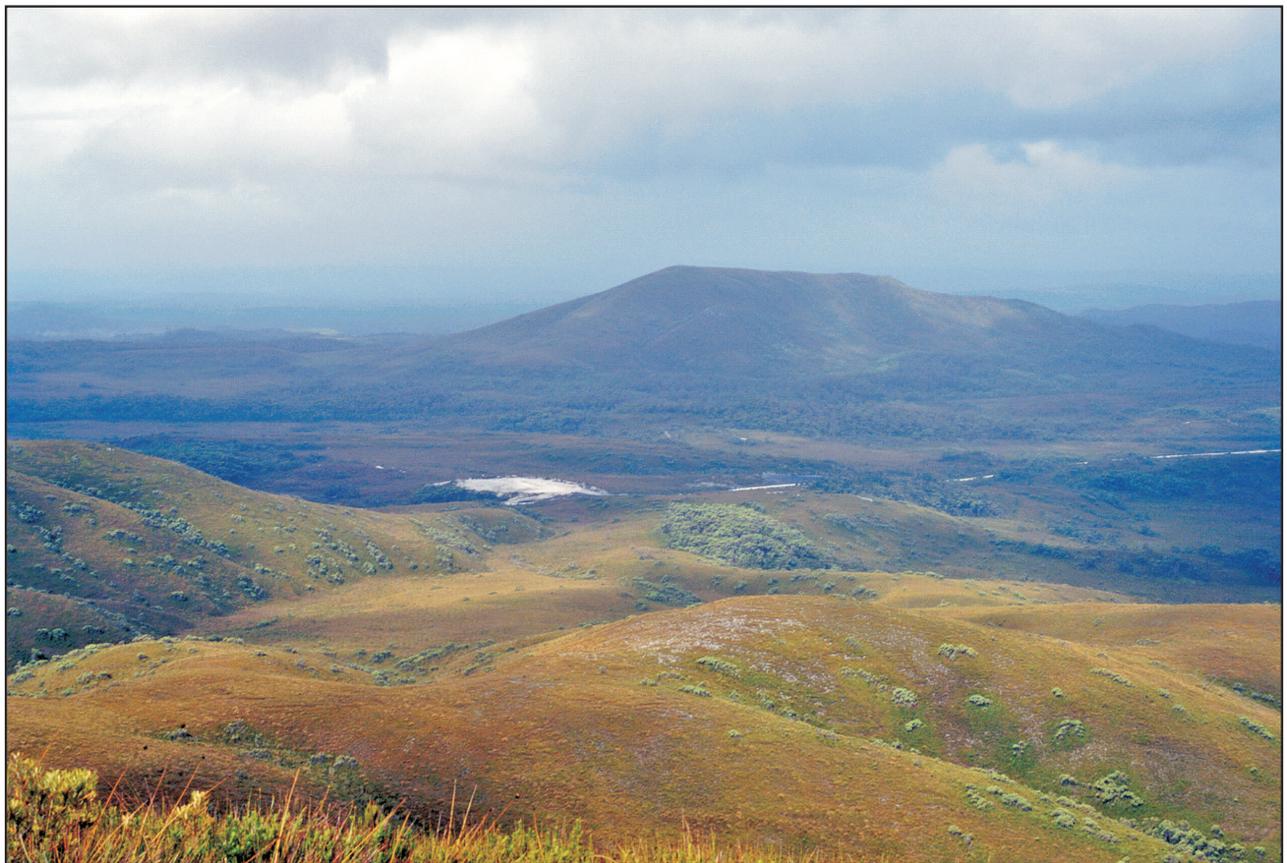


Tasmanian Geological Survey

Record 2004/05

***The nature and origins of copper
and tin-tungsten deposits in the
Balfour–Temma area, northwest
Tasmania***



By Jafar Taberi and Ralph Bottrill



MINERAL RESOURCES TASMANIA

DEPARTMENT of INFRASTRUCTURE, ENERGY *and* RESOURCES

The nature and origins of copper and tin-tungsten deposits in the Balfour–Temma area, northwest Tasmania

by J. Taheri and R. S. Bottrill

CONTENTS

Abstract	3
Introduction	4
History and ore production	4
Recent exploration	4
Regional geological setting	6
Local geology	8
Metamorphism	11
Mineralisation and associated alteration	11
Copper lodes	11
<i>Murrays Reward</i>	12
<i>Toner River</i>	12
<i>Balfour South</i>	12
<i>Summary of field observations</i>	17
<i>Drill core</i>	17
Tin-tungsten deposits	21
Fluid inclusions	23
Summary	26
Oxygen isotopes	26
Discussion	26
Sulfur isotopes	29
Discussion	29
Geochemistry	32
Ore genesis	39
Introduction	32
Genetic models	33
Further work	37
Summary	37
References	39

Appendices

1. Reports issued by exploration companies involved in the Balfour area	41
2. Mineral deposit locations, Balfour–Temma area	45
3. Sample locations, Balfour–Temma area	48
4. Brief descriptions of the Balfour–Temma deposits	53
5. Fluid inclusion data, Balfour–Temma area	60
6. Geochemistry of hydrothermally-altered rocks, Balfour–Temma area	65

