Mineralogy and stable isotope geochemistry of the Beaconsfield, Salisbury and Lefroy goldfields

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ABSTRACT

The quartz veins of the Tasmania Reef at Beaconsfield consist of auriferous microcrystalline quartz with a central core of ankerite. Sulphides are distributed throughout the two to six metre wide reef, which has grades ranging from 14 g/t to 38 g/t Au. The host rock is the Ordovician Cabbage Tree Formation (quartzose sandstone and minor conglomerate).

The quartz veins at Lefroy usually contain less than 3 g/t Au. The host rock at Lefroy consists of Ordovician Mathinna Group (Powell and Baillie, in press) lutite.

Thin-section slides indicate eight phases of vein development of the Tasmania Reef. Most of these phases have been preceded by a period of brecciation. Quartz and pyrite developing phases precede, or are simultaneous with, two gold depositing phases and are followed by chalcopyrite-sphalerite-galena-ankerite veins, annealing quartz veins, and finally 'vuggy' ankerite veins.

Beaconsfield gold has an average fineness of 934 and Lefroy gold has an average fineness of 972. Both the high fineness values and the narrow finess range indicate that these deposits are hypothermal. Arsenopyrite geothermometry indicates that the temperature of formation was between 370°C and 440°C. The $\partial^{34}S$ of pyrite ranges from +7 to +24.7 ‰ and the average $\partial^{18}O$ values of the reef quartz is 17.9 ± 0.8 ‰.

The Beaconsfield and Lefroy reefs are the result of precipitation from deep-seated fluids ascending through faults associated with the Devonian Tamar Fracture System.

INTRODUCTION

The Beaconsfield / Salisbury goldfield consists of a number of prospects and small mines, and the Ophir deep lead. The only important mine was the Tasmania Mine, which produced 26.6 t Au from 1.04×10^6 t ore between 1877 and 1914, corresponding to an average grade of 24.7 g/t Au. The reef was mined to a depth of 450 metres. Water and stability problems in the porous host rock were the main factors contributing to closure of the mine. The 1987 annual report of ACM–Beaconsfield Gold lists ore reserves to be 0.7×10^6 t ore at an average grade of 24 g/t Au. The Beaconsfield gold mine prospect is at present dewatered to a depth of 154 m below surface collar. The Lefroy goldfield produced only 5.2 t Au from scattered mines.

This paper presents the geological setting, mineralogy, fineness of the gold, and stable isotope geochemistry of the two goldfields, as examples of hypothermal ore formation derived from fluids of metamorphic origin.

Since the publication of the Geological Survey Exploratory Report of the Beaconsfield 1:63 360 geological map (Gee and Legge, 1974), detailed information has been accumulated based on drill-hole data interpreted by Allstate Tricentrol, Austamax, Renison Goldfields Consolidated, and Australian Consolidated Minerals / Beaconsfield Gold. Our study is based on core samples from diamond-drill holes A4, B4, B9, B10, B11, B12, B13, B14, B15, B16, B17, S1, S2, S4, S5 and museum specimens, and summarises parts of the manuscript of the Ph.D. thesis of D. W. Russell.

GEOLOGICAL SETTING

INTRODUCTION

The Beaconsfield / Salisbury and Lefroy goldfields are situated in Ordovician sediments on opposite sides of the Tamar Fracture System (fig. 1).

West of the River Tamar

The Precambrian basement consists of quartzite and phyllite which are unconformably overlain by a Cambrian suite of chert, slate and greywacke. A northerly-trending body of serpentinite, pyroxenite and gabbro crops out four kilometres to the west of Beaconsfield. The Cambrian succession is conformably overlain by an Ordovician rudite-arenite association, the Cabbage Tree Formation, which in turn is overlain by the Ordovician Gordon Limestone correlate, a massive grey-blue limestone with some silty intervals. Permian siltstone, sandstone and shale crop out to the east of Beaconsfield, and unconformably overlie the Ordovician rocks.

The Cabbage Tree Formation, which consists of quartzose sandstone and minor conglomerate, is up to 280 m thick and acts as a host for the auriferous reef (fig. 2). In places, the base of the formation is a fine-grained, black pyritic and

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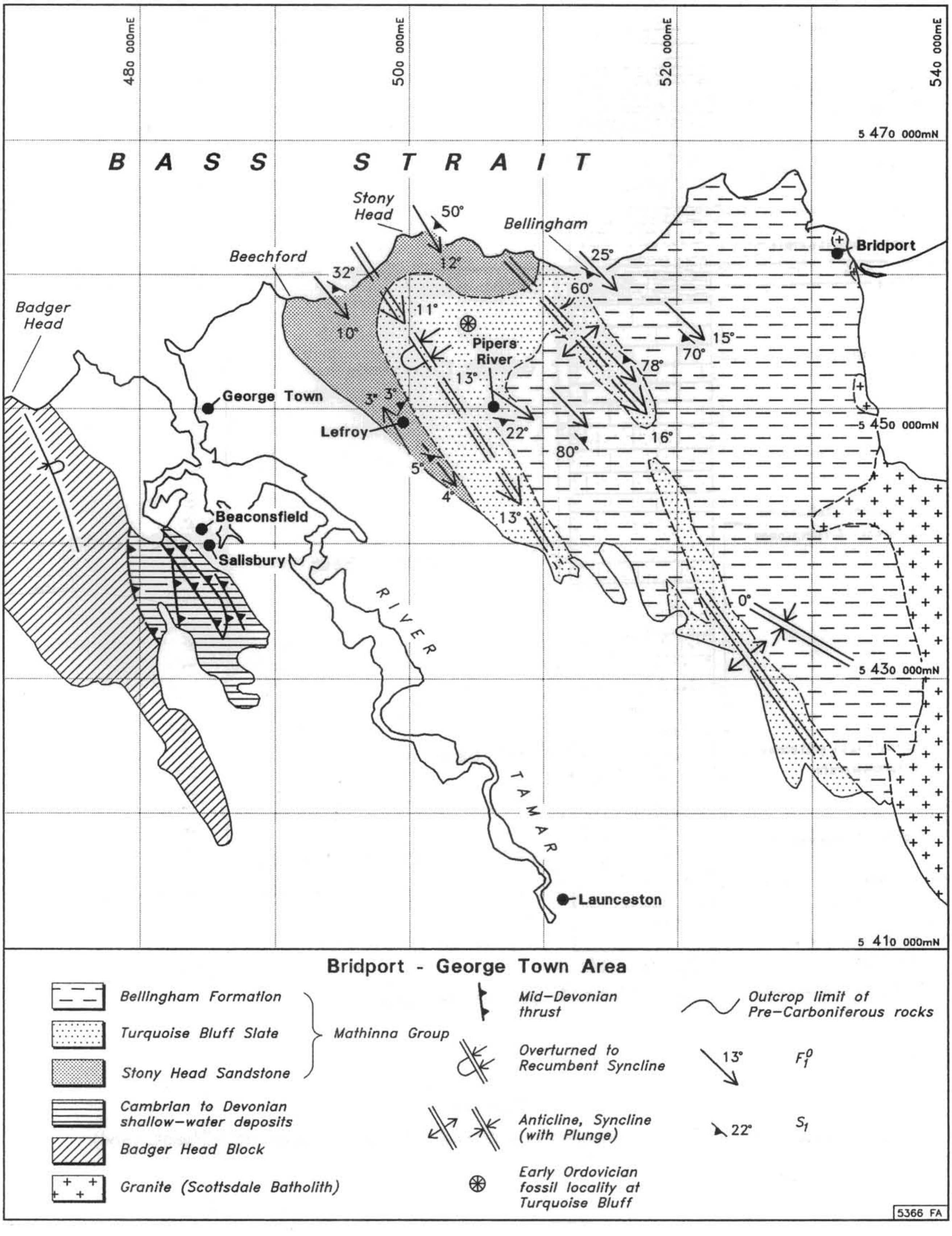

Figure 1

Location map of the Beaconsfield, Salisbury and Lefroy areas (after Powell and Baillie, in press).

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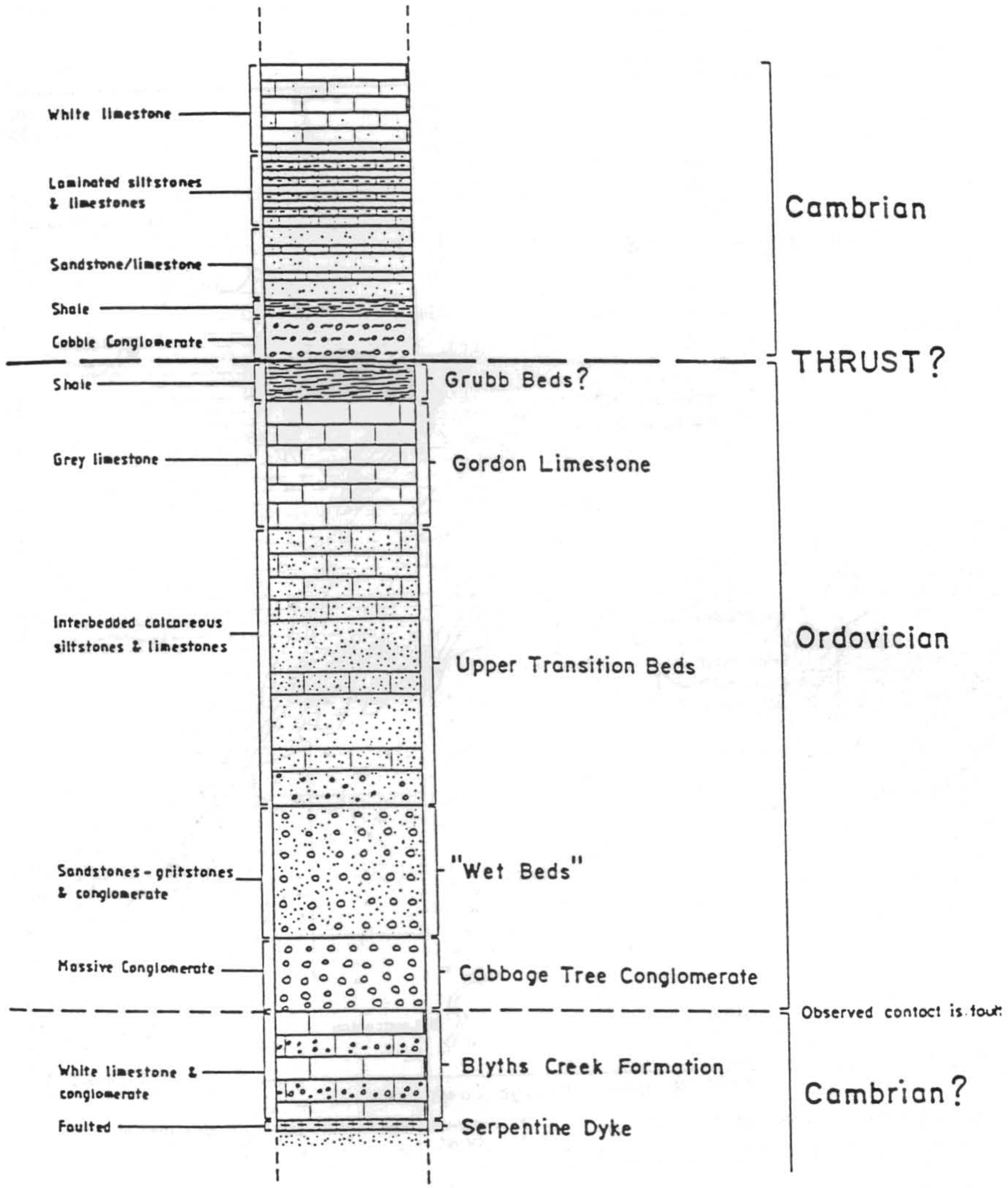

