcopyrite and pyrite with gold in the sulphides, either disseminated or as breccia cement. Tabular lode gold deposits radiate and encircle the copper deposit (one of which being host to the Ironclad Mine). Gold ore occurs not in discrete quartz reefs but in diffuse zones of above average sulphide concentration.

4.5.5: LUCKNOW (WENTWORTH)

Although geographically related to the Iron Duke and other deposits of the area (Fig. 4.6), the Wentwoth deposit at Lucknow is quite different, even unique. The deposit is located at the ?faulted junction of a serpentinite with what has variously been described as a diorite, a hornblende felsite and an augite andesite. Harper (1920) described the deposit but by then most of the mines had closed and were flooded. Consequently our knowledge of the deposit is rudimentary. This problem is further compounded by neglible outcrop, and cover of mullock and tailings (Harper, 1920). Veins consisting of quartz, calcite, and host-rock fragments tend to occur along the serpentinite/andesite boundary, but no veins are found actually in the serpentinite. Gold occurs as a series of chutes, whose geometry is poorly defined.

4.6: DEPOSITS OF THE COBAR AREA & CANBELEGO

Cobar is a major base-metal producing area, and is also an important gold producer, gold being primarily a byproduct of base-metal exploitation. Cobar produced 11.7 m tonnes of ore during the period to 1971, for a yield of 205,000 tonnes Cu, 38,000 Kg Au and 118,000 Kg Ag (making Cobar New South Wales' second most productive goldfield (Fig. 4.2). Canbelego, which is situated 45 Km east of Cobar is also one of New South Wales most productive goldmining areas. Five deposits in the Cobar area produced in excess of 500 Kg of Au (with grades in brackets; data of Brooke, 1975):

DEPOSIT	Au (Kg)	Ag (Kg)	Cu (tonnes)
[NEW] OCCIDENTAL	19,984 (9.5)	-	-
GREAT COBAR	9,128 (2.2)	46,710 (11.2)	115,000 (2.75%)
NEW COBAR	7,398 (8-11)	457 (4.5)	5,600 (1.13%)
CHESNEY	868 (2-9)	n a	6,219 (1.76%)
PEAK	617 (21)	9,362 (311)	-

The Cobar deposits occur in a north-south trending belt of Early Devonian rocks, close to the contact between the Great Cobar Slate and the Chesney greywacke, also a locus of faulting.

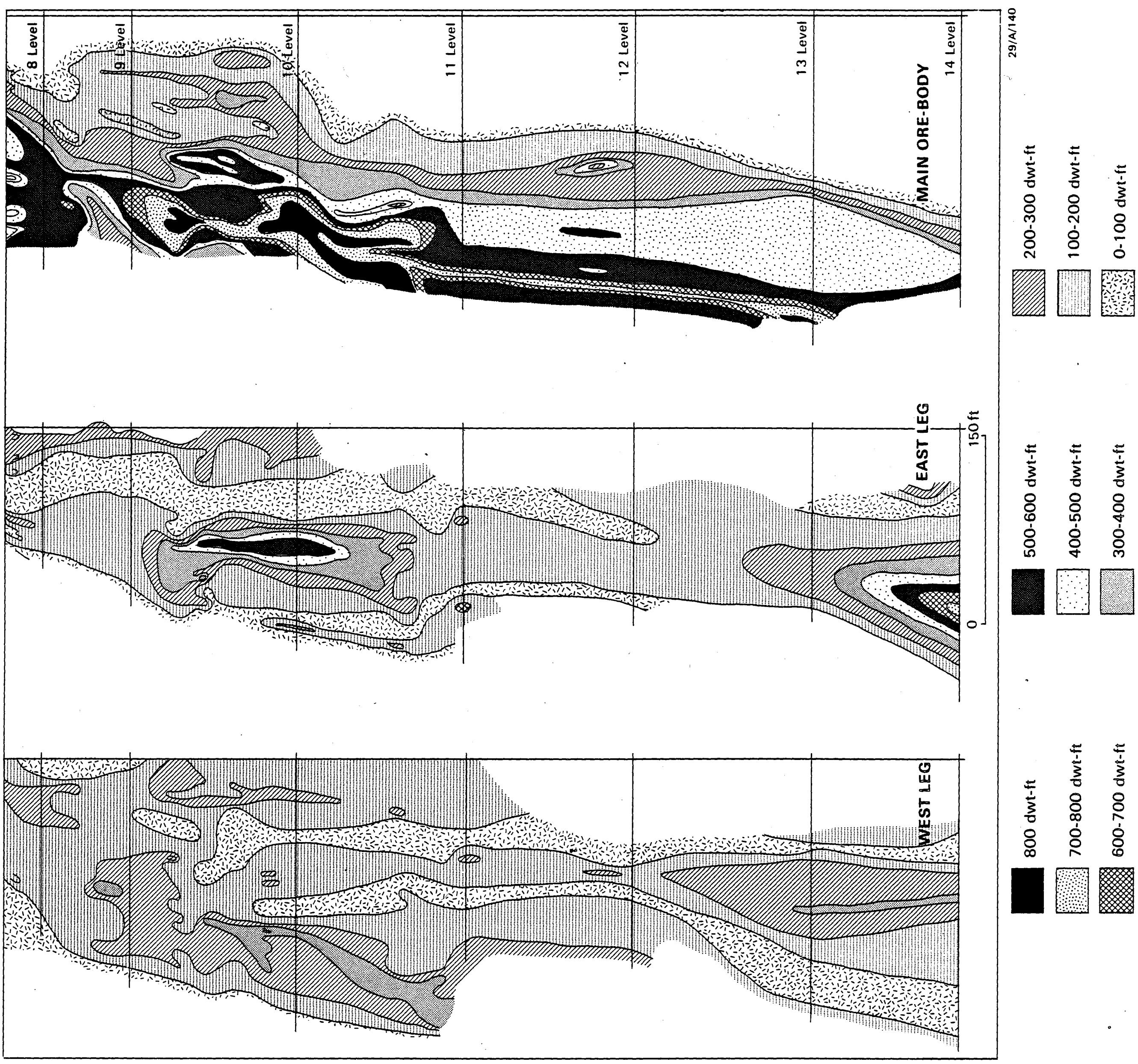


Fig. 4.7: Geology of the New Occidental lodes, Cobar (Sullivan, 1951).

4.6.1: THE PEAK PROJECT

Cobar Mines Pty. Ltd. discovered new gold and base-metal reserves at the old Peak mine (discovered in 1895) in 1981, and have identified an in situ (geological) resource of 4.5 m tonnes of ore grading at 0.7% Cu, 1.6% Pb, 21 g/t Ag and 7 g/t Au. Mineralization occurs in the Great Cobar Slate, a thin-beddded turbidite sequence with underlying sandstones of the Chesney Formation. Ore is localized by the presence of a shear zone and occurs as a series of lenses surrounded by an envelope of weaker mineralization, well developed pervasive silicification and quartz veining. Each lens is sub-parallel to the main cleavage, and each has different mineralogical characteristics.

1,2	gal, pyrr, gold
3	cpr, pyrr, sphal, gal, gold
4	sphal, gal, pyrr, pyr, cpr
5	pyrr, gal, sphal, cpr, gold

The lenses are at least 650 m deep, have a strike length of 110 - 230 m and are 8 - 25 m in thickness.

4.6.2: [NEW] OCCIDENTAL

The New Occidental mine was renamed Occidental in 1889. Mineralization occurs at the junction of sandy to fine tuff to the west and coarser rocks to the east (Sullivan, 1951). This junction represents a discordance of dip, presumeably a fault, although it is not described as such. The ore is traditionally regarded as five lodes named: Gossan, Western, Eastern, Bowman's and Albion. In fact, judging by the map presented in Sullivan (1951) apart from the Gossan, the lodes are contiguous and define an apparently stratiform and strata-parallel body which is folded at its southern end resulting in a considerable thickening of the orebody (Fig. 4.7). There are also (evidently unmineralized) quartz lodes but their relationship to mineralization is poorly described.

Ore consists of quartz, pyrite, pyrrhotite, chalcopyrite, gold and minor galena, sphalerite and magnetite. The quartz is fine-grained and has the appearance of chert, and evidently replaced chloritic slate (Sullivan, 1951). Bismuth mineralization is seen in the Albion lode (Sullivan, 1951).

Solomon, Schmidt and Walshe (BMR newsletter #2, 1985) proposed a genetic model for the Cobar deposits involving formation during cleavage formation, by water circulating through a thick column of sedimentary rocks undergoing deformation. Brill et al. (unpub. manuscript) interpret stable isotopic data as consistent with this model. Quartz from mineralized veins gives $d^{18}O$ of 10.4 - 12.4 ‰, while veins outside the ore zone give a range of 11.2 - 13.3 ‰. Whole-rocks in the alteration zone give 6.8 - 7.6 ‰ while unaltered equivalents give 8.9 - 9.7 ‰. The nearly identical isotopic values of both mineralized and unmineralized presumed metamorphic veins implies participation (Brill et al. concluded) of metamorphic fluids. This model also gains support from K-Ar and Rb-Sr ages on alteration white mica which show that alteration was contemporaneous with Early Devonian deformation (Binns, 1985).