Figures

1. Location map showing the mineral deposits in the Balfour–Temma area	5
2. Regional geology, northwest Tasmania	7
3. Local geology, Balfour–Temma area	9
4. Sketch showing the occurrence of copper lode along the fold hinge, Balfour South	17
5. Generalised paragenetic table for hydrothermally-formed minerals, Balfour copper belt	21
6. Frequency distributions of homogenisation temperatures in quartz from Balfour Copper Belt, Specimen Hill and Temma areas	25
7. Relationships between the distribution of homogenisation temperatures in different copper-tin-tungsten deposits and the underlying granite, Balfour–Temma area	27
8. Distribution of oxygen isotope values in different copper and tin-tungsten deposits relative to the underlying granite	28
9. Distribution of sulfur isotope values in different copper and tin-tungsten deposits relative to the underlying granite	31
10. Magnetic image showing the relationship between the underlying magnetic bodies and the locations of copper deposits in the Balfour–Temma area	36

Plates

1. Southern end of the Murrays Reward open cut showing the occurrence of the copper lode along a NNW-trending fault	13
2. As for Plate 1, showing the details of the mineralisation	13
3. Silicified, sheared, boudinaged and mineralised carbonaceous slate, Murrays Reward mine	14
4. Intensely brecciated copper ore (chalcopyrite and minor pyrite) containing remnants of deformed carbonaceous slate clasts, Murrays Reward mine.	14
5. Leached, late stage brecciation in a copper ore, Balfour Blocks prospect	14
6. Massive, mylonitised copper ore, Murrays Reward mine	14
7. Silicified rock veined by barren quartz veins, Murrays Reward open cut	14
8. Copper lode consisting of quartz, chalcopyrite veinlets and pyrite pods, Toner River	15
9. Toner River copper lode with the adjacent late barren quartz veins	15
10. A close up of Plate 9 showing the elongated pyrite pod within the lode	15
11. Early-formed silicified rock (adjacent to the copper lode), veined by near-vertical barren quartz veins cut by late, shallowly dipping thin barren quartz veins, Toner River prospect	16
12. An old shaft sunk on the main copper lodes, Toner River prospect	16
13. Fault/sheared-related copper lode, South Balfour, consisting of quartz, pyrite and chalcopyrite	18
14. Porous quartz after carbonate which is characterised by rhombohedral cavities, Balfour Blocks	18
15. Occurrence of quartz veins along the axial surface of kink-bands near The Clump prospect	18
16. Silicified rocks with minor pyrite cut by later generations of barren quartz veins, DDH BC9, Murrays Reward	20
17. Silicified carbonaceous slate cut by barren quartz veins, DDH BC11, Murrays Reward	20
18. Two styles of silicification, DDH BC11, Murrays Reward	20
19. Silicified dolomite vein with minor pyrite and chalcopyrite in carbonaceous slate, DDH BBC9, Murrays Reward	20
20. A general view of 'quartz-dolomite' alteration over eight metres of core, DDH BBC 11, Murrays Reward	21
21. Early dolomite, siderite-magnesite cut by late barren quartz veins	22
22. Dolomite, siderite cut by quartz and pyrite veinlets, DDH BBC11, Murrays Reward	22
23. A typical form of quartz-chalcopyrite lode observed in drill core, DDH BC11, Murrays Reward	22
24. Introduced, late quartz-chalcopyrite replacing earlier-formed, silicified carbonate, DDH BC11, Murrays Reward	22
25. Network of quartz-cassiterite-wolframite veins hosted by siltstone in the Specimen Hill area	23

Tables

1. Deformation events in the Balfour–Temma area	10
2. Oxygen isotope values of the quartz samples, Balfour, Temma and Specimen Hill areas	29
3. Sulfur isotope data for the Balfour and Temma deposits, northwest Tasmania	30

Abstract

The Balfour Copper Belt is a 35 km long, narrow (commonly less than 2 km wide), NNW-trending mineral field in northwest Tasmania. The copper deposits are hosted by pyritic, carbonaceous and chloritic slate and siltstone of Mesoproterozoic age.

Geological, geochemical, mineralogical, stable isotope and fluid inclusion studies suggest that the copper deposits along the copper belt at Balfour were formed during regional hydrothermal events which focussed metamorphic, late granitic and meteoric fluids along faults. These fluids dissolved, transported and subsequently deposited copper, possibly from an existing, sediment-hosted copper deposit.

The copper deposits are transgressive to the stratigraphy and occupy dilational zones such as fault splays, and vein intersections. The style of mineralisation varies from veins and fracture-fillings to breccia-fillings, replacement and disseminated to semi-massive pods. The deposits are characterised by:

- (1) simple primary mineralogy, persisting over the entire belt, comprising chalcopyrite, quartz \pm pyrite \pm carbonates \pm chlorite;
- (2) extensive fracturing, shearing and brecciation of different generations;
- (3) uniform, but high (sedimentary-dominated) sulfur isotope values (\sim 20–23‰);
- (4) fluid inclusions of low salinity (2–15 wt% equivalent NaCl) and variable homogenisation temperatures (<200 to 400°C);
- (5) lack of any correlations between the fluid inclusion homogenisation temperatures and sulfur isotopic data and the depth of underlying granite, as interpreted from gravity data; and
- (6) being generally anomalous in Co, Ni, and to a much lesser extent Au, but lacking any other heavy metals.

The source of the copper is conjectural, but some suggestions can be made. Copper-anomalous, sedimentary pyrite-rich, carbonaceous slate and siltstone has been identified within the Balfour area and may represent a low-grade, stratiform copper deposit. This represents a possible source of sulfur and copper for the fault-related copper deposits along the belt. Magnetic images indicate a direct association between the locations of the copper ore deposits in the Balfour and the Temma areas and some linear anomalies probably representing underlying, shallow, strongly magnetic bodies. The Temma deposits are associated with magnetite-rich ironstones but the nature of the magnetic bodies in the Balfour area is unknown. It is possible that similar iron formations or mafic/ultramafic rocks, representing the original source for the copper deposits, occur within the area. Low grade copper is known in Proterozoic basalts, but these have not been observed in the mineralised areas. The magnetic nature of the copper-rich units identified at Balfour is not known.