Figure 2

Stratigraphic section of the Beaconsfield area relating to the mineralisation (after Pease, 1984).

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siliceous mudstone which is strongly sheared. The next 30 m consist of medium-bedded, hard, black, well-cemented siliceous sandstone, alternating with thin beds of quartz conglomerate often containing chromite grains. Within the next 30 m, conglomeratic zones (with medium to coarse quartz and chert pebbles) become more abundant. Approximately 60 m above the base the gritty lenses become less frequent, the predominant rock type being a 'flaggy' cross-bedded, medium to fine-grained sandstone. The uppermost 200 m of the formation consists of well-bedded micaceous quartz sandstone and buff-coloured siltstone.

The major structure of the Beaconsfield and Salisbury areas is a Lower Palaeozoic fold belt of alternate slices of east-dipping Ordovician and Cambrian rocks. Various authors (Gee and Legge, 1974; Green, 1959) interpret this as an imbricate pile thrust against the stable Precambrian rocks of the Asbestos Range (6 km west of Beaconsfield). The tectonic event associated with this structure is thought to be the pre-late Middle Devonian Tabberabberan Orogeny. A series of post-thrust NE-trending faults have controlled the gold mineralisation in the area.

East of the River Tamar

The River Tamar valley is a graben controlled by faults with a northwest strike. To the east, the Mathinna Group forms the basement of northeast Tasmania, where it consists locally of argillaceous lutites of Ordovician age which are, unlike the Cabbage Tree Formation, deposits of turbidity currents.

The major trend of the regional folding is NW-SE, which parallels the trend on the western side of the River Tamar; folding occurred during the Tabberabberan Orogeny.

Other than the graben structures, the regional faulting pattern is not clear. Powell and Baillie (in press) assume that the mid-Devonian imbricate thrust near Beaconsfield is either the frontal thrust or a splay off the sole thrust which continues beneath the exposed Precambrian basement. Local minor faulting of the Mathinna Group sediments in the Lefroy Goldfield has been identified.

MINE SEQUENCES

Beaconsfield Goldfield

The drilling program at Beaconsfield has established a consistent mine sequence from one drill hole to another. This sequence consists of the Ordovician sediments sandwiched between two slices of Cambrian sediments.

The basal Cambrian unit, the Blyths Creek Formation, consists of layers of white limestone interspersed with conglomerate horizons. In some areas of the mine, the drill holes intersected a serpentinite dyke beneath the Blyths Creek Formation.

The Ordovician succession commences with the Cabbage Tree Formation, overlying the first thrust fault (fig. 2 and 3). The Cabbage Tree Formation is a siliceous, massive, pebble conglomerate which grades into the "Wet Beds". This is an historical term used to describe the Lower Transition Beds. The Transition Beds are the host rocks for the mineralisation in a pre-existing fault zone. The conglomerate and grit of the "Wet Beds" merge upwards into the interbedded calcareous siltstone and limestone of the Upper Transition Beds. Close to the top of the Ordovician sequence, the calcareous siltstone merges into a correlate of the Gordon Limestone. The top of the Ordovician sequence in the mine is a shale unit called the Grubb Beds.

It is at this stratigraphic horizon that the second thrust fault occurs. A Cambrian cobble conglomerate unconformably overlies the Grubb Beds. The Cambrian sequence then consists of shale, sandstone, limestone, siltstone and white limestone units.

The Ordovician sequence gradually fines from the bottom to the top. It has an average dip of 55°E in the upper sections of the mine. This dip is steepened to 80°, and then at depth reduces to 20°. It is thought that this suggests a shallow fold parallel to the strike of the bedding (Pease, pers. comm., 1984).

Lefroy Goldfield

The Mathinna Group sediments, which host the mineralisation, consist of a strip about 0.8 km wide of strongly folded and cleaved siltstone, sandstone and slate which have been slightly metamorphosed. These sediments have an average strike of N30°W and a dip of between 30°W and 50°W.

Within the goldfield are thirty auriferous formations which lie *en echelon*, and are associated with a series of east-west faults and shear zones. Some lodes show evidence of repeated movement along fault planes. The lode system strikes at N80°E and has dips ranging from 65°S to 90°S (Hughes, 1953).

THE ORE BODIES

Beaconsfield Reef

The Tasmania Reef is a fissure reef striking N50°E, with the quartz emplaced on a pre-existing fault zone (Gee and Legge, 1974). The reef is 395 m long and varies in width from 20 mm to eight metres, averaging 2.5 m wide. It has a 50–60°SE dip and a 55° NE plunge. The reef is displaced by two major and numerous smaller fault zones.

Gold values in the Tasmania Reef have been reported to vary with depth (Noldart and Threader, 1974). Over the first 120 m, an average grade of 38 g/t Au was maintained. This dropped to 25 g/t Au over the next 90 m, continuing downward to 3.8 g/t at 415 m depth. However, at the 450 m level the average grade had risen to 20 g/t Au. The assay results of DDH B4 at the 540 m level range from 2.6 g/t to 591 g/t, with composite values between 41 g/t and 92 g/t Au. Figure 4 gives a longitudinal section of the reef, indicating drill-hole intersections.

In the upper levels of the reef the gold occurs as free gold in quartz with minor sulphides. With depth the mineralisation changes, with an increasing amount of the gold being intimately associated with pyrite. Accessory sulphides at depth are chalcopyrite, sphalerite, arsenopyrite and minor galena, with siderite and ankerite as important gangue minerals (Noldart and Threader, 1974).

In summary, the Beaconsfield Goldfield mineralisation is controlled by NE-striking faults which transect the east-dipping Ordovician Cabbage Tree Formation. The quartz reefs, which are emplaced along these Late(?) Devonian faults, are also controlled by changes in lithology. To the west, the reef runs out at the massive conglomerate

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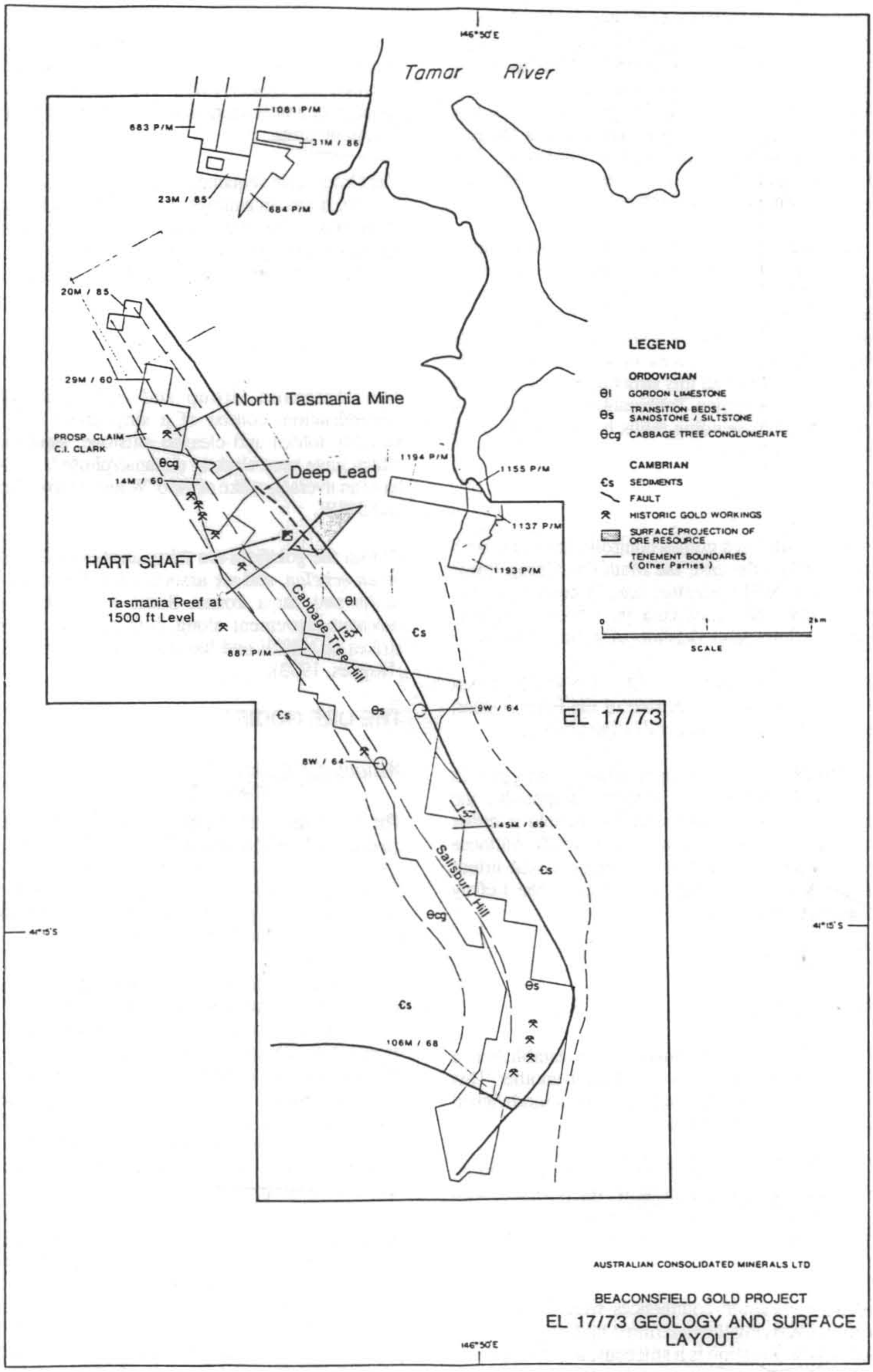

Figure 3

Regional geology of the Beaconsfield and Salisbury goldfields.