4.6.3: CANBELEGO (Mt BOPPY) MINES

The Mt Boppy lodes produced some 13,500 Kg of gold (from 1901 to 1937) making them the largest individual gold mine in New South Wales (Gilligan, 1977). There has been little geological work on the deposits since the study of Andrews (1911). Gilligan (1977) examined mullock and other specimens from the deposit, but was prevented from examining the underground workings as they are inaccessible.

The deposits occur at the northern extremity of a belt of Siluro-Devonian volcanics and sediments, which extend south to Mineral Hill. In the vicinity of Mt Boppy, Silurian conglomerate and sandstone overlie poly-deformed Cambro-Ordovician schist and meta- greywacke. The Mt Boppy lodes occur at the unconformity between these two major units, which is tightly folded. Mineralization occurs on the limbs of the folded unconformity (resulting in an east and a west lode), while the axial zone predominantly consists of ?barren quartz.

The nature of the mineralization is poorly understood. Apparently some sulphide was massive, but it also occurred interstitially to clasts in the Silurian conglomerate (Gilligan, 1977). Ore minerals include: pyrite, sphalerite, galena, arsenopyrite, chalcopyrite, cubanite and gold. Gilligan (1977) proposed a submarine volcanogenic origin, mainly it seems because sub-marine volcanic rocks of comparable age outcrop some 1 km away, and presumed sedimentary pyrite is present in the hanging wall rocks to mineralization! Although the descriptions of this deposit are poor it shares some similarities with the Cobar deposits:

- Ore is seemingly stratiform and ?stratabound.

- Neither deposit is apparently located in quartz lodes, although some ore at Mt Boppy occurs in breccias which transgress the unconformity (Gilligan, 1977).

- Massive sulphide ore is present

- Ore mineralogy is similar (though arsenopyrite and cubanite have not been described at Cobar, and bismuth mineralization is apparently absent at Mt Boppy - this may be a function of the lack of detailed mineralogical studies).

- Both deposits occur at the junction of different rocks types of presumed contrasting mechanical properties.

- Ore morphology appears to have been controlled, or modified by folding in the host-rocks.

4.7: THE HILLGROVE DEPOSITS

Hillgrove and smaller satellite deposits are located in the New England Terrane (Section1). Hillgrove was one of the State's major gold producers, with a recorded production of >15,000 Kg gold plus 2,000 tonnes of scheelite and 14,700 tonnes of antimony. The deposit is currently undergoing an expansion of underground working. Proven and probable reserves are: 125,000 tonnes at 9.7 g/tonne Au, 2.4% Sb and 0.42% As.

The deposit is hosted by metasediments (schist, quartzite, slate and meta-greywacke) which were intruded by a felsic igneous rocks - the Hillgrove adamellite and Bakers Creek diorite. The latter is itself intruded by dykes of microgranite, aplite, "felsite" and porphyry, which also intrude the metasediments. The metasediments are folded, with a NE or NW trend, and well-developed cleavage (Harrison, 1953). NW-trending fractures evidently acted as channelways for fluids, and host the ore.

Ore ranges from "simple fissure fillings to zones of extensive fracturing and brecciation" (Harrison, 1953). In general there is a close spatial association between mineralization and dykes. Most lodes occur in the metasediments but some extend into the adamellite. Slickensiding is common. Harrison (1953) identified thrree stages of mineralization:

Quartz-scheelite
Quartz-gold-pyrite-arsenopyrite
Stibnite-calcite-siderite

The first two evidently do not occur together. Harrison (1953) suggests that scheelite is restricted to within or close to the Hillgrove adamellite. The third phase occurs as breccia infill.

Taylor and Comsti (1984) examined fluid inclusions from the deposit, and concluded that deposition of quartz and scheelite occurred from a boiling fluid, whereas pyrite-arsenopyrite-gold mineralization is associated with liquid-rich inclusions with "filling temperatures" (i.e. vapour disappearance temperatures?) of 195-250°C. The later stibnite-antimonide -siderite mineralization is associated with inclusions which homogenize in the range 100 - 195°C. No salinity measurements were carried out, and the temperature of the boiling fluid was not determined. It is therefore difficult to be sure that magmatic fluid was involved in the mineralization.

Gulson et al. (1985) present the results of lead isotope analysis of 23 stibnites, which contain between 2 and 550 ppm Pb. So called "distal" deposits (low in Ag and Au) have a uniform 206/204 isotopic ratio of 18.48 to 18.53. "Proximal" deposits show a greater range. Part of this variation may arise owing to a different source for the lead in these deposits. The lead was thought to have been derived from continental crust and not the mantle.

4.8: THE DRAKE, RED-ROCK & LUNATIC GOLD-SILVER DEPOSITS

The Drake field occurs 560 Km NNE east of Sydney, and was discovered in 1886. There are numerous small deposits; the most productive being the Lady Jersey (530 Kg), Adeline (215 Kg) and Lady Hampden (62 Kg Au and 2,800 Ag). The fields of Red Rock and Lunatic occur 10 Km north of Drake (Fig. 4.8). Recent drilling has identifed the following reserves in the area:

DEPOSIT	TONNES ORE	Au (g/tonne)	Ag (g/tonne)
Strauss	587,000	3.0	-
Guy Bell	60,700	4.12	-
North Kylo	144,000	1.72	-
Lady Jersey	?	3.50	-
Lady Hampden	1,400,000	0.90	84.0
Silver King	300,000	0.20	144.0
White Rock	1,400,000	?	105.0
Red Rock	180,000	0.90	66.0

Much of the mineralization is hosted by Permian volcanics of the Drake Volcanics. At the Lady Hampden deposit ore is hosted by silicified

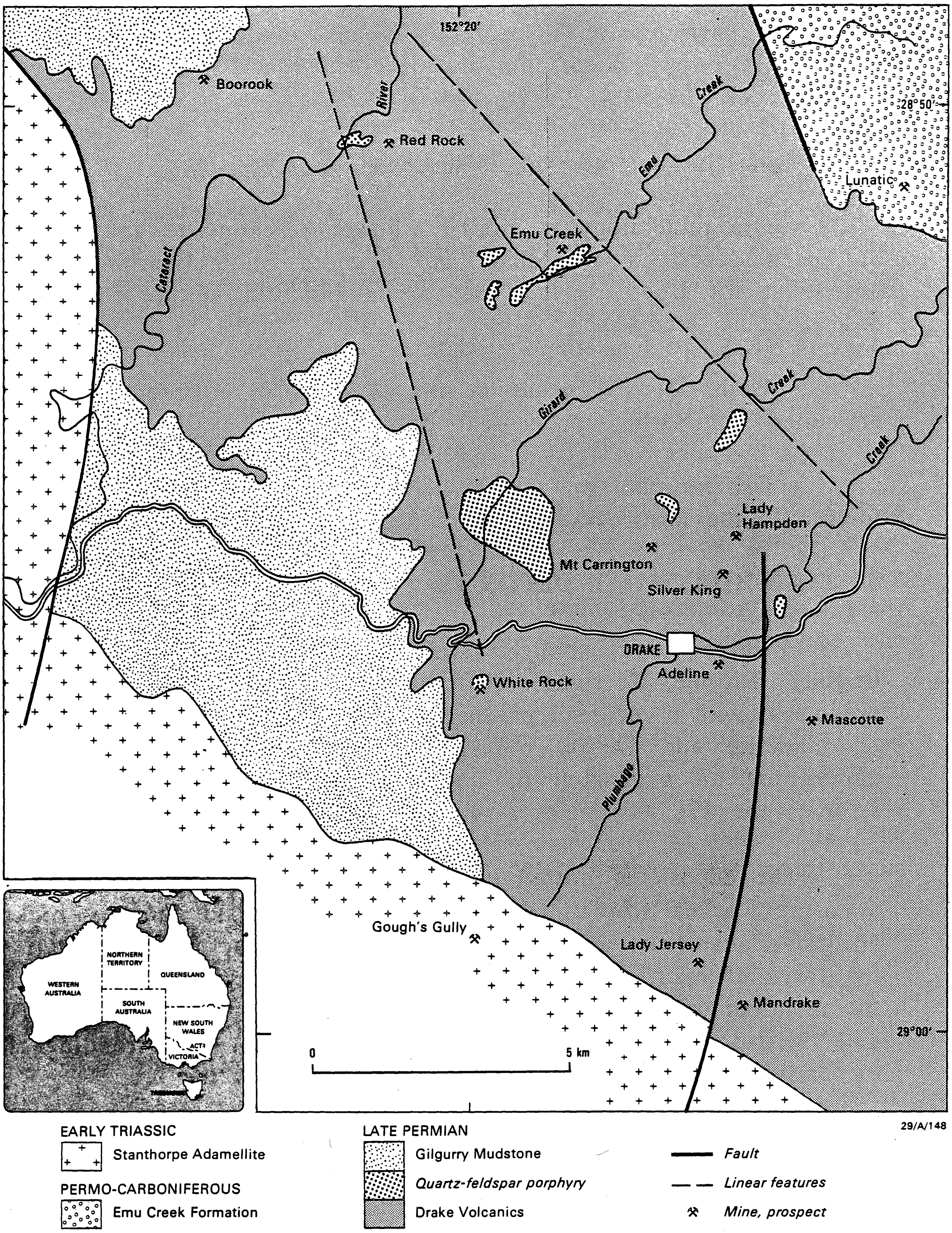


Fig. 4.8: Geology of the Drake mineral field (from Bottomer, 1986)

tuffs of basaltic to andesitic composition (Bottomer, 1986) although Herbert (1983) regards them as rhyolites. The deposit is actually primarily a silver deposit (see above) and silver occurs as pearcite, proustite, Ag-poor tennantite and native metal alloys. Pyrite is the main sulphide present (10 - 20%) with minor sphalerite, galena and chalcopyrite (<2%). No arseno-pyrite or pyrrhotite have been recorded. Bottomer (1986) has described two alteration types: early pervasive white-mica, microcrystalline quartz, kaolinite and pyrite overprinted by a quartz and adularia.