In contrast, tin-tungsten-polymetallic deposits, located mainly in the centre of the copper belt, are related to the underlying Devonian Pieman Granite. These deposits exhibit characteristics typical of Devonian granite related mineralisation (cassiterite, wolframite, quartz, pyrrhotite, arsenopyrite, tourmaline, chalcopyrite and pyrite) and are fracture controlled. Sulfur isotope values are mostly lower than those from the Balfour copper deposits, ranging from 7.4 to 15.2‰. Fluid inclusions are of high temperatures (up to 400°C), low salinity (\sim 7 wt% equivalent NaCl) and vary in compositions from H₂O to H₂O + CO₂ \pm CH₄. They may represent fluid immiscibility in the H₂O–CO₂ system.

Reconnaissance studies (geological, geochemistry, mineralogy, fluid inclusions and stable isotopes) from a few copper-base metals deposits in the Temma area show some similarities (oxygen and sulfur isotopes, and fluid inclusion results) between these deposits and the copper deposits occurring along the belt. A related origin for the formation of these deposits is suggested.

While every care has been taken in the preparation of this report, no warranty is given as to the correctness of the information and no liability is accepted for any statement or opinion or for any error or omission. No reader should act or fail to act on the basis of any material contained herein. Readers should consult professional advisers. As a result the Crown in Right of the State of Tasmania and its employees, contractors and agents expressly disclaim all and any liability (including all liability from or attributable to any negligent or wrongful act or omission) to any persons whatsoever in respect of anything done or omitted to be done by any such person in reliance whether in whole or in part upon any of the material in this report.

Introduction

Copper deposits occur in a 35 km long, NNW-trending belt near Balfour in northwest Tasmania. The belt is relatively narrow, less than 2 km wide in the northern section, but becomes more broad and diffuse towards the south (fig. 1). There are also some tin and tungsten deposits in close proximity to some of the larger copper deposits, mainly in the middle of the belt (fig. 1). These exhibit distinctly different mineralogical, geochemical and geological features to the copper deposits. The Temma district, about 20 km to the west, also contains some copper deposits, mostly distinct from those at Balfour.

Although there have been a number of studies of the mineralisation within the area, there are still some fundamental questions that remain to be answered, such as:

- Are the ore fluids responsible for the formation of the copper deposits the same as those for tin-tungsten deposits?
- What is the likely source for copper?
- What is the role of underlying granite in the formation of copper deposits along the belt?
- Is the mineralisation at Temma genetically different from copper mineralisation along the Balfour belt?
- What is the economic potential of the belt as whole?

This study contributes much new information helping our understanding of the nature and sources of the ore bodies. It mainly comprises:

- mineralogical, petrological, structural, geochemical, isotopic and ore fluid studies of several different deposits within the belt and, to a lesser extent, a few deposits in the Temma area;
- discussions on possible origins of the ore-forming solutions and how the copper mineralisation fits among other mineralising events in Tasmania; and
- an assessment of the potential for economic resources within the area.

History and ore production

The first mineral discovery made on the Balfour field was of alluvial tin in the early 1880s. This deposit was worked on very small scale for some twenty years prior to the discovery of copper ore in Tin Creek (Cassiterite Creek) in 1901 (Ward, 1911). During the next few years there was very little tin mining, but extensive prospecting and development work was carried out in the copper deposits.

Copper mineralisation was first discovered by T. C. Murray and F. H. Smith in 1901 in the Balfour area. Mining activities actually started from 1906 and reached the highest level in 1909. Mining commenced at Murrays Reward in 1910 and this became the only mine to produce a significant quantity of copper within the area. The Balfour Central deposit, located 500 m northwest of the Murrays Reward mine, also

produced a few hundreds tonnes of ore. Ore production practically ceased in the 1920s, presumably due to the low price of copper at the time. Leases over the main copper lodes were held until 1967 by the Balfour Mining Syndicate, although Broken Hill Pty. Ltd. surveyed the copper mines in 1965 for tin under an agreement with the syndicate.

The production of either tin or copper is not well known. Although it is unlikely that substantial quantities of either were produced, copper production was greater both in terms of tonnage and value. Based on available Department of Mines records, a total of 126 tons of metallic tin was produced between 1907 and 1942. According to Thomas and Henderson (1943), a total of 6380 tons of copper ore was also produced, mainly from Murrays Reward and the Balfour Central workings by 1917. Some 3.8 tons of metallic copper was produced between 1929 and 1941. More recently, in 1990, some 130 tonnes of ore containing 24.8% copper was mined by Martin Laan (M. Laan, pers. comm.). Old reports indicate that only very rich patches of ore grading between 12 and 35% copper were mined.

The township of Balfour appears to have had a peak population between 1912 and 1917, when some 300 to 800 people were present, decreasing to just a few people by 1942. Presently the township of Balfour has about five part-time residents and only the scattered remains of some original buildings can be found.

Recent exploration

The following is a summary of the major modern exploration activities within the Balfour-Temma area. A comprehensive list of references is included as Appendix 1, with deposit locations listed in Appendix 2.

Rio Tinto (1950)

A magnetic survey indicated a series of NNW-NW-trending anomalies, passing through the Specimen Hill area. This was later confirmed by a survey carried out by BHP in 1965.