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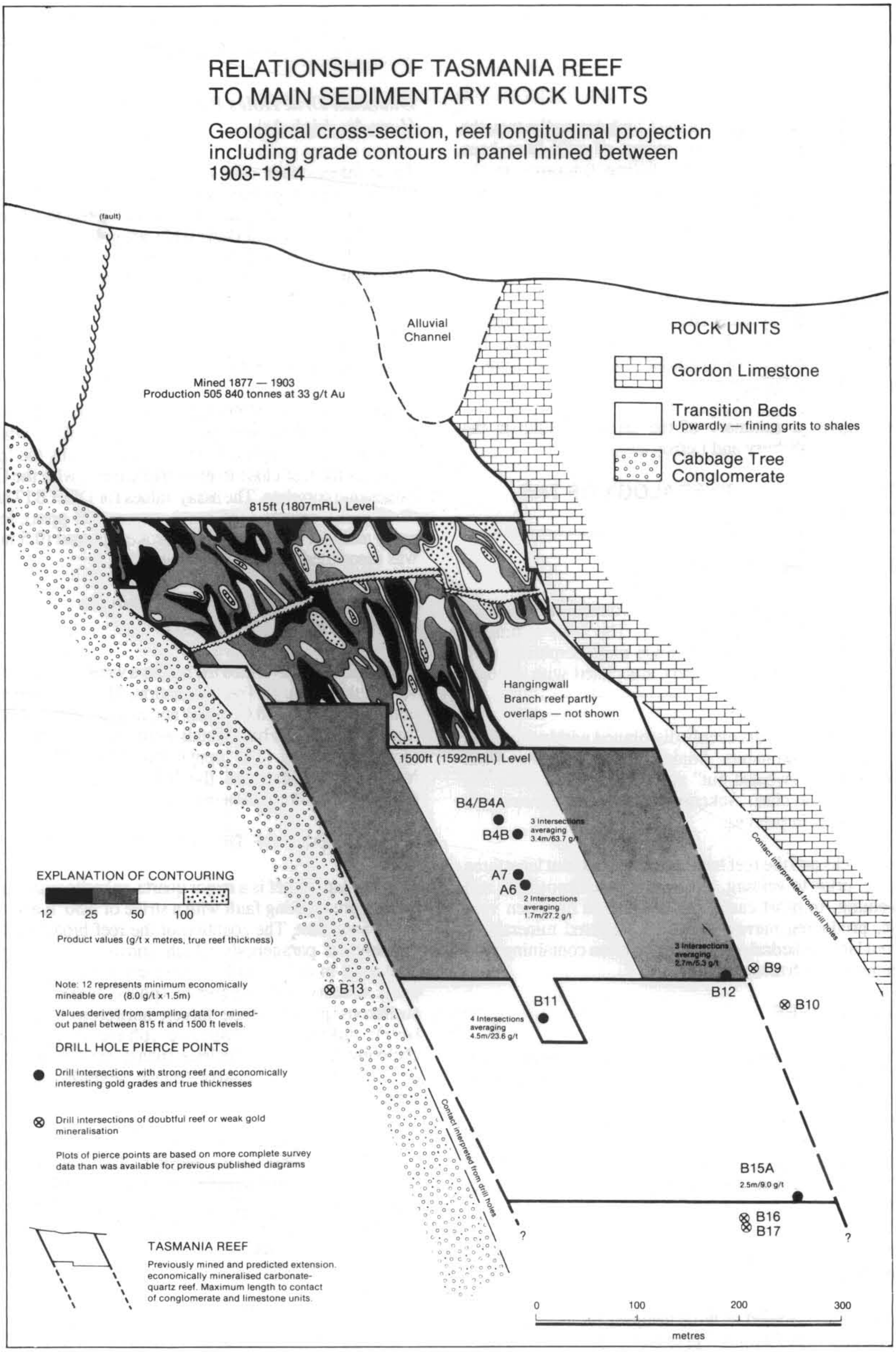

Figure 4

Longitudinal section of the Tasmania Reef at Beaconsfield. The quartz reef dips at an angle of 50°, is up to 400 m long, and up to six metres thick. The drill hole intersections with the reef are indicated by the hole code (e.g. B11). (After ACM, 1987 Annual Report).

beds, while to the east the reef is terminated at the base of the limestone.

Salisbury Reef

While quartz veining occurs in the Cambrian sediments, the veins are non-auriferous. Low assays of gold have been determined from quartz veins filling fractures in the Ordovician Transition Beds, but no major quartz reef has been intersected to date.

Lefroy Reef

The auriferous reefs at Lefroy are emplaced in a south-dipping fault system. The auriferous quartz occurs on the walls of the vein, with barren quartz in the centre. The reefs are intersected by two younger, barren quartz veins in almost horizontal fault planes.

Figure 5 gives a summary of the drilling results in the Beaconsfield, Salisbury and Lefroy areas.

PETROLOGY AND MINERALOGY OF THE TASMANIA REEF

PETROLOGICAL DESCRIPTIONS

The quartzose clastic sediments of the Transition Beds often show evidence of recrystallisation. The host sediments appear to have suffered a low-grade metamorphism, with sericite and chlorite in the matrix associated with residual clays.

Syngenetic pyrite occurs evenly distributed within the clasts of fine-grained sediments. Some of this pyrite has been skeletonised or "sweated out" and recrystallised along the boundaries of the clast. Ankerite is pervasive, occurring as veins as well as in patches.

The host rocks and the reef have been brecciated at least three times; i.e. prior to veining, during sulphide deposition, and post-veining. In most cases, the brecciation has been very intense, producing narrow zones of shattered minerals or shattered large euhedral pyrite crystals, often containing gold within the micro-fractures.

TASMANIA REEF

The reef is a sulphide mineralised quartz-ankerite vein associated with disrupted quartzose clastic sediments with minor stringer veins. There are four different styles of intersection of the Tasmania Reef, as delineated by drilling. These intersections, as described below, illustrate the strong lithological control placed on the reef by the Transition Beds. Assay values and drill logs were provided by Goldfields Exploration.

Diamond-Drill Hole B11 — (High Au, base metals and moderate As)

This drill hole consisted of three wedges, 11, 11_A and 11_B, with gold assays of 59 ppm, 9 ppm and 13 ppm respectively. The thickness of the reef was 4.5 m and averaged 23.6 g/t Au.

The ankerite-quartz vein was well mineralised by gold, copper (1466 ppm), lead (133–820 ppm) and zinc (675–1000 ppm), but with only moderate values of arsenic (620–1395 ppm). These intersections were approximately 130 m from the footwall of the Cabbage Tree Formation, close to the centre of the reef.

Diamond-Drill Holes B10, B12, B15A, B16 — (Low Au, high As)

These intersections were close to the hangingwall near the Gordon Limestone correlate contact. The reef was a well mineralised pyrite/arsenopyrite, but brecciated ankerite quartz vein. Assays of DDH $B15_A$ are gold (8.67 g/t), copper (133–359 ppm), lead (261–565 ppm), zinc (556–943 ppm) and arsenic (6269 ppm). The average reef thickness was 2.5 m with a gold assay value of 9.0 g/t.

Diamond-Drill Holes B9, B17 — (Low mineralisation)

Towards the edges of the reef there was no evident veining, but the ground became broken at the depth at which the intersection was expected. This is illustrated by the 'patchy' nature of the reef close to the upper contact with the Gordon Limestone correlate. The assay values for DDH B17 are gold (0.45 ppm), arsenic (145 ppm), copper (25 ppm), lead (68 ppm) and zinc (700 ppm). The broken ground (0.5 m thick) was associated with minor stringers.

Diamond-Drill Hole B13 — Within the conglomerate — (No Au, As)

This drill hole intersected the reef as a weak quartz-carbonate vein in the Cabbage Tree Formation. The gold values could not be measured (<0.01 ppm) and arsenic values were very low (3.3 ppm). The base metals were assayed as being copper (451 ppm), lead (305 ppm) and zinc (159 ppm). This intersection illustrated the lithological control of the Cabbage Tree Formation on the reef.

MINERALOGY OF THE TASMANIA REEF

The Tasmania Reef is a major quartz-ankerite vein emplaced along a pre-existing fault with a strike of N50°E and 50–60° to the southeast. The zonation of the reef broadly relates to the mineral paragenesis which consists of eight phases. These are in order: milky coarse crystalline quartz (phase one); creamy ankerite/pyrite (phase two); quartz with auriferous pyrite (phase three); auriferous quartz (phase four); ankerite/arsenopyrite (phase five); ankerite/chalcopyrite/sphalerite/galena (phase six); non-auriferous fine blueish-white quartz (phase seven); and 'vuggy' ankerite (phase eight).

Most of these phases have been preceded by a period of brecciation, some more intense than others, causing micro-fracturing and straining of quartz crystals. The major minerals are quartz, ankerite, pyrite and gold, with minor chalcopyrite, arsenopyrite and accessory minerals of sphalerite and galena.