Silver King is similar to Lady Hampden, and mineralization here occurs with disseminated sulphide and as quartz-sulphide veinlets in pervasively altered zones. The highest silver grades are associated with quartz and K-feldspar alteration, which is enclosed in a more widespread white-mica clay zone.

White Rock consists of zones of stockwork veining in an altered intrusive rhyolite breccia. This breccia is intruded near the SE margin of a large body of massive porphyritic dacite, intrusive into andesitic lavas and tuffs (Bottomer, 1986). The veins are irregular and sinuous, 1 - 2 cm wide and exhibit crustiform layering (Herbert, 1983). Silver occurs as pearcite, Ag-rich tetrahedrite, native silver and minor suphides (Herbert, 1983, gives a full account of the mineralogy of the deposit). Alteration consists of kaolinite and montmorillonite with late carbonate. There is a strong correlatiojn between Ag, Pb and Zn.

Red Rock mineralization is disseminated and as vein stockworks in altered volcaniclastic rocks (Perkins, 1987). The ore assemblage is similar to the other deposits and includes acanthite and argentite. Two distinct alteration zones were identified by Perkins (1987): an outer propylitic zone (chlorite, illite, illite-montmorillonite, pyrite, calcite) and an inner illitic zone (illite, illite-montmorillonite, pyrite, adularia, calcite, chlorite, minor quartz sphene and base-metal sulphides). A metal zonation is evident with a central Ag, Au, Zn and Pb zone and peripheral Zn, Pb and Ag. Primary and pseudosecondary fluid inclusions are two- and three-phase (the latter containing CO_2). The former homogenize at 222 - 295°C and have a salinity of 0.5 - 7.0 wt% NaCl equiv. A depth of 800 m for ore-formation was estimated.

Sulphur isotope data for the deposits are presented by Herbert and Smith (1978), Andrew et al. (1985) and Perkins (1987). Andrew et al. (1985) concluded that the sulphur was magmatic in origin, possibly extracted from the local volcanic pile and Perkins (1987) also arrived at this conclusion.

DEPOSIT	$d^{34}S$ ‰
SULPHIDES	
WhiteRock/Lady Hampden	-14.3 - -1.9
All Nations/Lead Block	-7.0 - -2.5
Emu Creek	0.8
Red Rock	-10.0 - -1.0
Herbert and Smith (1978)	-29.5 - +2.4
SULPHATES	
Herbert and Smith (1978)	-3.3 - -13.0

Andrew et al. (1985) quote $d^{18}O$ ‰ data for quartz veins and void fillings from unspecified localities of 8.5 - 11.4 and Perkins (1987) presents data for quartzes of 7.1 - 9.7 ‰. Both authors conclude that seawater was a possible constituent of the ore-forming solutions.

Lead isotopic ratios of galena, sphalerite and pyrite are uniform, and different to those in the neighbouring granites and other stratigraphic units (Gulson et al., 1985). Three whole-rocks and K-feldspar samples of the Drake Volcanics define an array showing an apparent age of 1500 m.y, while local granites define an apparent age of 800 m.y., probably the average age of the source region (Gulson et al., 1985). The line for the volcanics passes through the sulphide line from Lady Hampden which suggests that the Pb in the Lady Hampden ore is derived from the Drake Volcanics and not the granites.

5. DISCUSSION & CONCLUSIONS

5.1: PREAMBLE

The gold deposits of Eastern Australia seem to bear out the old adage that "gold is where you find it". There are a number of different styles of mineralization which occur widely through out the Palaeozoic rocks of Eastern Australia, in a variety of host-rocks and were apparently deposited at different times in geological history. In this final section a tentative classification is proposed (excluding placer deposits).

Classification is handicapped by a rather severe lack of even rudimentary descriptive data for a large proportion of the several thousand gold mines and significant occurrences. It is proposed, however, to divide the deposits into three fundamental groups on the basis of whether magmatic, meteoric/seawater or metamorphic water was predominant during mineralization. Mineralization, may however involve two (or more) fluid types (*c.f.* Kidston), but it is considered that these categories provide useful "end-member" groups.

The basis for the classification is threefold: alteration mineral assemblages, fluid inclusion data and stable isotope data. The latter is somewhat ambiguous if viewed in isolation. Furthermore interpretation of the isotope data is hampered in many cases by the absence of representative data for the unaltered host-rocks (or indeed complete absence of any data whatsoever). It is becoming evident that the composition of vein quartz in many deposits is controlled to some extent by the isotopic composition of the host-rocks (Golding et al., 1987; R.T. Gregory, pers. comm., 1988).

The classification is as follows:

1. DEPOSITS INVOLVING MAGMATIC WATER AS A MAJOR COMPONENT.

1a: Porphyry gold-copper(-Mo) systems
1b: Diatreme-hosted deposits
1c: Skarn-hosted deposits

Magmatic fluid is here defined as fluid exsolved from a melt phase, or part of an immiscible melt-fluid system. Evidence for the participation of magmatic fluid consists of one or a combination of high temperature alteration minerals (e.g. K-feldspar and biotite, skarn-type assemblages), hypersaline fluid inclusions which homogenize above 400°C (Fig. 5.1) and isotopic data for the presence of fluid with a restricted range in $\delta^{18}O$ of ca. 9 ‰. Such high temperature hypersaline fluids may show evidence for boiling, or other forms of immiscibility.

2. DEPOSITS INVOLVING METEORIC OR SEAWATER AS A MAJOR COMPONENT

2a: Epithermal deposits (both terrestrial and submarine)
2b: Volcanogenic massive sulphides

Evidence for the participation of meteoric fluid includes one or a combination of low temperature alteration mineralogy (e.g. argillic), low salinity fluid inclusions which homogenize below 350°C and isotopic data for the presence of fluid with low $\delta^{18}O$ values. Inclusions may or may not indicate boiling. An association with volcanic rocks is nearly always apparent although the mineralization clearly post-dates extrusion. It may be linked to the presence of co-magmatic rocks, but there are few if any systematic radiogenic isotope studies aimed at demonstrating a link between mineralization and intrusives co-magmatic with the volcanic pile.

3. DEPOSITS INVOLVING METAMORPHIC WATER AS A MAJOR COMPONENT

3a: Post-peak deformation amagmatic vein deposits
3b: Occidental (Cobar) type deposits

Metamorphic fluid is here defined as fluid produced by prograde metamorphic devolatilization reactions. Evidence for the participation of metamorphic fluid consists of a combination of low salinity and CO_2-CH_4 -bearing fluid inclusions (*c.f.* Wall, 1987) which homogenize below 350°C and isotopic data for the presence of fluid with $\delta^{18}O$ in the range +4 - +25 ‰. Neither fluid inclusion nor isotopic data allows an unequivocal differentiation between metamorphic and meteoric fluid in some cases (Fig. 5.1) and geological setting is an important criterion (below).

This classification must be regarded as somewhat tentative, since many of the deposits lack detailed studies. It is recognized that some of these groups may overlap to some extent, e.g. porphyry systems may be gradational to epithermal systems in which there is no evidence for the influence of magmatic fluid (see below).

5.2: PORPHYRY GOLD-COPPER-Mo DEPOSITS

These deposits are spatially and temporally associated with dioritic to monzonitic plutons, which show alteration characteristic of porphyry copper deposits. Gold is accompanied by copper and is subordinate to it, and molybdenite may also be present (as at the Yeoval deposit for example). Possible examples are the Gidginbung and Peak Hill deposits which are situated close to the Goonumbla porphyry copper deposit (Jones, 1985). The postulated intrusive source of mineralization has not been identified at either of these deposits, and high temperature alteration mineralogies have not been observed. There are no fluid inclusion or isotopic data at all. The observed alteration assemblages could equally well be the product of a meteoric-dominant system such as the Rotokawa geothermal system in New Zealand (Krupp and Seward, 1987). This particular classification therefore requires research to establish the genesis of these important deposits.

5.3: SKARN-HOSTED DEPOSITS

Skarn-hosted gold deposits, which include Red Dome, Browns Creek, Little Cadia and Ironclad show unambiguous evidence for the presence of high temperature fluid of magmatic origin. The origin of gold mineralization itself is not so clear cut, but it seems probable that gold was introduced in the magmatic fluid, as it is believed to have been in porphyry copper systems (Trudu and Bloom, 1988). In fact it is worth noting that some of these cited deposits (not Red Dome) are spatially related to monzonitic to dioritic intrusives which show porphyry style alteration. Fluid inclusion data from the Red Dome deposit (Ewers and Sun, 1988) show the dominance of hypersaline (non-boiling) magmatic fluid, and virtual absence of meteoric water.