BHP (1963-1965)

Work carried out by BHP included drilling, costeaning and geochemical sampling. Seven vertical diamond-drill holes were drilled at the Specimen Hill tin-tungsten prospect. It was found that there are numerous thin quartz-tin-tungsten veins but the overall tin content was considered to be too low to justify open-pit mining and there are not sufficient thick veins for conventional underground mining techniques.

Pickands Mather and Co. International (1965-1967)

An extensive area of the Rocky Cape Group was geochemically sampled. Some discordant magnetite lodes near Temma (to the west of Balfour) were also

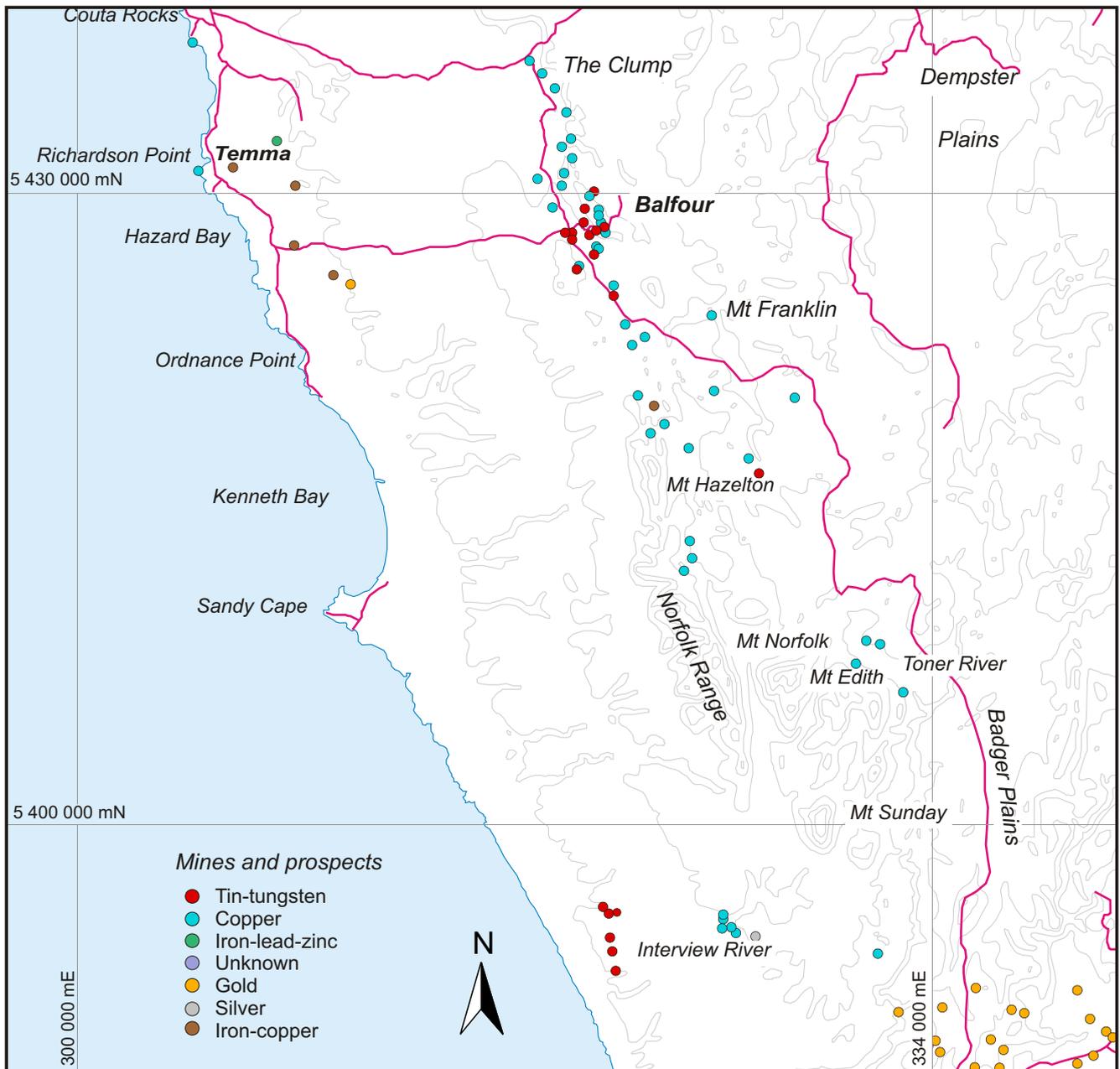


Figure 1

Location map, showing the mineral deposits in the Balfour-Temma area

drilled. The results indicated that these are relatively thin bodies (10 to 15 m thick) with some low grade Zn, Ag, Pb and Cu.

ACI Ltd (1968-1974)

Thirty-seven diamond-drill holes were drilled on eight old prospects including Waratah, Pierpont Morgan, Gully, Development, Murrays Reward, Central Balfour, Balfour Blocks, and The Clump over a strike length of 17 km in the Balfour area. Eight diamond-drill holes were drilled over a strike length of 750 m at The Clump prospect. Quartz-dolomite-chalcopyrite zones were found to be up to 20 m wide, with an average copper content of around 0.5%. The samples were not analysed for gold content. ACI also drilled 19 holes at the Murrays Reward mine. Some of the better intersections were:

- 13.2 m @ 0.62% Cu, from 42.5 m, DDH 21;
- 21.7 m @ 1.40% Cu, from 62.5 m, DDH 16;
- 25.5 m @ 0.77% Cu, from 195.0 m, DDH 36;
- 21.2 m @ 0.94% Cu, from 84.43 m, DDH 14.