Quartz

There appear to be four generations of quartz. The first generation is coarsely crystalline (0.3–2 mm), with the white crystals growing at right angles from the host rock (fig. 7, plate 1). The quartz was determined as α quartz by IR and XRD methods. Finer-grained α-quartz (<15 μm) tends to be associated with the gold in phases three and four, as discussed later (fig. 7, plate 2). These quartz crystals

Location	Hole	Diversions	Reef intersection (m)	Average Au (g/t) (assay)	Maximum Au (g/t) (assay)	Reef width (m)
Beaconsfield	A6	A6 (i)	580	7.7	14.4	1.7
	B4	A, B	610	63.7	591	0.6
	B11	A, B, C	693	59	354	4.5
	B12	A, B	719	5.3	25.4	2.7
	B13	-	682	0.07	0.12	2.7
	B14	-	nil	nil	nil	-
	B15	A	887	8.7	13.3	3.0
	B16	-	917	1.9	2.4	1.1
	B17	-	937	0.45	0.45	1.0
Salisbury	S1	-	170	trace	0.017	-
	S2	-	230	0.2	4.75	-
	S4	-	nil	nil	nil	-
	S5	-	nil	nil	nil	-
Lefroy	Chum	3 holes (1935)	250	0.6	-	2.4
	Golden Era	4 holes (1936)	101	11.2	-	1
	Morning Star	4 holes (1937)	171	0.75	-	10
	Land-O-Cakes	4 holes (1938)	nil	trace	-	-
	Volunteer	2 holes (1937)	nil	nil	-	-

Figure 5

Summary of diamond-drill holes.

(generations 1–3) often have undulose extinction as a result of subsequent deformation. The final phase (i.e. seven) of quartz occurs as a bluish fine-grained matrix cementing previously brecciated minerals and wall rock (fig. 7*, plate 9). At times this quartz occurs in dilational cracks in pyrite crystals.

Carbonates

While the ankerite and calcite are not intimately associated with gold, carbonates are all-pervading in the reef and occur in patches in some host sediments. The carbonates are coarse-grained and are a creamy colour, more so than the milky quartz. In many cases the carbonate crystals exhibit evidence of subsequent deformational forces. The first generation of ankerite is associated with the majority of the non-auriferous pyrite precipitated during the second phase of mineralisation.

During phase five (post-gold), ankerite crystallised with pyrite and arsenopyrite (fig. 7, plate 7). The following pulse of fluids (phase six) precipitated further ankerite in association with pyrite, chalcopyrite (~2%) and minor sphalerite and galena. The final phase of the reef development consisted of the formation of fine cross-cutting veins of carbonate containing vugs. These veins often caused minor lateral displacement and were associated with brecciation.

Pyrite

This is the major sulphide mineral in the reef and it has two sources; recrystallisation from the host rocks and the ascending ore fluids. In the latter case, pyrite is associated with three phases of mineralisation. The bulk of the pyrite was preciptated with the first pulse of carbonate-rich fluids. The following silica-rich fluids crystallised both pyrite and

* Figure 7 is located in the pocket at the rear of this bulletin.

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gold. At that stage, the pyrite formed coarse euhedral crystals containing small inclusions of gold. In phase five, the pyrite was associated with ankerite and arsenopyrite (fig. 7*, plate 7) and at times replaces ankerite.

Gold

Gold has several forms in the reef and these are classified as follows:

1. Very small inclusions in pyrite;
2. Small exsolution structures in pyrite (fig. 7, plate 3);
3. Large inclusions in pyrite (fig. 7, plate 4);
4. Fillings in micro-fractures in pyrite (fig. 7, plate 4);
5. Coarse grains partially replacing euhedral crystals of pyrite (fig. 7, plate 5);
6. Coarse grains completely replacing euhedral pyrite crystals (fig. 7, plate 6);
7. Discrete grains in quartz (fig. 7, plate 2);
8. Discrete thin threads in quartz (fig. 7, plate 5).

The gold occurring as very small (<30 μm) inclusions in pyrite is not related to the subsequent micro-fracturing. This was the initial gold deposited with the pyrite and quartz during phase three. Prior to phase four, the existing pyrite suffered extensive micro-fracturing. Subsequently, a second generation of gold was precipitated in and around the fractured pyrite (gold forms described in points 2 to 8 above). There is some evidence for remobilisation of the first generation gold from the body of the pyrite and into the micro-fractures. This remobilised gold may have 'seeded' the coarser second-generation gold. It is unlikely that there would be sufficient first-generation gold to be remobilised and then replace the large coarse euhedral parent pyrite crystals. Phase four appears to be the major gold mineralisation event in which gold replaced euhedral crystals of pyrite (partially or completely), and also formed free gold grains in finely crystalline quartz.

Other Sulphides

Arsenopyrite was deposited separately from the other minor sulphides during phase five, and is not associated with the gold mineralisation. This mineral has an acicular habit and is embedded in ankerite (fig. 7, plate 8). Chalcopyrite occurs as coarse grains (fig. 7, plate 8), at times replacing pyrite and containing inclusions of sphalerite and minor galena. Occasionally, the sphalerite replaces the ankerite. The sphalerite has a pale colour, suggesting that it is the low-iron end member. This in turn indicates that these minerals were formed at lower temperatures, in the waning stages of reef development. Meneghinite occurs as a rare mineral in the reef.

PARAGENESIS

Most of the eight identified phases of reef development (fig. 6) have been preceded by brecciation to some exent. This form of deformation caused host rock fracture (phases one and eight), intensive micro-fracturing of the pyrite (phase four), strongly shattered sulphides in narrow zones (phase six), and strained quartz/ankerite crystals. The phase four deformation was instrumental in remobilising some of the first-generation gold and providing suitable sites for deposition of the second-generation gold.

MINERAL	PHASES OF PARAGENESIS							
	1	2	3	4	5	6	7	8
Quartz	X		X	X			X	
Ankerite		X			X	X		X
Pyrite		X	X		X			
Gold			X	X				
Arsenopyrite					X			
Chalcopyrite						X		
Sphalerite						X		
Galena						X		
PLATES	1		2	3,4, 5,6	7	8	9	

Figure 6

The sequence of mineral deposition in the Tasmania Reef, Beaconsfield.

After the initial brecciation, the first mineral precipitated was quartz, the crystals of which grew into the centre of the vein from the host rock (fig. 7, plate 1). Further fracturing paved the way for the emplacement of the extensive ankerite and pyrite veining within the fault zone (phase two).

Phase three heralded the first and minor gold mineralisation. Quartz, pyrite and gold were co-precipitated, with the gold forming very small inclusions (<3 μm) in the pyrite crystals or being embedded in the quartz (fig. 7, plate 2). A significant phase of brecciation then caused intensive micro-fracturing and shattering of the euhedral pyrite crystals. This deformation remobilised the very small gold inclusions in the pyrite, moving the gold into the micro-fractures. The phase four ore fluids precipitated quartz and coarse grains of gold. The gold formed as discrete grains and thin threads throughout the finely crystalline quartz. Some of the gold precipitated adjacent to pyrite crystals in the quartz, and some replaced or partially replaced the euhedral pyrite crystals which initially contained the first generation gold (fig. 7, plates 3 to 6).

A following pulse of ore fluids (phase five) introduced thin stringers of ankerite containing fine needle-like crystals of arsenopyrite and pyrite. Phase six was associated with the deposition of the minor sulphides in ankerite. The chalcopyrite contains inclusions of sphalerite and rare galena. The chalcopyrite replaces pyrite and at times, the sphalerite replaces the earlier ankerite. Prior to this phase there had been a period of intense brecciation which developed thin strips of shattered sulphides within the ore (fig. 7, plate 8). At the outset of phase seven, broader-scale brecciation shattered adjoining host rock; these fragments were annealed by fine blueish-white quartz crystals (fig. 7, plate 9). The final phase of mineralisation emplaced thin 'vuggy' veins of ankerite through the previous minerals.

 N.B. Figure 7 is at the end of the report

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MINERALOGY OF SALISBURY AND LEFROY

While no gold mineralisation was observed in the Salisbury samples, historical descriptions (Twelvetrees, 1903) indicate that there were two types of occurrences of gold. Gold was associated with quartz veins containing pyrite, arsenopyrite and stibnite, but unfortunately, the micro-relationships were not described. Adjacent to the serpentinite, iron-stained silicious formations contained patchy amounts of gold, which was often coated with a black manganese layer. There were unconfirmed reports that nuggets of gold were found in large vugs in this formation.

The mineral suite at Lefroy has a few significant additions in comparison to the Tasmania Reef. The gold at Lefroy is intimately associated with quartz, pyrite, chalcopyrite, meneghinite and an unknown sulphide containing Zn, Sb, Fe and Cu. Historical records describe a macro-relationship between gold, arsenopyrite and stibnite (Gee and Legge, 1974).

FINENESS OF GOLD

INTRODUCTION

Native gold and native silver have almost identical atomic radii (1.439 Å vs 1.441 Å) and as such, silver and gold form a continuous alloy system. Historically, the purity of gold has been expressed in terms of the 'fineness' of the Au content expressed in per mil.

Electron probe micro-analysis was used to determine the composition and hence the fineness of gold grains from the study area. The three groups of samples analysed were:

- diamond-drill core samples from Beaconsfield: DDH B4, $B4_B$, $B4_A$ (125 spot analyses);
- Lefroy Goldfield samples provided by the Queen Victoria Museum, Launceston (39 spot analyses);
- alluvial grains/nuggets from both areas (70 spot analyses).

The results of these analyses were used:

(1) to identify the gold signature of the different gold provinces;

(2) to determine the order of gold mineralisation generations and relate them to the sulphide mineralogy, and;

(3) to indicate the different conditions of ore genesis between the two goldfields.

Figures 8 and 9 demonstrate the distinctive gold signatures of the Beaconsfield and Lefroy goldfields.

These figures exclude the New Pinafore Mine results, which differ from all other Lefroy results.

A range of experimental studies has demonstrated that as the temperature for crystallisation of gold decreases, the fineness of the gold is reduced (Antweiler and Campbell, 1976).

This greater mobility of silver at lower temperatures translates into gold with a lower fineness being formed at lower temperatures in the waning phases of mineralisation. Hence, gold formed close to the deep-seated source (hypothermal) will have a greater fineness in comparison with gold formed close to or on the surface (epithermal). The classification of gold based on fineness was developed by Fisher (1950), and has had only minor modifications (fig. 10).

REEF GOLD

Analyses of fineness in both the Beaconsfield and Lefroy areas have consistently been higher than 900 (with the exception of the New Pinafore Mine). This places both the Beaconsfield and Lefroy ore deposits into the hypothermal group, in which the mineralisation is formed at depth.