It therefore becomes important to establish the mechanisms of transport of Au and Cu (and Mo) in magmatic fluids. Given the chloride-rich nature of the brines chloro-complexes are obvious candidates, possibly including Na or K, but thermodynamic data is extremely limited, and experimental work is justified. A possible explanation for the Au-Cu association lies in the high temperature of the solutions (see also Huston and Large, 1988).

5.4: DIATREME-HOSTED DEPOSITS

Diatreme-hosted deposits are currently the most important single type of deposit, the most notable examples being the Kidston and Mt Leyshon deposits. The work of Baker and others has provided reasonable evdience that the fluids involved in the initial stages of ore-formation were magmatic in origin, hypersaline, periodically boiling and in excess of 500°C. Meteoric fluid, however, became more important during the latter stages of ore formation. Mineralization contains Mo and Bi although apparently not

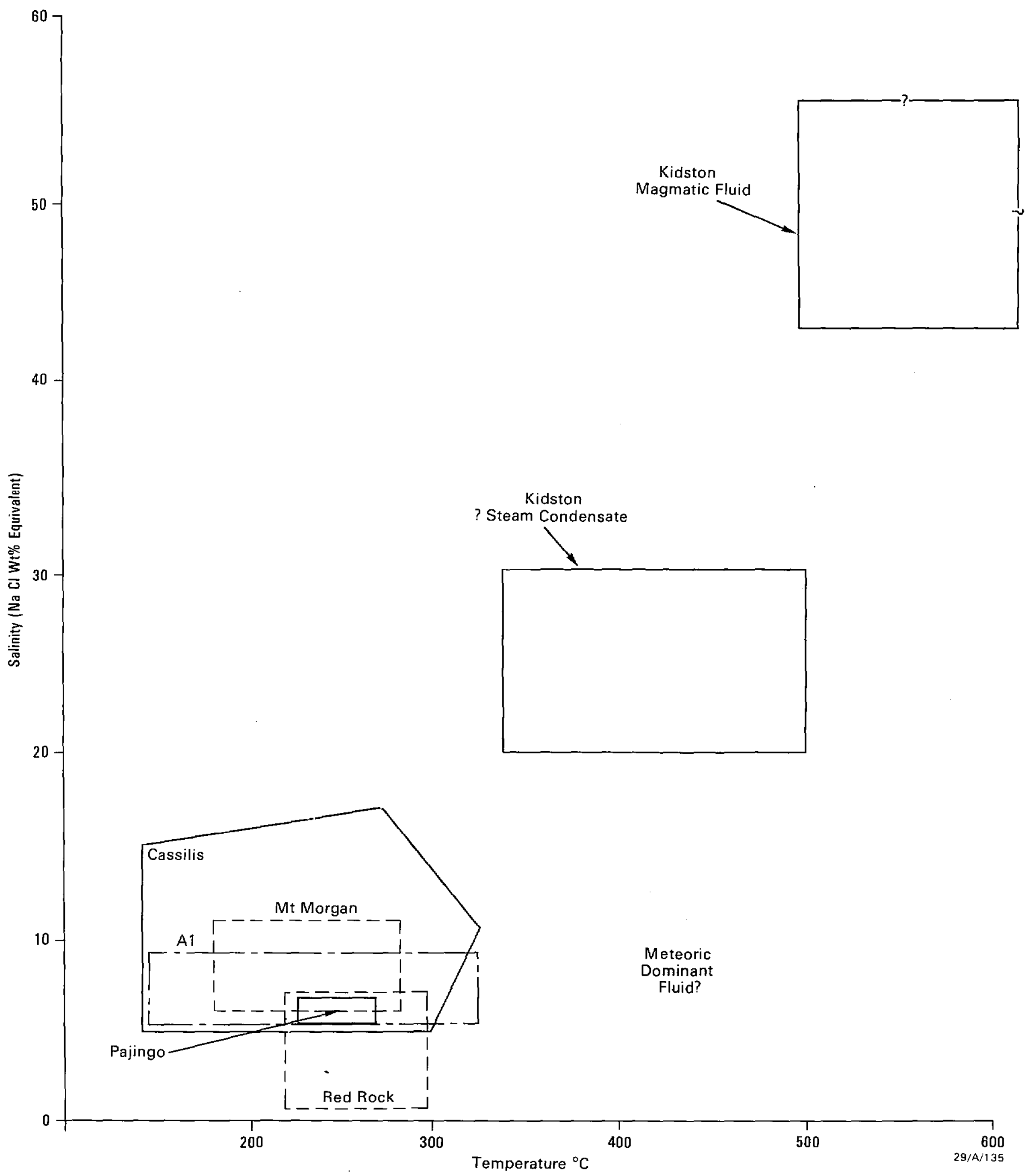


Fig. 5.1: Compilation of fluid inclusion data from sources given in text. Note the three fluid types so-defined.

much copper (chalcopyrite is present). Tellurides have also been noted.

The evidence for magmatic fluid plus the spatial (and probably temporal) association of mineralization with explosive volatile release from a magma, suggest the possiblity that gold was derived from magmatic fluids. Indeed sulphur isotope data suggests that sulphur in the ore was not derived from the local host-rocks.

5.5: EPITHERMAL SYSTEMS

Much has been written on epithermal deposits recently, particularly using modern geothermal systems as analogues of the fossil ore-forming systems. Here the term is defined as a deposit formed at < 1 km depth, from fluids up to 350°C, in volcanic rocks, probably as a result of hydrothermal movement produced by a co-magmatic intrusion. Numerous deposits of Eastern Australia can be so classified, and these include the Red Rock, Drake and Lunatic deposits, Pajingo, Yalwal-Panbula, possibly Mt. Coolon and Golden Plateau and numerous others. Most of these deposits are situated along the eastern coast and are virtually unknown in Victoria and western New South Wales. The deposits are hosted by volcanic rocks (lavas and pyroclastics) which range in composition from rhyolitic to andesitic. They are generally faulted (which provided access to the mineralizing solutions) but folding is rare. Most examples are Carboniferous or later, but the Yalwal-Panbula deposits may be Late Devonian (Taylor, in prep.). It seems probable that the deposits are related to intrusives (not identified at many of the deposits) co-magmatic with the host volcanic sequence, which acted as a heat source mobilizing essentially meteoric fluids or in the case of the Red Rock/Drake deposits, seawater.

Fluid inclusion data (Fig. 5.1) and isotopic data suggest that magmatic fluid is not an important component of the ore-forming solutions, implying that gold is carried by (modified) meteoric solutions (and/or seawater) and leached from the host-rocks. This is indeed suggested by lead isotope data. Unlike the magmatic solutions described above, it seems that these meteoric solutions could not carry significant Cu, but base-metals are commonly enriched as are Ag, As and Sb. An under- standing of the geochemistry of these elements in the ore-forming solutions would therefore shed light on genetic processes.

Further investigation of these deposits is required, particularly a radiometric study to link ore formation to volcanism. The presence of pyrophyllite in such deposits is not uncommon and zeolites also occur. The stability of these phases in the context of the inferred conditions of ore-formation is worthy of consideration. Taylor (pers. comm., 1988) considers that pyrophyllite is not a primary alteration phase but is the result of metamorphism of a pre-existing Al-rich alteration zone.

The presence of older gold accumulations of Siluro-Devonian age to the west in Victoria, raises the possibility that some epithermal gold mineralization is sourced in older ore-grade gold accumulations.

5.6: VOLCANOGENIC MASSIVE SULPHIDE SYSTEMS

Volcanogenic massive sulphide deposits have contributed a significant proportion of Eastern Australia's current and past gold production. Examples include: Mt Morgan, Mt Chalmers, Captain's Flat, Woodlawn and Hellyer and Que River (in Tasmania). As their origins are relatively well understood they will not be discussed in detail here, except to say that the geochemistry of gold transport and deposition in such systems is not well understood. Huston and Large (1988) have suggested that chloride complexes of gold are important and consequently chloride-rich, oxidized and acidic solutions are optimal for ore transport. Such solutions probably involve an originally quite oxidized fluid (e.g. seawater) which became acidic through wall-rock alteration (and derived its gold content by leaching it from its host-rocks). However, more constraints on the nature of the ore-forming solutions (e.g. oxidation state, sulphur content, gas content, cationic ratios, pH etc.) need to applied before a satisfactory geochemical model is developed.

5.7: AMAGMATIC POST-PEAK DEFORMATION VEIN DEPOSITS

This group of deposits is probably the least well-defined category considered here. Its characteristics are that ore occurs virtually throughout Eastern Australia in various host-rocks e.g. slates (Bendigo, Ballarat, Maldon, Castlemaine, Hill End, Hargraves, ?Gympie), in intermediate dykes (Woods Point - Walhalla, Gympie) in granitoids (numerous examples in New South Wales, particularly Adelong and Wyalong; possibly Charters Towers and Etheridge) in schists (Cassilis, Sebastopol) and in meta-volcanic rocks (Stawell, although much of the mineralization at Stawell is hosted by slate). Mineralization postdates peak deformation and is evidently not *directly* associated with any igneous intrusion (deposits in granitoids often show evdience for a considerable time-gap between intrusion and mineralization). In deposits with reasonable documentation of the structure mineralization is seen to occur in quartz veins in brittle or brittle-ductile high strain zones (reverse fault zones to mylonites). Quartz is post-dated to some extent by carbonates and sulphide assemblages are similar between deposits (although as mentioned previously, detailed studies are uncommon). In general the deposits are characterized by high antimony (in rare cases of economic proportions), arsenic (uneconomic) and low silver.