The overall result was the delineation of an inferred resource of about 0.5 Mt. @ 0.8% Cu for the Murrays Reward prospect. All the core drilled by ACI was probably disposed of after the exploration program, as there seems to be no trace of it in Tasmania. Unfortunately, much of their work was poorly documented in their exploration reports.

ACI also conducted some surface and underground sampling, costeaning, and IP surveys. Some lithological contacts at The Clump and Specimen Hill were found to be anomalous in copper. Three types of

outcrop were intensely prospected at The Clump prospect area:

- (1) the 'dolomitic quartzite formation';
- (2) a large quartz vein in the southern part of The Clump area; and
- (3) outcrops of limonitic and hematitic 'gossan' developed on pyritic sedimentary rocks.

It was found that only the 'dolomitic quartzite formation' contained significant copper mineralisation (Jackaman, 1972). This was tested by underground workings at the mine site, two adits and a shaft to the north of the mine, as well as by over thirty trenches and pits.

CRA Exploration Pty Ltd (1978–1985)

Eight diamond-drill holes were drilled at the Specimen Hill prospect. It was found that the tin veins were of high grade (average 0.8% Sn and 1.02% WO₃), but they were too thin and too low in vein density to be considered economically significant.

The strong magnetic anomalies in the Little Eel and Possum Creek prospect areas near Temma were tested by two diamond-drill holes drilled by joint venture partner Geopeko. The best intersection was 3 m @ 2% Pb and 13 g/t Ag. CRA also focussed on the base metal potential of the region, including exploration for Pb-Zn within the Cowrie Siltstone unit east of Balfour.

Soloriens Mining Proprietary Limited (1988–1992)

Previous exploration activities were reviewed. A regional gravity survey at an approximately one kilometre station spacing was undertaken. Results from the gravity surveys, previous magnetic data and air photo interpretation indicated that the copper mineralisation may occur at fault intersection sites within a corridor, trending NNW in the Balfour town area and changing to NW in The Clump prospect area. A small but significant anomaly (1 mgal) found by this survey east of the old workings at Murrays Reward was not confirmed by a later review.

A preliminary lead isotope study indicated that the lead in pyrite and galena has a common source from both the copper and tin-tungsten deposits. Isotope ratio growth curves are indicative of a Cambrian age, but if geological and geophysical evidence and the high thorium content for both types of the mineralisation are considered, then a likely source is a Devonian granite carrying lead remobilised from older (Precambrian) rocks (Veska, 1993).

CRA Exploration Pty Ltd (1993–1997)

This company studied the Balfour area for sediment-hosted Cu deposits, looking for stratiform concentrations within favourable sedimentary units, and large, irregular stratabound silica-dolomite bodies (these models will be described in more detail

in the *Genetic Models* chapter). Some of the work included:

- Reviews of previous exploration, mineralisation styles, gravity and aeromagnetic data
- Detailed geological mapping of The Clump and Murrays Reward mines.
- Analysis of 135 float and outcrop samples from various localities for Ag, Au, As, Cu, Pb, Zn, Fe and Mn. The only significant results were from the mineralised areas along the copper belt; best values included 2.3% Cu in 'massive chloritic rock' and 0.8% As and 1.03 ppm Au in a 'quartz-pyrite rock' from the Balfour South deposit.
- Soil geochemical traverses over a pyrrhotitic siltstone along the Balfour copper belt. Copper values up to 34 ppm were found, but were mostly less than 10 ppm.
- Detailed geophysical surveys, including airborne and ground magnetics within the Balfour copper belt.

Regional geological setting

The geology of northwestern Tasmania has been studied by many geologists including Spry (1957, 1962), Gee (1968), Gee *et al.* (1969), Bell (1972), Lennox *et al.* (1982), Brown (1989), Turner (1989), Seymour and Baillie (1992), Everard *et al.* (1996) and most recently by Everard *et al.* (2002) from which a summary is given below and in Figure 2.

The Mesoproterozoic Rocky Cape Group contains the oldest rocks in the area and forms the basement sequence in northwest Tasmania. It consists of a thick, unfossiliferous, dominantly siliciclastic shelf sequence, the basement of which is unknown. According to the most recent classification (Everard *et al.*, 2002), the Rocky Cape Group has been divided (from youngest to oldest) into:

- Jacob Quartzite (Gee, 1968)
- Irby Siltstone (Gee, 1968)
- Detention Subgroup (Gee, 1968)
- Cowrie Siltstone (Spry, 1957; Gee, 1968)
- Balfour Subgroup
- Lagoon River Quartzite (Gee *et al.*, 1969; Bell, 1972)
- Pedder River Siltstone (Bell, 1972)

The Balfour Subgroup consists of interbedded sandstone and siltstone, carbonaceous pyritic siltstone and shale, quartz arenite and chloritic siltstone. It conformably overlies the Lagoon River Quartzite and is apparently conformably overlain by a correlate of the Cowrie Siltstone in the vicinity of Balfour. The Balfour Subgroup and the Cowrie Siltstone are potential source rocks for copper mineralisation along the Balfour copper belt and in the Temma area. This will be discussed in the chapter on genetic models.