In his work on the fineness of deep veins, Shelton (1986) predicted that hypothermal mineralisation would have formed at a depth of 2–3 kilometres. At Beaconsfield and Lefroy, the ore fluids would have precipitated gold with a high fineness as the more mobile silver streamed past.

The significantly higher mean fineness of Lefroy gold (974), compared with that of Beaconsfield (937), indicates that the Lefroy reefs were either stratigraphically below those at Beaconsfield or closer to the source, and in a higher temperature/pressure environment.

An alternative explanation for the high fineness of the Lefroy gold would be that this goldfield has suffered supergene enrichment (Broadhurst, 1935). In this oxidising environment, silver is more mobile. However, the absence of silver-poor rims in gold grains and the paucity of significant supergene minerals, both in historical records and in the museum specimens, strongly indicate that the reefs at Lefroy have not been exposed to supergene enrichment.

GOLDFIELD	FINENESS RANGE	MEAN (1)	NUMBER (1)	MEAN (2)	NUMBER (2)
BEACONSFIELD	900–950	934	125	937	52
LEFROY (3)	952–993	972	33	974	25
NEW PINAFORE	814–857	832	8	832	8

Figure 8

Gold fineness signatures of the Beaconsfield and Lefroy goldfields.

Note: Mean (1) = Fineness mean of all analyses in that locality
Mean (2) = Fineness mean of the centre of analyses of gold grains in quartz
Lefroy (3) = These figures exclude the New Pinafore Mine results.

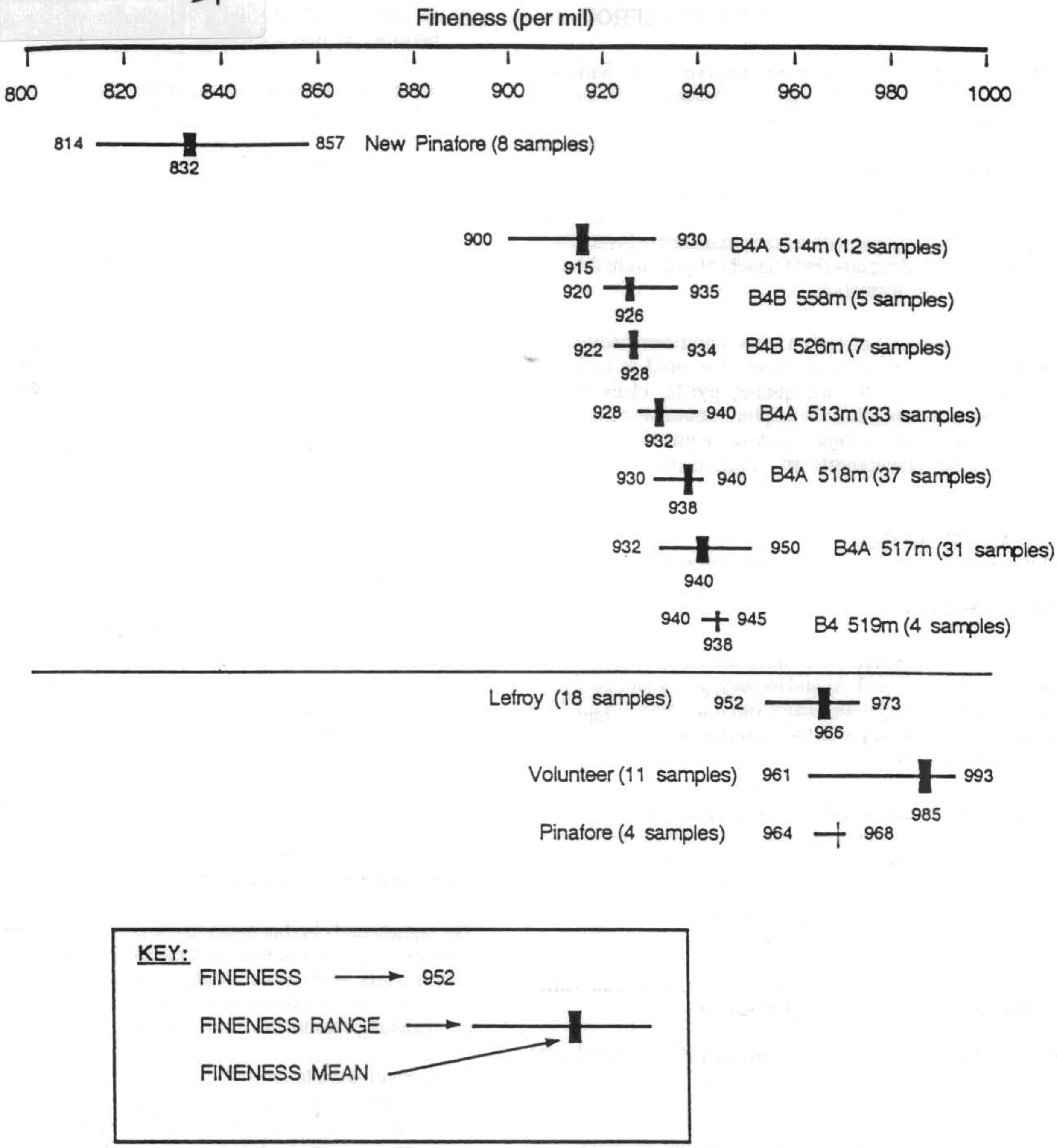

Figure 9

Gold fineness (per mil) microanalyses: ranges and deposit averages for the goldfields in this study.

ALLUVIAL GOLD

The origin of placer deposits is problematical in the view of some authors. Some argue that the chemical processes of solution and deposition will produce placer deposits, while others suggest that the mechanical processes of erosion and transport will hammer out flakes or nuggets of gold from the mother lode (Boyle *et al.*, 1975).

Desborough (1970) called upon aspects of each theory for his explanation of the origin of placer deposits. Physical weathering and erosion of the present reef will produce fragments of gold in eluvial placers. During transport the silver is oxidised from the surface of the gold grains. As the silver is changed into its ionic state, it becomes more mobile because its ionic radius is smaller (1.13 Å) than that of the metal atom (1.44 Å). Hence, low temperature, aqueous solutions preferentially remove silver from the rim. As this solution process continues, a very thin porous rim is developed on the surface of the gold grain (5–20 µm). The end result of this process is a thin rim with higher fineness than the core. As the gold grains are transported, they may incorporate gangue material or other gold grains and at the same time, the continued silver solution process produces gold rims with higher fineness. That is, as distance increases, fineness increases.

Alluvial gold collected from this study area demonstrates the features described above. For the twenty grains analysed, 16 had higher fineness at the margins. The average difference between fineness of the centre and the margin for all grains was + 17 points of fineness.

CLASSIFICATION	FINENESS RANGE	e.g. A & C[1] (average)	BEACONSFIELD (average)	LEFROY (average)
EPITHERMAL	500–800	666		
LOWER MESOTHERMAL	750–850	776		
UPPER MESOTHERMAL	800–900	896		
HYPOTHERMAL	800–1000	925	937	974
OXIDISED ORE ZONE (Boyle, 1979)	990–1000	–		
SUPERGENE (Shelton, 1986)	900–999	–		

Figure 10

A classification of gold based on fineness (after Fisher, 1950)
Note: A & C[1] — Antweiler and Campbell described samples of fineness in a modified Fisher classification (i.e. they subdivided the mesothermal section).

Two traverses across small gold nuggets produced the fineness profile illustrated in Figure 11. The Johnsons Creek nugget had a difference of + 36 points of fineness between the centre and the edge. The thickness of the silver-poor rims is 18 μm, falling with the order described by Desborough (5–20 μm).

The chemical conditions which would satisfy silver leaching from a gold alloy at 25°C are illustrated in Figure 12 (Pourbaix, 1966). While silver has a large area of 'immunity' in this system, gold has a greater area of 'immunity'. The difference between the two areas would describe the conditions in which alluvial gold grains would develop silver-poor rims.

While silver depletion occurs at the rim of the gold grains, the composition of the centre remains constant. Hence, the gold signature of the centre should fall within the fineness range of the parent reef. The Johnsons Creek nugget has a mean fineness of 938 (13 analyses) away from the rim, while the mean fineness of the centre of gold grains in the Tasmania Reef quartz is 937 (52 analyses). The strong correlation of these results shows that the Johnsons Creek nugget was formed from the Tasmania Reef, or similar, in the Beaconsfield area.

SILVER DISTRIBUTION WITHIN GOLD GRAINS (REEF)

As previously discussed, gold crystallised early in the paragenetic sequence tends to be finer than that crystallised later. This principally reflects the higher mobility of silver versus gold in ore solutions. A similar mechanism can be used to explain the increasing silver content (i.e. decreasing fineness) towards the margin of a gold crystal/grain.

The initial core of the gold grain will have formed at the higher temperatures of the system and hence will have a higher fineness. As the crystallisation continues, more silver will be incorporated in the alloy, producing a lower fineness towards the edge (Sakharova and Demidov, 1972). In epithermal deposits, the fineness difference between the centre and edge of a grain may be up to 100 units or more. This is indicative of an unstable system with a sequence of ore fluid pulses, each with different physical and chemical conditions. Two important conditions which control the precipitation of gold and silver are temperature and pH. In their recent study, Huston *et al.* (1992) demonstrate that a decrease in temperature or an increase in pH may produce silver-rich rims. The result of such a system can be the formation of zoned gold grains. However at depth fluid systems will be more stable, especially if they are below the level of boiling. Hence, hypothermal systems would have a more restricted range of fineness, both within and between gold grains.

The reef gold occurs in two forms, gold in quartz and inclusions in sulphides (predominantly pyrite). Throughout the reef samples, gold associated with quartz has a higher fineness than gold associated with the pyrite or other sulphides.

Figure 13 condenses the fineness results of 80 gold grains, each of which was analysed both in the centre and near the edge. In order to control variables when calculating the differential (Δ) between the centre and edge of grains, the gold grains were classified into the two goldfields and then the host mineral of the gold.

In all cases in Figure 13, the 'Fineness Differential' (i.e. fineness of grain's centre–fineness of grain's edge) is positive, if only marginally so. This suggests that the Beaconsfield and Lefroy reefs are hypothermal. The conditions of ore precipitation would have been consistent (temperature and fluid composition), with only a small increase in silver towards the grain edge. In epithermal situations, the conditions of ore precipitation fluctuate rapidly (Boyle, 1979), giving rise to a larger fineness differential.