The main difference between individual examples of this group appears to be the different host-rock lithologies which may also account for slightly different base-metal contents, isotopic composition (Appendix 2) and sulphide abundances in the various lodes. Importantly the absolute age of mineralization is very poorly defined for most of the deposits cited above. Most are Mid to Late Devonian but some (e.g. Cassilis) could be Silurian (MacLennan, 1987). Radiometric dating of some of these deposits is justified.

Green et al. (1982) and MacLennan (1987) have proposed that magmatic fluid (source unspecified) is important in the genesis of the Cassilis and A1 deposits. A model which which envisages that the deposits hosted by slates (Castlemaine, Ballarat, Bendigo) formed in response to metamorphic dewatering of the Lower Palaeozoic sedimentary sequence has been proposed by Sandiford and Keays (1986) and Wall (1987): Metamorphic dehydration reactions which attended crustal thickening and burial of the Lower Palaeozoic sedimentary sequence during the Devonian Tabberabberan Orogeny, are thought to have provided a gold-enriched fluid. Sandiford and Keays (1986) have emphasized the role of large possibly listric faults, which may tap deep crustal levels during metamorphism and thus act as conduits during dewatering of the metamorphic pile. Wall (1987) suggests that reduction is important in ore deposition, and advocates a model whereby incoming fluid is reduced by graphite in the host-rocks and production of CH_4. Mixing of this fluid with newly arrived CO_2-rich gold-bearing fluid caused oxidation of gold bisulphide complexes.

Bain et al. (1988) relate the deposits of the Etheridge field, hosted by Proterozoic granitoids, to a period of batholithic intrusion during the Late Silurian to Mid Devonian and note that the deposits tend to occur at a greenschist-facies metamorphic front caused by fluid circulation initiated by granitioid intrusion. This model could be applied to deposits of in Victoria and New South Wales. It would be difficult to distinguish between fluid which was of meteoric origin and had interacted with the metamorphic pile at depth as the result of granitoid induced regional scale convective systems and metamorphic fluid sensu stricto.

5.8 OCCiDENTAL-TYPE DEPOSITS

These are structurally, isotopically and temporally similar to the previous category. Although mineralization does not occur in well-defined quartz lodes, they can be related to large scale circulation of fluid through the Lower Palaeozoic sequence during deformation (Solomon et al., 1988). in other words these deposits are considered to be a variant of the previous category, with the difference that these deposits probably formed *syn- to post-peak deformation.*

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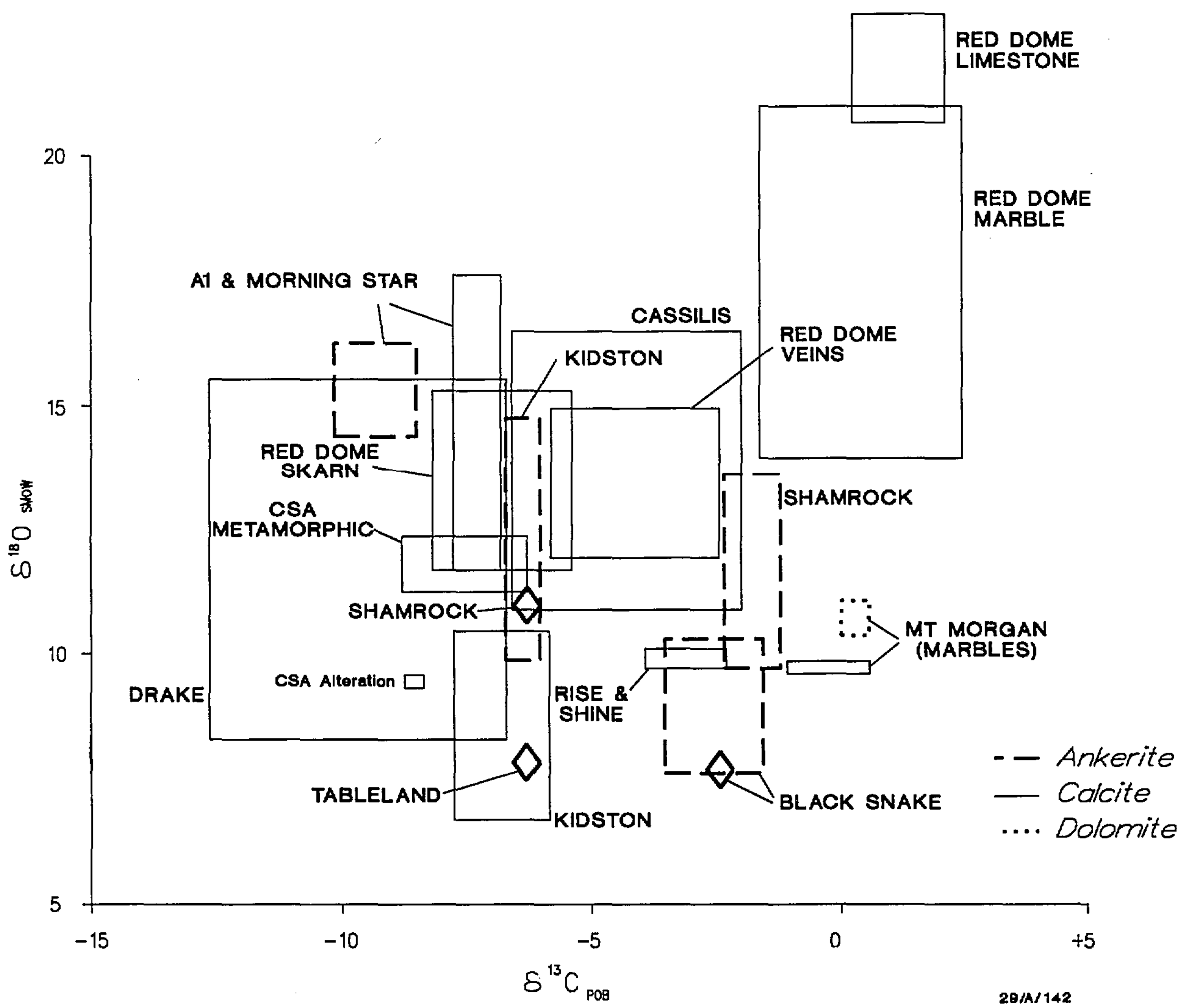
Appenidx. 2. Compilation of Stable Isotope Data



RED DOME LIMESTONE
RED DOME MARBLE
A1 & MORNING STAR
CASSILIS
RED DOME VEINS
KIDSTON
RED DOME SKARN
CSA METAMORPHIC
SHAMROCK
SHAMROCK
MT MORGAN (MARBLES)
CSA Alteration
DRAKE
RISE & SHINE
TABLELAND
KIDSTON
BLACK SNAKE
Ankerite
Calcite
Dolomite
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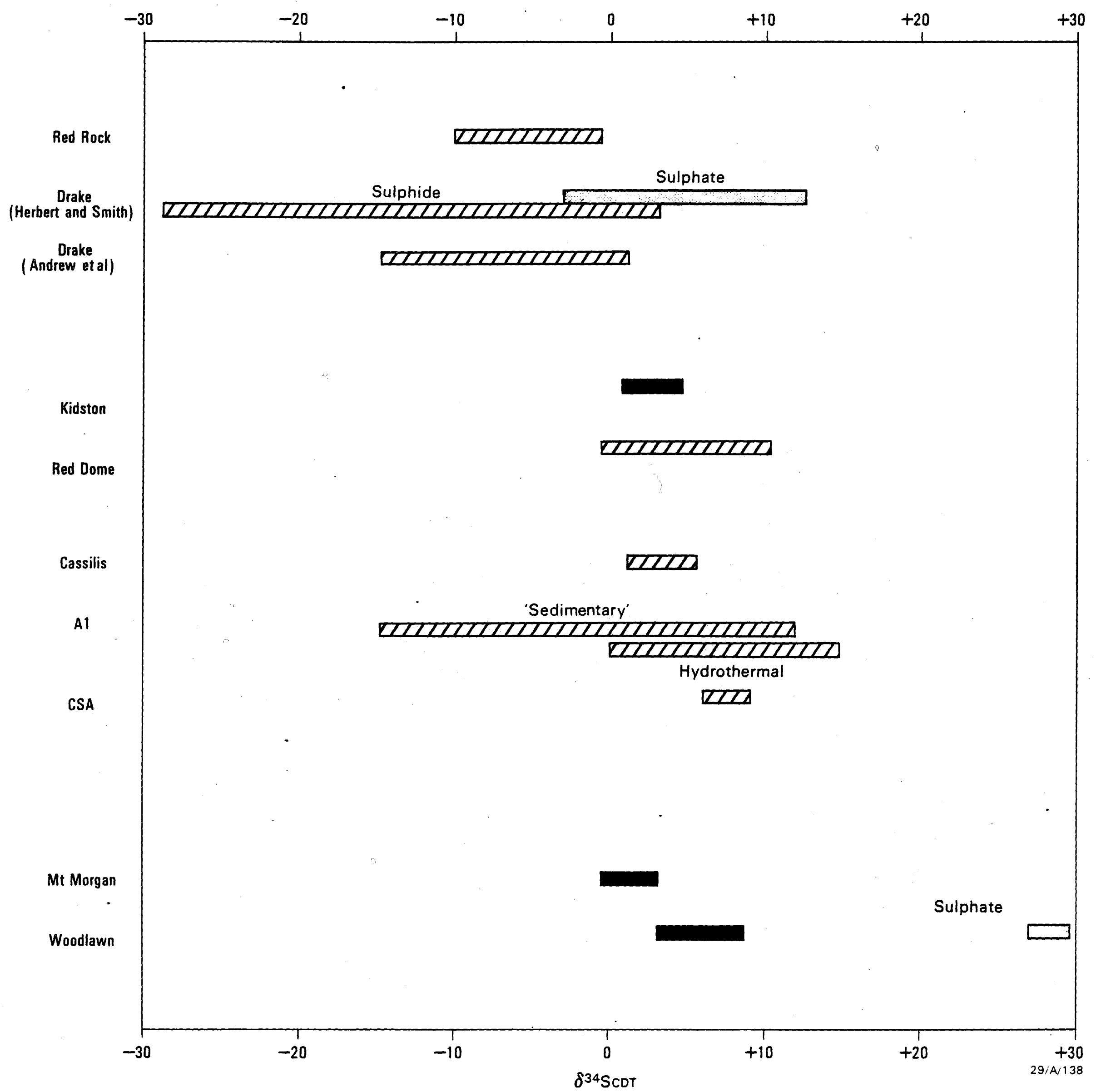
29/A/142