A tectonically stable, shallow marine depositional environment is suggested for the formation of the quartzites. In contrast, the Cowrie Siltstone is mainly carbonaceous, and diagenetic pyrite is very common,

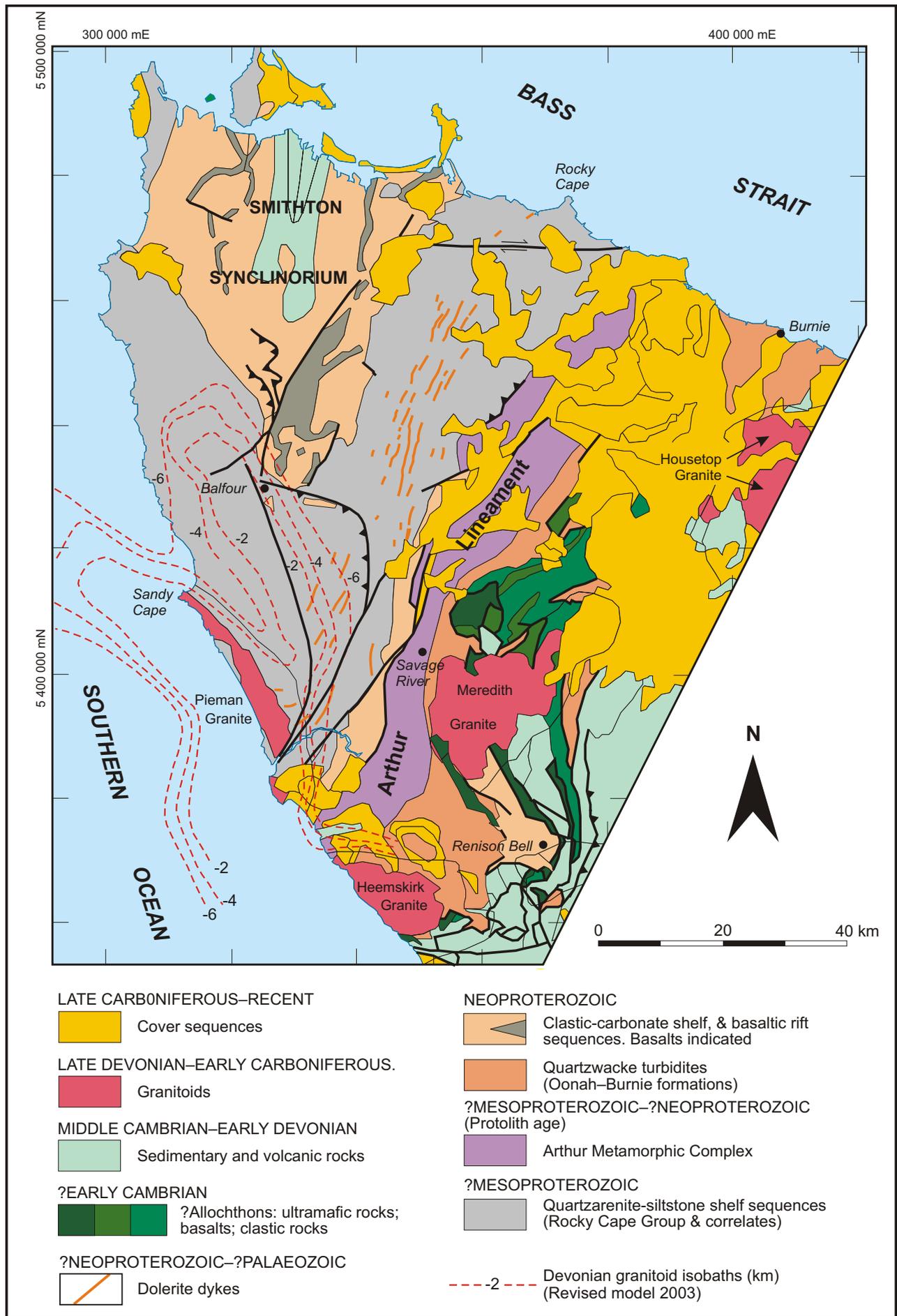


Figure 2
Regional geology, northwest Tasmania

indicating reducing depositional conditions. It has been interpreted that the Cowrie Siltstone was deposited in a large, shallow, stagnant lagoonal environment, largely isolated from marine currents (Everard *et al.*, 2002). The presence of likely anhydrite casts in the unit is consistent with shallow water, locally evaporitic conditions. The Balfour Subgroup represents a much higher-energy environment with current-influenced deposition than the Cowrie Siltstone.

The Rocky Cape Group is overlain by the Togari Group of Neoproterozoic–Early Cambrian age. A low angle unconformity separates Rocky Cape Group rocks from the overlying Togari Group along the eastern margin of the Smithton Synclinorium, near the mouth of the Black River east of Smithton (Lennox *et al.*, 1982; Brown, 1989). On a regional scale, the Rocky Cape Group is overlain by the Togari Group at different stratigraphic levels in different localities around the margin of the synclinorium (Seymour and Baillie, 1992; Everard *et al.*, 1996). This has previously been ascribed to a compressional deformational event prior to Togari Group deposition, but it is also consistent with extensional tectonism during that time (Everard *et al.*, 2002).

The Togari Group is up to four kilometres thick and mainly consists of conglomerate, dolomite and chert, siliceous and volcanoclastic sedimentary rocks, and basalt. It is divided into the Forest Conglomerate and Quartzite (0–120 m thick), Black River Dolomite (800 m), a sequence of intercalated lithicwacke, tholeiitic basalt, diamictite, lithicarenite, hematitic ironstone, mudstone and impure carbonate (Kanunnah Subgroup 1400 m), Smithton Dolomite (1500 m), and the uppermost Salmon River Siltstone (350 m).