Berman *et al.* (1973) demonstrated that for epithermal systems, the gold in pyrite had a higher fineness than the gold in quartz. However, they also noted that in deep mesothermal systems, the gold in pyrite had a *lower* fineness than the gold in quartz, as is the case here. This supports the hypothesis that the Beaconsfield and Lefroy reefs are at least deep mesothermal.

The analyses of gold grains have described the goldfields in terms of gold signatures; Beaconsfield with a fineness mean of 934 (range 900–950), Lefroy with a fineness mean of 972 (range 952–993), and a later mineralising event at the New Pinafore Mine with a fineness mean of 832 (range 814–857). These gold signatures can be used to identify the origin of gold grains and suggest the general conditions of mineralisation.

FINENESS PROFILE	18µ	32µ	40µ	48µ	56µ	64µ	72µ	80µ	88µ	96µ	104µ	112µ
% Ag from the edge	1.27	2.79	0.03	3.04	4.4	3.98	3.88	4.58	4.47	4.34	4.22	4.13

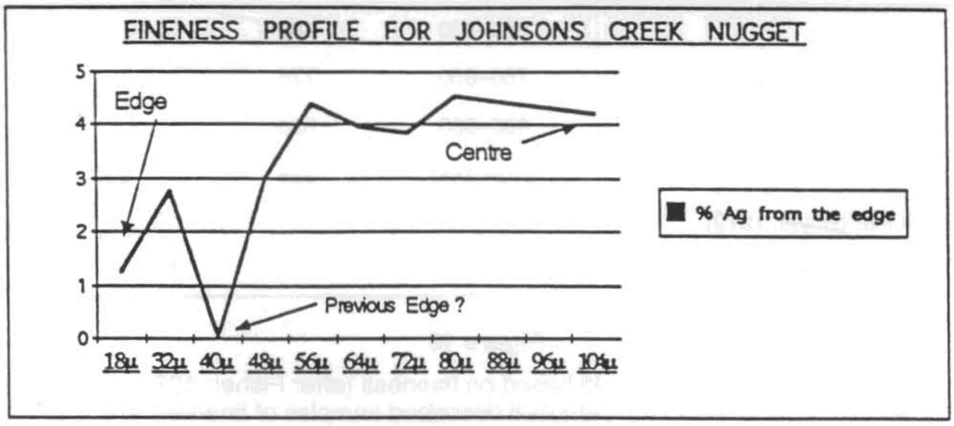

FIGURE 4e (i)

FINENESS PROFILE	2µ	5µ	10µ	15µ	20µ	25µ	35µ	50µ	60µ
% Ag from the edge	4.43	5.37	5.8	5.49	5.15	5.72	5.38	5.73	5.54

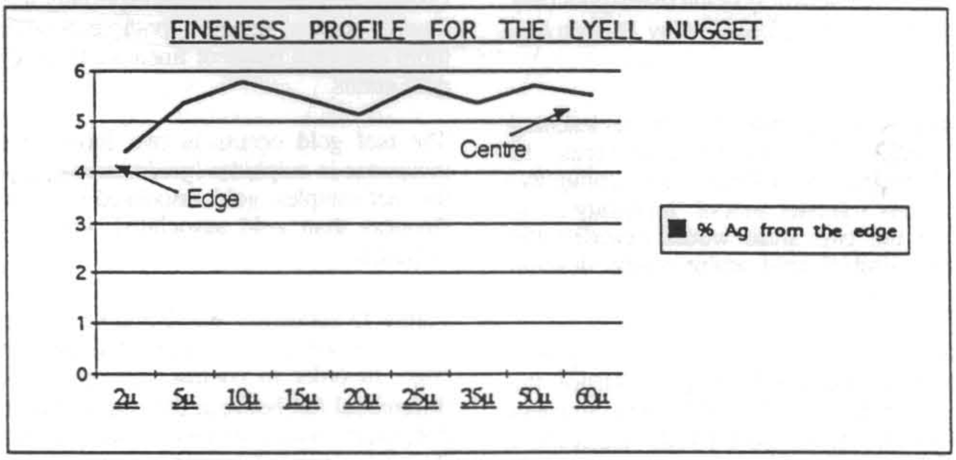

Figure 11

Profiles of the microanalyses of fineness for the Johnsons Creek nugget (Beaconsfield) and the Lyell nugget, illustrating the depletion of silver at the edge.

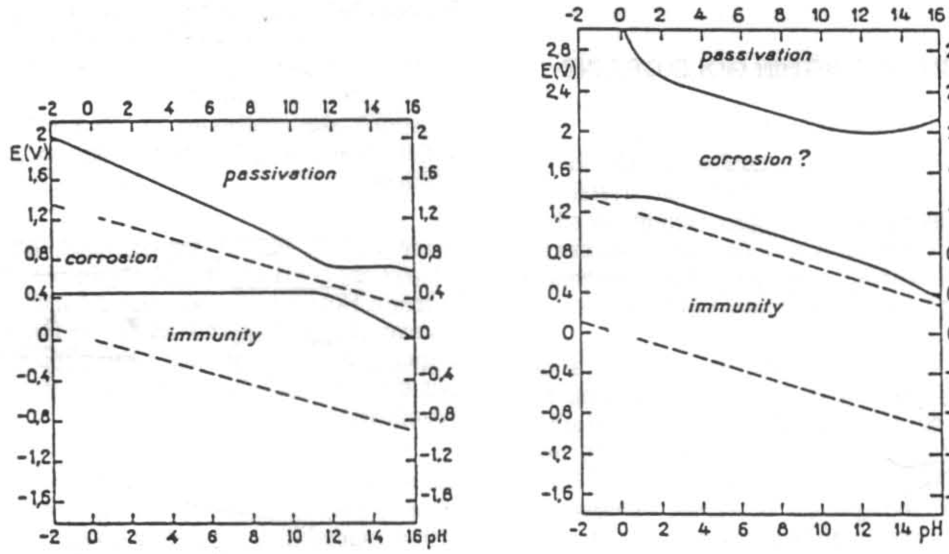

Figure 12

Theoretical conditions of corrosion, immunity and passivation of silver, gold and silver/gold at 25°C (source: Pourbaix, 1966). (silver on left, gold on right).

5 cm

GOLDFIELD	HOST MINERAL	CENTRE (mean)	EDGE (mean)	DIFFERENTIAL (Δ)	NUMBER
BEACONSFIELD	Quartz	938	934	+ 4	46
	Pyrite [(1)]	932	930	+ 2	32
LEFROY	Quartz	974	970	+ 4	2
	Sulphides [(1)]	966	na	na	8

Figure 13

"Fineness Differential (Δ)" between the centre and edge of gold grains.
Note [1]: Associated sulphides with the pyrite were mainly arsenopyrite with minor chalcopyrite.

Both goldfields were mineralised at depth (hypothermal), either close to the source of the mineralising fluids or in a region of low-grade metamorphism and/or deformation. This is supported by the low fineness differential between fineness of the core and margin of gold grains, indicating an environment which was stable within a narrow range of temperature and fluid composition. Huston *et al.* (1992) argue that "the presence of consistently high fineness electrum indicates high temperature (300–350°C) gold deposition". The gold from Beaconsfield and Lefroy has a very narrow and high fineness range, significantly more so than the samples studied by Huston *et al.* (1992). This suggests that the Beaconsfield and Lefroy goldfields were mineralised at temperatures greater than 350°C.

The fineness data suggests that both deposits are hypothermal (350°C) and that the Beaconsfield mineralisation would have occurred at a slightly lower temperature than that at Lefroy.

STABLE ISOTOPE GEOCHEMISTRY

A study of stable isotopes was conducted to determine the source of the hydrothermal solution relating to the gold mineralisation. The major aspect of this study involved 37 measurements of $\partial^{24}S$ on pyrite extracted from the reef, eight $\partial^{18}O$ analyses of reef quartz, and six additional geothermometric analyses of arsenopyrite in order to establish the temperature of the reef during phase five, immediately after gold deposition.

SULPHUR ISOTOPES

The sulphur for isotopic analysis was extracted from the sulphide by using Cu_2O as an oxidising agent at 950°C. The resultant SO_2 was analysed on a VG Micromass 602D stable isotope mass spectrometer, using techniques described by Ohmoto and Rye (1979). The isotopic composition of sulphur is expressed in terms of $\partial^{34}S$ where:

$$\delta^{34}S\ Sample = \left[\frac{(^{34}S/^{32}S)\ Sample}{(^{34}S/^{32}S)\ Standard} - 1\right] \times 100‰$$

The international accepted standard is troilite (FeS) from the Canyon Diablo meteorite (i.e. $\partial^{36}S_{CDT}$).

The results are show in the table below.

SOURCE OF SULPHUR

The sulphur isotopes of this study (fig. 14) indicate a combination of sources of the sulphur. No other sulphur isotope data from the northern Tasmanian goldfields were available for comparison.

The pyrite associated with the mineralisation has a $\partial^{34}S$ mean = + 8.9‰ and a range of + 6.5 to 12.7‰. Pyrite not associated with the mineralisation has a $\partial^{34}S$ mean = + 13.5‰ and a range of +7 to + 26.7‰. These values are too high to have been derived from a deep seated magmatic

LOCATION	PYRITE			CHALCOPYRITE		
	No.	Range (‰)	Mean (‰)	No.	Range (‰)	Mean (‰)
DDH B4 (Beaconsfield)	21	+7 → +11.1	+8.9	3	+6.5 → +9.3	+7.9
Lefroy (Native Youth)	3	+12.1 → +12.7	+12.4	1	+12.5	+12.5
Barren DDH B4	13	+7 → +24.7	+13.5	-	-	-

Figure 14

Pyrite and chalcopyrite sulphur isotope values.

sediments or bacterial action. Alternatively, the observed values are too light to be purely derived from either Devonian seawater (+ 18 to + 25‰) or connate pore fluids which had originated from seawater. These factors indicate mixing or fractionation of parent fluids prior to the precipitation of the ore. To allow significant fractionation to occur, either the boiling of the ore fluids caused the loss of ^{32}S leaving sulphides enriched in ^{34}S, or sufficient time elapsed in a long fractionating column to produce enrichment in ^{34}S at the zone of ore deposition.