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Red Rock
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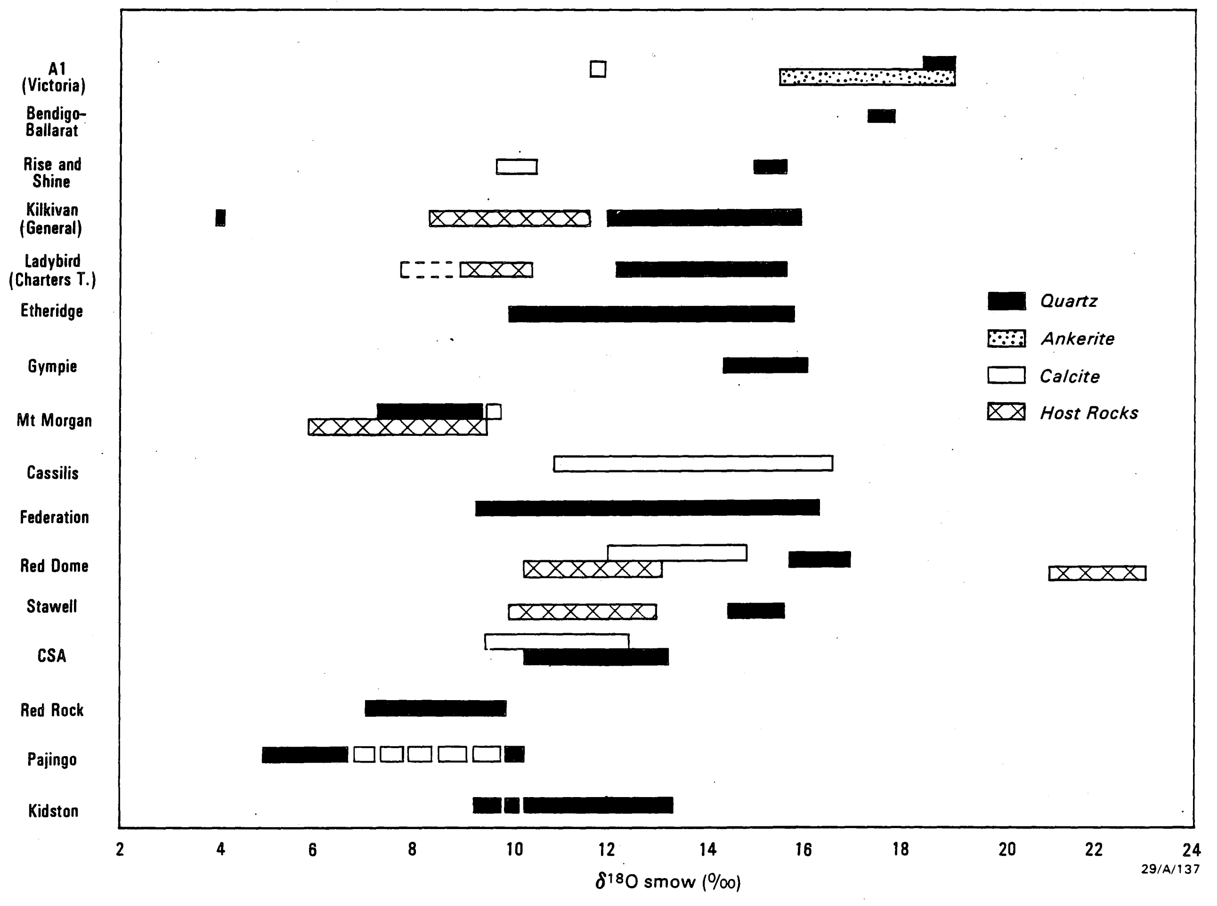
Sulphide
Sulphate
Drake
(Andrew et al)
Kidston
Red Dome
Cassilis
A1
'Sedimentary'
Hydrothermal
CSA
Mt Morgan
Woodlawn
Sulphate
$\delta^{34}S_{CDT}$
29/A/138


A1 (Victoria)
Bendigo-Ballarat
Rise and Shine
Kilkivan (General)
Ladybird (Charters T.)
Etheridge
Gympie
Mt Morgan
Cassilis
Federation
Red Dome
Stawell
CSA
Red Rock
Pajingo
Kidston
Quartz
Ankerite
Calcite
Host Rocks
2
4
6
8
10
12
14
16
18
20
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δ18O smow (‰)
29/A/137

PROVINCE	DEPOSIT	LOCATION	ROCK TYPE	MINERAL	d18O	d13C	d34S	dD	SOURCE	COMMENTS
Gympie	S. Ellen Harkins			quartz	16.0±0.1				Golding and Wilson (1981)	Three samples
Gympie	No 3 Pheonix			quartz	14.4±1.3				Golding and Wilson (1981)	Two samples
Gympie	London Extended			quartz	15.2				Golding and Wilson (1981)	
Gympie	Milton Extended			quartz	15.9				Golding and Wilson (1981)	
Gympie	No 7 and No 8 Monkland			quartz	15.0				Golding and Wilson (1981)	
Stawell	Stawell		Mine schist	whole-rock	13.0±0.8				Golding and Wilson (1981)	Six samples
Stawell	Stawell		Basalt	whole-rock	10.0±0.4				Golding and Wilson (1981)	Two samples
Stawell	Stawell		Quartzes	quartz	14.9±0.5				Golding and Wilson (1981)	Fifteen samples
Glenn Wills	Cassilis		Vein	pyrite			-1.75		MacLennan (1987)	
Glenn Wills	Cassilis		Vein	galena			-4.48		MacLennan (1987)	
Glenn Wills	Cassilis		Vein	sphalerite			-1.82		MacLennan (1987)	
Glenn Wills	Cassilis		Vein	pyrite			-1.60		MacLennan (1987)	
Glenn Wills	Cassilis		Vein	galena			-4.50		MacLennan (1987)	
Glenn Wills	Cassilis		Vein	sphalerite			-1.43		MacLennan (1987)	
Glenn Wills	Cassilis		Vein	pyrrhotite			-1.85		MacLennan (1987)	
Glenn Wills	Cassilis		Vein	calcite	14.3	-4.0			MacLennan (1987)	Calc. 18O water 7.6
Glenn Wills	Cassilis		Vein	calcite	10.9	-6.6			MacLennan (1987)	Calc. 18O water 4.2
Glenn Wills	Cassilis		Vein	calcite	16.6	-2.5			MacLennan (1987)	Calc. 18O water 9.9
Glenn Wills	Cassilis		Vein	calcite	13.4	-2.9			MacLennan (1987)	Calc. 18O water 6.7
Glenn Wills	Cassilis		Vein	calcite	12.4	-2.0			MacLennan (1987)	Calc. 18O water 5.7
Woods Point	A1 mine		Vein	ankerite	14.4	-9.6			Green et al. (1982)	
Woods Point	A1 mine		Vein	ankerite	15.7	-9.7			Green et al. (1982)	
Woods Point	A1 mine		Vein	ankerite	15.4	-9.0			Green et al. (1982)	
Woods Point	A1 mine		Vein	ankerite	14.3	-9.9			Green et al. (1982)	
Woods Point	A1 mine		Vein	ankerite	16.4	-8.5			Green et al. (1982)	
Woods Point	A1 mine		Vein	ankerite		-8.6			Green et al. (1982)	
Woods Point	A1 mine		Vein	quartz	18.5				Green et al. (1982)	
Woods Point	A1 mine		Vein	quartz	19.1				Green et al. (1982)	
Woods Point	A1 mine		Vein	quartz	18.6				Green et al. (1982)	
Woods Point	A1 mine		Vein	ankerite		-10.1			Green et al. (1982)	
Woods Point	A1 mine		Vein	ankerite	15.1	-9.7			Green et al. (1982)	
Woods Point	A1 mine		Wall-rock	ankerite	15.5	-9.0			Green et al. (1982)	
Woods Point	A1 mine		Vein	ankerite		-8.4			Green et al. (1982)	
Woods Point	A1 mine		Altered dyke	ankerite		-7.3			Green et al. (1982)	
Woods Point	A1 mine		Vug	calcite	11.7	-6.8			Green et al. (1982)	
Woods Point	A1 mine		Vug	calcite		-6.7			Green et al. (1982)	
Woods Point	Morning Star		Altered dyke	calcite	17.8	-7.5			Green et al. (1982)	
Drake	White Rock		Vein	calcite	9.4	-7.9			Herbert (1983)	Fluid 18O = 10.1 (151°C)
Drake	White Rock		Vein	siderite	-	-7.5			Herbert (1983)	Fluid 18O = 8.3 (?°C)
Drake	White Rock		Vein	calcite	9.6	-8.8			Herbert (1983)	Fluid 18O = 8.9 (169°C)
Drake	Border Chief	K-tunnel	Vein	calcite	10.1	-12.2			Herbert (1983)	Fluid 18O = 11.1 (138°C)
Drake	Red Rock		Vein	calcite	10.4	-9.6			Herbert (1983)	Fluid 18O = 7.3 (200°C)
Drake	Adeline		Vein	calcite	8.3	-6.8			Herbert (1983)	Fluid 18O = 10.2 (148°C)
Drake	Lady Hampden		Vein	calcite	15.4	-13.9			Herbert (1983)	Fluid 18O = 9.9 (154°C)
Drake	Silver King		Vein	calcite	15.5	-14.0			Herbert (1983)	Fluid 18O = 10.1 (152°C)
Drake	Mascotte		Vein	calcite	15.6	-12.6			Herbert (1983)	Fluid 18O = 12.9 (117°C)
Drake	Lunatic	gold lodes	Vein	calcite	6.5	-6.7			Herbert (1983)	
Drake	Lunatic	stibnite lodes	Vein	calcite	7.9	-6.8			Herbert (1983)	
Gympie	Rise and Shine		Greenstone	whole-rock	8.0				Golding et al. (1987)	
Gympie	Rise and Shine		Greenstone	whole-rock	7.0				Golding et al. (1987)	
Gympie	Rise and Shine		Greenstone	whole-rock	9.6				Golding et al. (1987)	