The basalt units (Spinks Creek Volcanics) form the middle to lower part of the Kanunnah Subgroup and are thickest east of the Roger River Fault. They mainly consist of massive to locally pillowed, dominantly tholeiitic basalt. The volcanic rocks are metamorphosed up to the prehnite-pumpellyite or, rarely, greenschist facies. They are commonly anomalous in copper, reaching up to 590 ppm (Everard *et al.*, in press). Copper appears to vary erratically, does not show any relationships with other elements, and is unrelated to the particular basalt suite. The basalt is thought to be a possible copper source for the copper mineralisation in the Temma–Balfour area.

The post-Proterozoic units present are siliceous gravel with interbedded quartz sand and clay of probable Tertiary age (?pre-basalt), Tertiary basalt and Quaternary talus, alluvium and swamp deposits. Tertiary basalt occurs mostly as thin hill cappings, which are probably the dissected remnants of an extensive series of flows that once covered much of the region. Chemically the basalts are mostly moderately fractionated and range from basanite through alkali olivine basalt and hawaiite, to transitional olivine basalt and tholeiite.

Two early phases of syndepositional extension were followed by at least four compressional phases of deformation within the area. The first two phases of deformation (D_1 , D_2) are possibly of Cambrian age whereas D_3 and D_4 are considered to be Devonian in age. D_3 is the main deformation phase and is characterised mainly by northwest-trending folding, some cleavage development and major northeast-directed low and high angle thrusts, one of which hosts the copper mineralisation at Murrays Reward mine along the copper belt. East of Balfour, ENE- to northeast-trending strike slip faults pre-date late northwest-trending reverse faults. One of these faults hosts vein style Sn–W mineralisation at Specimen Hill (Reed *in* Everard *et al.*, 2002).

Local geology

The geology of the Balfour area (fig. 3) has been studied in detail by Turner (1994). The following is basically a summary of the work carried out by Turner (1994) and Everard *et al.* (2002) with minor inputs derived from our field observations.

The rocks in the Balfour area mainly consist of the Balfour Subgroup and Cowrie Siltstone overlain by some minor Tertiary basalt and younger deposits (fig. 3). Balfour Subgroup is a sequence of siliceous sandstone and siltstone, carbonaceous pyritic siltstone and shale, quartz arenite and chloritic siltstone that conformably overlies the Lagoon River Quartzite and is conformably overlain by a correlate of the Cowrie Siltstone in the vicinity of Balfour. These rocks are unconformably overlain by the Togari Group, which consists of a discontinuous basal, siliceous conglomerate overlain by tholeiitic basalt and associated volcanoclastic rocks, and variably silicified dolomite.

The local structure of the Balfour area is dominated by a number of faults, including an east-trending fault which separates the Balfour South prospect area from a block containing Balfour. There is also the regionally extensive, northeast-trending, steeply-dipping Roger River Fault (fig. 3) that separates the block containing The Clump prospect area from the Balfour area. There are some NNW-trending faults of complex nature around Mt Frankland which form the eastern boundary to the block containing the Balfour and the Balfour South prospects.

Turner (1994) subdivided the older rocks of the Balfour area (Rocky Cape Group) on the basis of lithological associations, mainly the character of siltstone which is the most common rock type in the area. There are lithological sequences where the siltstone is dark grey (carbonaceous), whereas in other sequences it is green or olive (chloritic). The rocks along the Balfour track and west of Murrays Reward consist of a conformable, east-facing sequence ranging from quartz arenite to grey siltstone in the west, changing into green and grey siltstone with interbedded quartz arenite to the east, near Murrays Reward. Similar stratigraphy continues to the south and north of the Murrays Reward mine.