OXYGEN ISOTOPES

The quartz was put in a Ni vessel with an atmosphere of nitrogen. The sample was reacted overnight with BrF_5 at a temperature of 550°C in order to convert the silicon to SiF_4. The oxygen liberated was separated and converted to CO_2 and measured in the spectrometer mentioned above. The data are expressed as

$$\delta^{18}O\ Sample = \left[\frac{(^{18}O/^{16}O)\ Sample}{(^{18}O/^{16}O)\ Standard} - 1\right] \times 1000\ ‰$$

The standard was NBS 28, which has a $\partial^{18}O$ value of + 9.64‰ relative to Standard Mean Ocean Water (SMOW). The results are shown in Figure 15.

The average and standard deviation of all samples is + 17.9 ± 0.8‰ $\partial^{18}O$.

Location	Sample	Value (‰)
Tasmania Reef	B4/520	+17.5
Tasmania Reef	B4A/515.5	+17.4
Tasmania Reef	B4/515	+17.5
Tasmania Reef	B11/701.5	+19.6
Tasmania Reef	B4A/490	+18.4
Tasmania Reef	B4/519.4	+17.4
Tasmania Reef	B4A/517.6	+17.3
Tasmania Reef	B4A/514.2	+17.7
repeats:		
Tasmania Reef	B4/520	+17.8
Tasmania Reef	B4A/490	+17.6

Figure 15

Quartz oxygen isotopes ($\delta^{18}O_{SiO_2}$)

SOURCE OF THE TRANSPORTING WATERS

The oxygen isotope values ($\partial^{18}O$) for the quartz samples range from 17.3‰ to 19.6‰, with an average $\partial^{18}O$ value of 17.9‰. Using the temperatures of formation of arsenopyrite (fig. 16), the following equation was used to calculate the oxygen isotope values of the initial mineralising fluids:

$$\partial^{18}O_{H_2O} = \partial^{18}O_{SiO_2} - 3.57\ (10^6/\ T^2) + 2.73$$
(T = temperature in °K)

This equation describes the relationship between oxygen isotope fractionation and temperature for the quartz-water system. As explained below, the temperature of formation of the quartz appears appears to have been between 370°C and 440°C. Substitution of the appropriate temperature and quartz oxygen isotope values will generate the data in Figure 16.

The oxygen isotope values for the mineralising fluids, ranging from + 11.4‰ to + 15.3‰. indicate that they were of a metamorphic origin (Taylor, 1979).

ARSENOPYRITE GEOTHERMOMETRY

Six analyses of arsenopyrite from the Tasmania Reef, as intersected by DDH B4, were used to determine the temperature of crystallisation. The analyses of the arsenopyrite samples by the electron microprobe were reported in weight percent of the constituent elements. These values were converted to atomic ratios for each of Fe, As and S. The percentage of arsenic in the arsenopyrite, as calculated, was plotted on the Kretschmar and Scott (1976) pyrite-loellingite phase diagram to determine the temperature of formation. The range in temperature varies from 370° to 440°C, with a mean of 408°C and an average As content of 31.42% (fig. 17).

Burrett (1978) collected conodonts from the Gordon Limestone correlate at Flowery Gully, six kilometres south of Beaconsfield. This limestone is stratigraphically above the gold mineralisation, at the top of the Ordovician. Using the conodont colour index, Burrett determined a temperature of 300°C associated with the Tabberabberan Orogeny. Given the geographic and stratigraphic separation from Beaconsfield, these two temperature determinations are consistent.

DISCUSSION

Common to the Beaconsfield, Salisbury and Lefroy goldfields are the following features:

- a geological structure that trapped the gold mineralisation (i.e. faults and fractures);
- a heat engine to drive the transport mechanism of the ore fluids (i.e. metamorphism, deformation and/or magmatic intrusion);
- a source of ore fluids (e.g. metamorphism, granitoid, ultramafic), very much enriched in ^{18}O (i.e. $\partial^{18}O_{SiO_2}$ between + 17.3 and + 19.6‰.
- a source of sulphur with an appropriate $\partial^{34}S$ (i.e. heavy, $\partial^{34}S$ between + 6.5 and 12.7‰).

GOLD TRAP

These features need to be matched with the analytical data to produce a coherent and logical model of deposition.

The pre-existing fault structure of the Tasmania Reef was the localised expression of a channel for the ascending mineralising fluids. As pulses of ore fluid moved up the fault, thermodynamic factors changed, initiating chemical instability and hence precipitation of ore/gangue minerals in a confined zone. The cross-cutting Tasmania Reef is restricted to the Transition Beds sequence (upwardly-fining grit to shale) and does not persist into the Cabbage Tree Formation (to the west and stratigraphically lower), nor does it persist into the Gordon Limestone correlate (to the east and stratigraphically higher). The true width of the reef ranges from several centimetres to eight metres, reflecting

16/20

TEMPERATURE (°C)	QUARTZ OXYGEN ISOTOPE VALUE ($\delta^{18}O$)		
	+17.3‰	+17.9‰	+19.6‰
	Lowest value	Average value	Highest value
370	+11.4	+12.0	+13.7
410	+12.4	+13.0	+14.7
440	+13.2	+13.8	+15.3

Figure 16

Oxygen isotope values for parent waters ($\delta^{18}O_{H_2O}$).

Sample (DDH B4)	Atomic ratio Fe/As/S	% As in arsenopyrite	Temperature ± °C
1a	0.5815 / 0.5454 / 0.5605	32.32	440#
1b	0.6254 / 0.5977 / 0.6279	32.29	440
1c	0.6216 / 0.5870 / 0.6463	31.65	410
2a	0.6164 / 0.5751 / 0.6351	31.48	410
2b	0.6177 / 0.5741 / 0.6369	31.39	410
2c	0.6239 / 0.5575 / 0.6591	30.29	370

This result should be considered dubious as 8 wt.% of the arsenopyrite is minor elements not used in further calculations.

Figure 17

Temperature of formation of the Tasmania Reef.

stratigraphically higher). The true width of the reef ranges from several centimetres to eight metres, reflecting variations in the elastic properties of the enclosing wall rocks.

These factors indicate that both structural and lithological controls are significant in determining the trap environment, which resulted in a 400 m long ore panel plunging steeply to the east. A similar structural control is evident in the Lefroy goldfield.

HEAT ENGINE

Once a suitable trap environment exists, a mechanism for driving the ore fluids from the source to the site of deposition needs to be established. The Tabberabberan Orogeny and associated middle Palaeozoic granitoids have driven ore fluids in both the west and east of the State. While a major fault zone would permit hydrothermal fluid transport without a point source of igneous heat (e.g. an intruding granite magma), the thermal gradient from a deep-seated source to a site of deposition would also be a suitable mechanism to move mineralising fluids (Gibson *et al.*, 1975).

The western metallogenic province is associated with a granite/adamellite batholith intruded between 332–367 Ma, producing significant Sn, W and Ag-Pb-Zn (vein) deposits. The eastern metallogenic province is associated with a granitoid batholith intruded between 348–395 Ma. Inside the one kilometre subsurface contour of the batholith, significant Sn (greisen) disseminated, Sn-W (vein) and gold (reef) deposits occur. Locations of these deposits are shown on Figure 18.

The Beaconsfield gold reef is 60 km away from the closest surface expression of the western batholith (Dolcoath Granite) and 50 km away from the closest surface expression of the eastern batholith (Diddleum Granodiorite). The Lefroy goldfield is approximately 35 km away from the closest surface expression of the eastern batholith. This significant separation from the granitoids suggests that the gold mineralisation at Beaconsfield and Lefroy is more likely to be related to the Tabberabberan metamorphic/deformation processes, rather than the magmatic processes associated with the granitoid emplacement. However while both mechanisms have advantages and disadvantages as discussed later, magmatic and/or metamorphic processes could generate the heat required to drive the ore fluids from the source to the site of deposition.

METAL SOURCE

There could be several sources of the gold and silver. In the absence of suitable volcanic rocks or intrusions from which the metals could be leached (the closest outcrop of Mount Read Volcanics is 60 km away), the source is unlikely to be the host sedimentary rocks (minor Cambrian slate, Ordovician conglomerate, sandstone and limestone). A magmatic plume of ore fluids derived from an underlying granitoid magma would provide a feasible source for the metals, particularly if it was associated with the eastern batholith as this body has generated significant gold reef deposits. This granitoid dips steeply to the west, towards the two goldfields. However Lefroy is 20 km and Beaconsfield is 40 km away from the 4 km gravity-derived contour of granite/crust subsurface (Richardson, 1989), as shown in Figure 18. There is no accurate data relating to the granite subsurface beneath these goldfields.

Alternatively, the Cambrian ultramafic rocks (pyroxenites) two kilometres west of Beaconsfield may have been a source of the metals, which were mobilised during the low-grade metamorphism and deformation associated with the Tabberabberan Orogeny or the emplacement of the ultramafics. Serpentinite was intersected at the base of drill holes at Salisbury (DDH S1, S2) and Beaconsfield (844.3 m, DDH B13). Historical records of the Salisbury goldfield indicate that gold nuggets were associated with pale yellow-green serpentinite (Twelvetrees, 1903). It is unclear if the ultramafic rocks were regarded as the source or depositional environment of the gold. The Lefroy goldfield is 14 km to the northeast of these Cambrian pyroxenites, and ultramafic rocks are unknown in the northeast of Tasmania.

A final proposal for the source of gold mineralisation would be a deep-seated magmatic plume which rose up through deep faults. Both goldfields are 20–30 km from a seismic traverse between Savage River and Binalong Bay (Richardson, 1989). This traverse indicates that the depth of the Moho is approximately 26 km below the surface. If the faults or shear zones were sufficiently deep, they would provide a channel for the ascending fluids.

SOURCE OF SULPHUR AND OXYGEN

The consistently high $\partial^{18}O_{SiO_2}$ value of about + 17.9‰ for the eight quartz samples from the Tasmania Reef correspond, as discussed earlier, with initial mineralising fluids with a $\partial^{18}O_{H_2O}$ between + 11.4 and + 15.3‰ at respective temperatures of 370° and 440°C, as indicated by the arsenopyrite thermometry of the waters.

The rather high $\partial^{34}S$ values of pyrite ranging between + 6.5‰ and 12.7‰ could conceivably be the consequence of either boiling or fractionation in a long column, as would be proved by a deep-seated fracture zone.