PROVINCE	DEPOSIT	LOCATION	ROCK TYPE	MINERAL	d18O	d13C	d34S	dD	SOURCE	COMMENTS
Gympie	Shamrock		Porphyry	whole-rock	8.6				Golding et al. (1987)	
Gympie	Shamrock		?	chlorite	5.4				Golding et al. (1987)	
Gympie	Shamrock		Porphyry	whole-rock	9.0				Golding et al. (1987)	
Gympie	Shamrock		Porphyry	whole-rock	8.8				Golding et al. (1987)	
Gympie	Shamrock		Porphyry	whole-rock	9.4				Golding et al. (1987)	
Gympie	Shamrock		Porphyry	whole-rock	10.0				Golding et al. (1987)	
Gympie	Shamrock		Porphyry	whole-rock	11.2				Golding et al. (1987)	
Gympie	Shamrock		Porphyry	whole-rock	10.7				Golding et al. (1987)	
"Kidston"	Cumberland		Vein	quartz	15.7				Golding et al. (1987)	
"Kidston"	International		Vein	quartz	15.4				Golding et al. (1987)	
"Kidston"	Spero Meliora		Vein	quartz	15.7				Golding et al. (1987)	
"Kidston"	Dairymaid		Vein	quartz	15.5				Golding et al. (1987)	
"Kidston"	Havelock		Vein	quartz	10.8				Golding et al. (1987)	
"Kidston"	Jubilee Plunger		Vein	quartz	14.1 - 15.5				Golding et al. (1987)	
"Kidston"	Dividend Gully		Vein	quartz	15.5				Golding et al. (1987)	
"Kidston"	Knights of Malta		Vein	quartz	13.9				Golding et al. (1987)	
"Kidston"	New Zealand		Vein	quartz	14.0				Golding et al. (1987)	
"Kidston"	Kidston			quartz	9.4 - 9.8				Andrew and Baker, (1987)	Pre-brecciation
"Kidston"	Kidston			quartz	10.3 - 10.5				Andrew and Baker, (1987)	Early post brecciation
"Kidston"	Kidston			epidote				-51 - -57	Andrew and Baker, (1987)	Early post brecciation
"Kidston"	Kidston			K-spar	10.8				Andrew and Baker, (1987)	Early post brecciation
"Kidston"	Kidston			chlorite				-80 - -87	Andrew and Baker, (1987)	Early post brecciation
"Kidston"	Kidston			calcite	11.3-13.6				Andrew and Baker, (1987)	Early post brecciation
"Kidston"	Kidston			mica				-68 - -71	Andrew and Baker, (1987)	Early post brecciation
"Kidston"	Kidston			calcite	6.7 - 11.5	-7.8 - -5.9			Andrew and Baker, (1987)	Late post brecciation
"Kidston"	Kidston			ankerite	9.8 - 14.8	-6.7 - -6.0			Andrew and Baker, (1987)	Late post brecciation
"Kidston"	Kidston			pyrite			2.6 - 4.2		Andrew and Baker, (1987)	
"Kidston"	Kidston			sphalerite			2.4 - 2.9		Andrew and Baker, (1987)	
"Kidston"	Kidston			galena			1.1		Andrew and Baker, (1987)	
"Kidston"	Kidston			pyrrhotite			2.2 - 2.3		Andrew and Baker, (1987)	
Chillagoe	Red Dome			pyrite			-1.43		Ewers and Sun (1988)	
Chillagoe	Red Dome			pyrite			-0.95		Ewers and Sun (1988)	
Chillagoe	Red Dome			pyrite			-3.14		Ewers and Sun (1988)	
Chillagoe	Red Dome			pyrite			-0.35		Ewers and Sun (1988)	
Chillagoe	Red Dome			pyrite			7.16		Ewers and Sun (1988)	
Chillagoe	Red Dome			pyrite			12.25		Ewers and Sun (1988)	
Chillagoe	Red Dome			pyrite			2.07		Ewers and Sun (1988)	
Chillagoe	Red Dome			pyrite			1.68		Ewers and Sun (1988)	
Chillagoe	Red Dome			pyrite			2.84		Ewers and Sun (1988)	
Chillagoe	Red Dome			pyrite			-0.96		Ewers and Sun (1988)	
Chillagoe	Red Dome			pyrrhotite			1.55		Ewers and Sun (1988)	
Chillagoe	Red Dome			pyrrhotite			-2.88		Ewers and Sun (1988)	
Chillagoe	Red Dome			pyrrhotite			2.1		Ewers and Sun (1988)	
Chillagoe	Red Dome		limestone	whole-rock	1.2	22.2	2.3		Ewers and Sun (1988)	
Chillagoe	Red Dome		marble	whole-rock	0.54	17.0			Ewers and Sun (1988)	
Chillagoe	Red Dome		skarn	whole-rock	-3.1	13.5			Ewers and Sun (1988)	
Chillagoe	Red Dome		skarn (stage 1)	whole-rock	-7.4	13.5			Ewers and Sun (1988)	
Chillagoe	Red Dome		skarn (stage 2)	whole-rock	-6.7	13.7			Ewers and Sun (1988)	
Chillagoe	Red Dome			calcite	-3.4	12.7			Ewers and Sun (1988)	
Chillagoe	Red Dome			calcite	-7.4	13.4			Ewers and Sun (1988)	
Chillagoe	Red Dome			calcite	-6.7	14.0			Ewers and Sun (1988)	

PROVINCE	DEPOSIT	LOCATION	ROCK TYPE	MINERAL	d18O	d13C	d34S	dD	SOURCE	COMMENTS
Gympie	Rise and Shine		Vein	calcite	9.7	-2.5			Golding et al. (1987)	
Gympie	Rise and Shine		Greenstone	whole-rock	12.6				Golding et al. (1987)	
Gympie	Rise and Shine		Greenstone	whole-rock	6.3				Golding et al. (1987)	
Gympie	Rise and Shine		Greenstone	whole-rock	8.7				Golding et al. (1987)	
Gympie	Rise and Shine		Vein	quartz	15.3				Golding et al. (1987)	
Gympie	Rise and Shine		Vein	calcite	10.1	-2.3			Golding et al. (1987)	
Gympie	Rise and Shine		Vein	quartz	15.0				Golding et al. (1987)	
Gympie	Rise and Shine		Vein	calcite	14.7	-3.9			Golding et al. (1987)	
Gympie	Rise and Shine		Vein	quartz	15.3				Golding et al. (1987)	
Gympie	Rise and Shine		Vein	quartz	15.0				Golding et al. (1987)	
Gympie	Rise and Shine		Vein	quartz	15.6				Golding et al. (1987)	
Gympie	Rise and Shine		Vein	quartz	15.1				Golding et al. (1987)	
Gympie	Rise and Shine		Vein	quartz	9.8				Golding et al. (1987)	
Gympie	Rise and Shine		Greenstone	calcite?	10.5	-2.4			Golding et al. (1987)	
Gympie	Rise and Shine		Vein	calcite	9.8	-2.5			Golding et al. (1987)	
Gympie	Tableland		Vein	calcite	8.1	-6.5			Golding et al. (1987)	
Gympie	Tableland		Vein	quartz	15.6				Golding et al. (1987)	
Gympie	Commercial		Vein	quartz	15.9				Golding et al. (1987)	
Gympie	New Zealand		Vein	quartz	12.1				Golding et al. (1987)	
Gympie	Mariners		Vein	quartz	13.7				Golding et al. (1987)	
Gympie	Homeward Bound		Vein	quartz	12.6				Golding et al. (1987)	
Gympie	Black Snake		Vein	quartz	13.2				Golding et al. (1987)	
Gympie	Black Snake		Vein	ankerite	10.8	-3.5			Golding et al. (1987)	
Gympie	Black Snake		Vein	ankerite	7.7	-3.5			Golding et al. (1987)	
Gympie	Black Snake		Vein	ankerite	9.2	-1.7			Golding et al. (1987)	
Gympie	Black Snake		Vein	calcite	7.8	-2.6			Golding et al. (1987)	
Gympie	Black Snake		Porphyry	whole-rock	8.5				Golding et al. (1987)	
Gympie	Black Snake		Porphyry	whole-rock	9.3				Golding et al. (1987)	
Gympie	West Black Snake		Vein		13.1				Golding et al. (1987)	
Gympie	Victoria				4.1				Golding et al. (1987)	
Gympie	NW of Victoria		Porphyry	plagioclase	8.3				Golding et al. (1987)	
Gympie	NW of Victoria		Vein?	biotite	4.5				Golding et al. (1987)	
Gympie	Shamrock		Vein	orthoclase	11.1				Golding et al. (1987)	
Gympie	Shamrock		Vein	chlorite	5.2				Golding et al. (1987)	
Gympie	Shamrock		Vein	chlorite	4.7				Golding et al. (1987)	
Gympie	Shamrock		Vein	calcite	11.1	-6.4			Golding et al. (1987)	
Gympie	Shamrock		Vein	ankerite	12.0	-2.0			Golding et al. (1987)	
Gympie	Shamrock		Vein	ankerite	13.7	-1.6			Golding et al. (1987)	
Gympie	Shamrock		Vein	ankerite	10.7	-1.3			Golding et al. (1987)	
Gympie	Shamrock		Vein	ankerite	10.1	-1.2			Golding et al. (1987)	
Gympie	Shamrock		Vein	ankerite	9.7	-2.3			Golding et al. (1987)	
Gympie	Shamrock		Porphyry	whole-rock	8.5				Golding et al. (1987)	
Gympie	Shamrock		?	"sericite"	10.6				Golding et al. (1987)	
Gympie	Shamrock		Porphyry	whole-rock	9.3				Golding et al. (1987)	
Gympie	Shamrock		Porphyry	whole-rock	10.1				Golding et al. (1987)	
Gympie	Shamrock		Porphyry	whole-rock	11.0				Golding et al. (1987)	
Gympie	Shamrock		Porphyry	whole-rock	11.6				Golding et al. (1987)	
Gympie	Shamrock		Porphyry	whole-rock	11.0				Golding et al. (1987)	
Gympie	Shamrock		Porphyry	whole-rock	8.0				Golding et al. (1987)	
Gympie	Shamrock		Porphyry	whole-rock	9.4				Golding et al. (1987)	
Gympie	Shamrock		Vein	?quartz	9.7				Golding et al. (1987)	

PROVINCE	DEPOSIT	LOCATION	ROCK TYPE	MINERAL	d18O	d13C	d34S	dD	SOURCE	COMMENTS
Charters Towers	Ladybird	"north of Ladybird"	Granodiorite	whole-rock	7.5				Golding and Wilson (1981)	
Charters Towers	Ladybird	Ladybird dump	Granodiorite	whole-rock	7.8				Golding and Wilson (1981)	
Charters Towers	Old Imperial	Old Imperial dump	Altered granodiorite	whole-rock	8.7				Golding and Wilson (1981)	
Charters Towers	Ladybird	Ladybird (48m)	Altered granodiorite	whole-rock	8.8				Golding and Wilson (1981)	
Charters Towers	Ladybird	Ladybird (36m)	Altered granodiorite	whole-rock	10.4				Golding and Wilson (1981)	Described as "formation"
Charters Towers	Ladybird	Ladybird (48m)	Altered granodiorite	whole-rock	10.5				Golding and Wilson (1981)	Described as "formation"
Charters Towers	Ladybird	Ladybird (48m)	"Quartz lode"	whole-rock	13.7				Golding and Wilson (1981)	
Charters Towers	Ladybird	Ladybird (36m)	"Quartz lode"	whole-rock	13.8				Golding and Wilson (1981)	
Charters Towers	Ladybird	Ladybird (36m)	"Quartz lode"	whole-rock	14.2				Golding and Wilson (1981)	
Charters Towers	Brilliant Deep	Brilliant Deep (878m)	"Quartz lode"	whole-rock	12.2				Golding and Wilson (1981)	
Charters Towers	Mills United	Mills United (588m)	"Quartz lode"	whole-rock	13.6				Golding and Wilson (1981)	
Charters Towers	Queen Leases	Queen Leases (146m)	"Quartz lode"	whole-rock	15.3				Golding and Wilson (1981)	
Charters Towers	Queen Leases	Queen Leases (153m)	"Quartz lode"	whole-rock	15.6				Golding and Wilson (1981)	
Charters Towers	Caledonia P.C.	Caledonia P.C. (111m)	"Quartz lode"	whole-rock	15.7				Golding and Wilson (1981)	
Charters Towers	Millicans Caledonia	Millicans Caledonia	"Quartz lode"	whole-rock	14.7				Golding and Wilson (1981)	
Charters Towers	Day Dawn	Day Dawn #4AW (146m)	"Quartz lode"	whole-rock	14.4				Golding and Wilson (1981)	
Charters Towers	Day Dawn	Day Dawn #4AW (146m)	"Quartz lode"	whole-rock	15.0				Golding and Wilson (1981)	
Charters Towers	Lady Maria	Lady Maria (107m)	"Quartz lode"	whole-rock	14.5				Golding and Wilson (1981)	
Charters Towers	Rainbow P.C.	Rainbow P.C. (238m)	"Quartz lode"	whole-rock	14.7				Golding and Wilson (1981)	
Charters Towers	Rainbow #1	Rainbow #1 (61m)	"Quartz lode"	whole-rock	14.7				Golding and Wilson (1981)	
Charters Towers	Mary P.C.	Mary P.C. (40m)	"Quartz lode"	whole-rock	15.0				Golding and Wilson (1981)	
Charters Towers	Iron Duke	Iron Duke	"Quartz lode"	whole-rock	14.3				Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan		Jasper	whole-rock	7.6				Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan		Quartz porphyry	whole-rock	9.5				Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan		Altered chert	whole-rock	9.4				Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan		Pyritic chert	whole-rock	9.4				Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan		Altered chert	whole-rock	9.3				Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan		Chert	whole-rock	8.6				Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan		Altered porphyry	whole-rock	8.8				Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan		Limestone	whole-rock	8.9±0.5	0.3±0.3			Golding and Wilson (1981)	Average of 9 samples.
Cracow-Mt Morgan	Mount Morgan		Limestone	calcite	9.8	0.6			Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan		Limestone	dolomite	10.4	1.1			Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan		Limestone	calcite	9.6	-1.1			Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan		Limestone	dolomite	11.1	0.6			Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan		Limestone	dolomite	10.4	0.1			Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan		Qtz. feld. porphyry	whole-rock	6.8				Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan		Latite	whole-rock	7.0				Golding and Wilson (1981)	Early dykes
Cracow-Mt Morgan	Mount Morgan		Latite	whole-rock	7.9				Golding and Wilson (1981)	Early dykes
Cracow-Mt Morgan	Mount Morgan		Tonalite	whole-rock	6.6				Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan		Porphyrite	whole-rock	5.7				Golding and Wilson (1981)	Late dykes
Cracow-Mt Morgan	Mount Morgan		?	whole-rock	6.4				Golding and Wilson (1981)	Late dykes
Cracow-Mt Morgan	Mount Morgan	Orebody	Gossan	?	1.1				Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan	Orebody	Sphalerite ore	quartz	9.3				Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan	Orebody	Banded ore	quartz	8.8				Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan	Orebody	Breccia ore	quartz	8.3				Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan	Orebody	Breccia ore	quartz	9.4				Golding and Wilson (1981)	
Cracow-Mt Morgan	Mount Morgan	Orebody	Jasper ore	quartz	8.8				Golding and Wilson (1981)	
Cracow-Mt Morgan	Sugarloaf	Orebody	Siliceous ore	quartz	8.1				Golding and Wilson (1981)	
Cracow-Mt Morgan	Sugarloaf	Orebody	Siliceous ore	quartz	7.4				Golding and Wilson (1981)	
Cracow-Mt Morgan	Sugarloaf	Orebody	Siliceous ore	quartz	7.6				Golding and Wilson (1981)	
Gympie	Great Eastern			quartz	15.8±1.0				Golding and Wilson (1981)	Three samples