CONCLUSIONS

A suitable model for the deposition of gold must explain the origin of the metals and ore fluids, a physical transport mechanism, and a depositional environment. During the Devonian Period, the Tabberabberan Orogeny would provide a deep geothermal system through which Devonian seawater (high $\partial^{34}S$) and metamorphic waters (high $\partial^{18}O$) would have circulated. As the waters mixed down to 12 km (as proposed by Green *et al.* (1982) for the Woods Point Dyke Swarm, Victoria), a deep-seated magmatic plume (gold rich) interacted with the system. The resultant fluids moved up fault zones associated with the Tamar Fracture System and the ore was precipitated at a temperature around

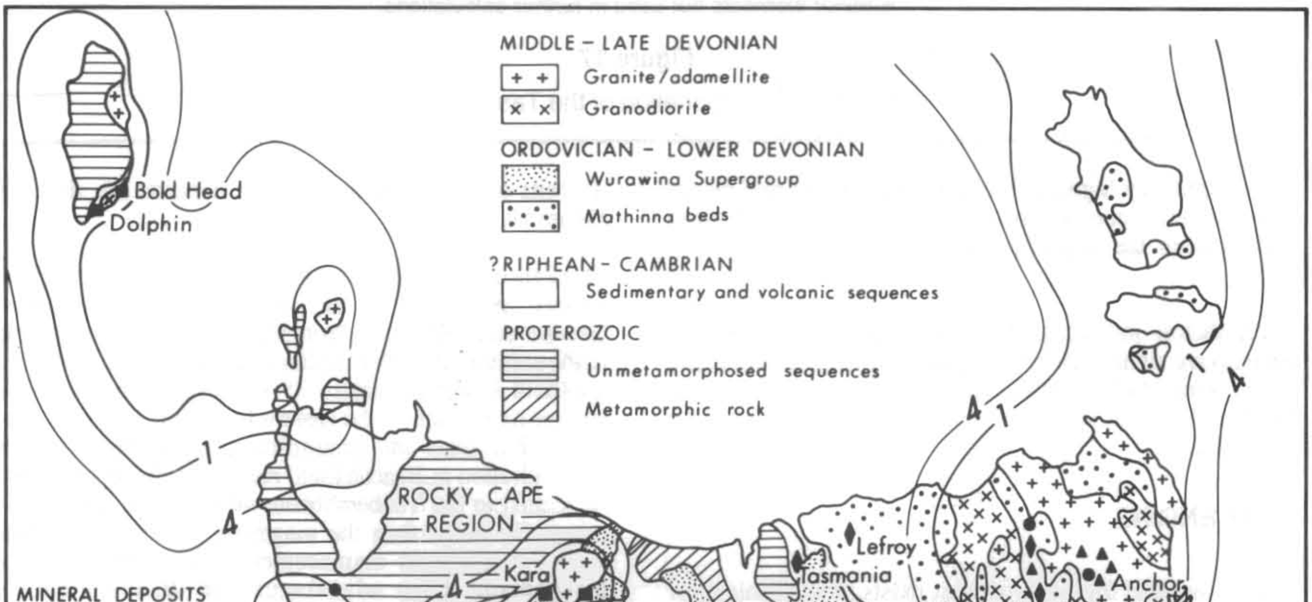

Figure 18

Location of tin, tungsten and related base metal vein deposits in northern Tasmania (from Collins *et al.*, 1989).

5 cm

410°C (as per arsenopyrite study). These results support the hypothermal, high temperature (350°C) nature of the mineralisation as determined by the study on the fineness of the gold.

This model is consistent with that proposed for the formation of many of the Eastern Australian gold deposits. Wilson *et al.* (1988) found that all known gold-bearing veins had oxygen isotope ($\partial^{18}O$) values of higher than + 15.7‰, indicating major deep-seated metamorphic fluid sources. They considered that many of the areas studied were structurally and tectonically placed to enable significant deep crustal and upper mantle contributions to ore-bearing fluids. The Beaconsfield, Salisbury and Lefroy gold deposits have geological similarities with, for example, the Woods Point Dyke Swarm in Victoria, and hence could have had a similar genesis.

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Without the generosity of the mining companies associated with the Beaconsfield mining prospect, the Tasmania Department of Mines, and the Queen Victoria Museum in Launceston providing access to samples and drill core, this study would have been virtually impossible.

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Figure 7

Colour plates of micrographs (in pocket).

1. Sample B4A, 517.6 m (PTS). *Phase 1:* First generation quartz crystals growing out from the vein wall. Void filled with carbonate. Width of field = 2 mm (XPL, TL).
2. Sample B4A, 518.6 m (PTS). *Phase 3:* Small free gold grains (A) in finely crystallised quartz. Width of field = 1 mm (RL).
3. Sample B4A, 513.4 m (PTS). *Phase 4:* Gold in pyrite. The early stages of gold replacing pyrite, forming exsolution(?) structures in pyrite. Width of field = 0.7 (RL).
4. Sample B4A, 513.4 m (PTS). *Phase 4:* Gold fillings in micro-fracture in pyrite caused by recrystallisation. Width of field = 1 mm (RL).
5. Sample B4A, 518.8 m (PTS). *Phase 4:* A thin vein of gold connecting a finely crystalline quartz vein with a euhedral pyrite crystal containing recrystallised gold. Width of field = 2 mm (TL, RL).
6. Sample B4A, 518.8 m (PTS). *Phase 4:* A coarse grain of gold (in quartz) almost completely replacing an euhedral pyrite crystal, the remains of which can be seen in the top right of the gold grain. Note the way in which the gold invades the adjacent quartz. Width of field = 2 mm (TL, RL).
7. Sample B4A, 513.3 m (PTS). *Phase 5:* Arsenopyrite has an acicular and fine needle-like habit and often embedded in ankerite. The large crystals are pyrite from a previous generation, some of which have been partially replaced by arsenopyrite. Width of field = 2 mm (TL, RL).
8. Sample B4, 527.8 m, 527.8 m (PTS). *Phase 6:* Chalcopyrite and pyrite (from a previous phase) in a carbonate which in turn is in a 1–2 cm quartz vein. Width of field = 1.5 mm (RL).
9. Sample B11B, 692 mm (DC). *Phase 7:* A broader scale brecciation shattered adjoining host rock; these fragments were then annealed by fine blueish-white quartz crystals (HS).

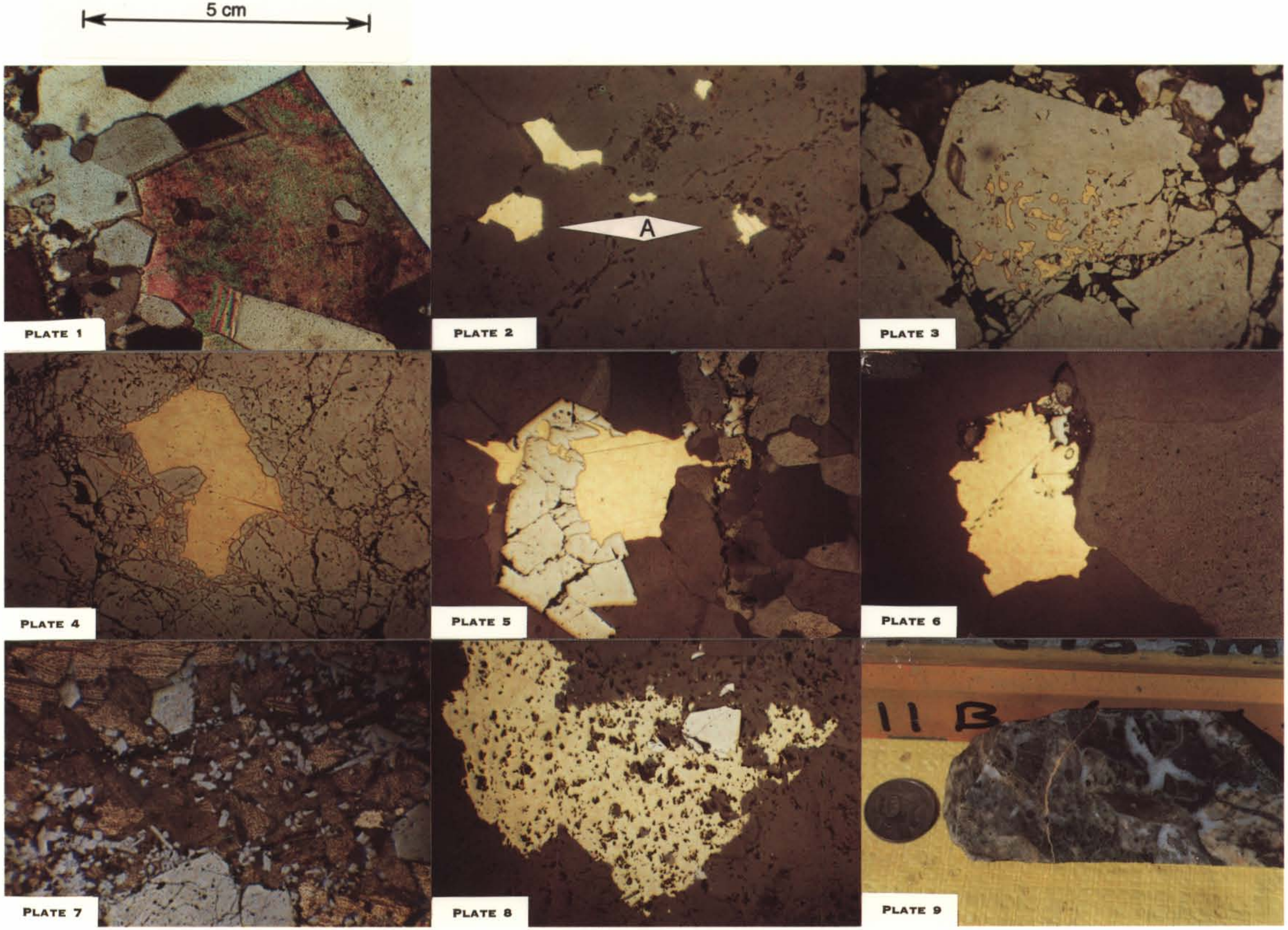

Figure 7 (Plates 1 to 9)
(Russell and Van Moort)