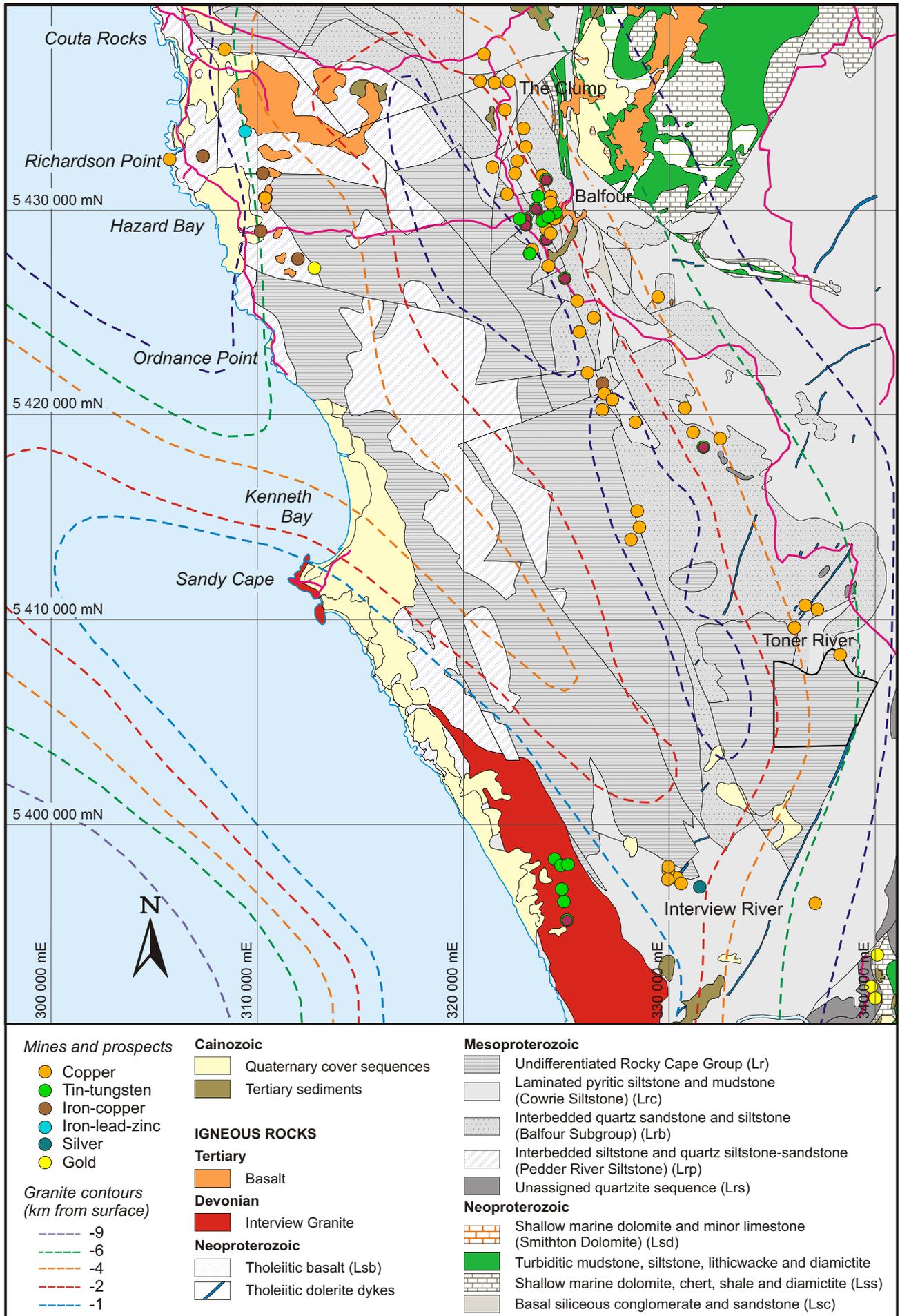


Figure 3. Local geology, Temma-Balfour area

The Neoproterozoic sequences (Togari Group) include units correlated with the Forest Conglomerate and the Spinks Creek Volcanics, both of which are present on Blackwater Road. These formations are laterally offset by some 2.5 km along the Roger River Fault and they reappear to the southwest (around 324 000 mE; 5 436 000 mN). The Black River Dolomite was not observed within the area.

The Forest Conglomerate and Quartzite consists of siliceous conglomerate and well-sorted quartz arenite. The Spinks Creek Volcanics are basaltic but most exposures are deeply weathered.

Based on the gravity interpretation of Leaman and Richardson (2003), the Rocky Cape Group has been overthrust onto the younger sedimentary rocks and basalt (i.e. Togari Group) of the Smithton Synclinorium. The succession has been folded, forming the eastern limb of a southerly extension of the large anticline that occurs south of Marrawah (Seymour and Baillie, 1992). Small scale, NNW-trending folds showing different plunges are also common within the area including at Balfour South, on the Heemskirk Road, on the Blackwater Road and around Specimen Hill. The relationships between these faults and the regional anticline are not yet known.

There are no granitic outcrops known within the Balfour–Temma area. The nearest outcrop of granite (the Pieman Granite) is at Sandy Cape, some 22 km southwest of Balfour. Based on a gravity interpretation (Leaman and Richardson, 2003), a NNW-trending granite spine shallowly underlies (~2 km) most of the copper and tin-tungsten deposits along the belt. Most of the Sn-W prospects, as well as some nearby copper deposits (e.g. Murrays Reward), occur where the interpreted granite surface is about two to four kilometres deep.

The Balfour and Temma areas are structurally complex. Everard *et al.* (2002) have recognised at least two extensional and four compressional deformation events; these are summarised in Table 1.

Extensional structures and the results of their influence on sedimentation are preserved in Rocky Cape Group rocks on the Temma coastline (Everard *et al.*, 2002). Extensional structures can be economically significant as they may act as conduits for the hot, ascending metal-rich brines from which some major stratiform copper deposits are believed to have been formed (Brown, 1984). There is evidence in the stratigraphy that the Roger River Fault originated as an extensional, syn-depositional fault, and formed the western boundary of a half-graben into which Togari Group sedimentary and volcanic rocks were deposited. This is indicated by marked variations in the thicknesses of stratigraphic units across the fault.

The first two compressional deformations (D₁ and D₂) are both probably Cambrian in age (Everard *et al.*, 2002). D₁ can only be seen on a microscopic scale, whereas D₂ has associated mesoscopic folds. The S₁ cleavage is commonly defined by an alignment of chlorite between variably sutured quartz and feldspar grains. It strikes about E–W and dips between 20° and 45°N in weakly deformed rocks from east of Mt Frankland.

The S₂ cleavage (related to D₂ structures) is similar in form to, but typically cross-cuts S₁. It is defined by preferred alignment of chlorite grains and strikes east-west and dips about 20° to 45° S.

D₃ structures are seen west of the Frankland River where a northwest-trending D₃ anticline deforms Balfour Subgroup sedimentary rocks. The northeast limb of the anticline is truncated by southwest-dipping thrusts. Reverse movement on thrusts has placed older (Rocky Cape Group) over younger (Togari Group) rocks. Exposure of the thrusts is typically poor. One

Table 1
Deformation events in the Balfour–Temma area (A. R. Reed and D. B. Seymour, pers. comm.)

<i>Deformation event</i>	<i>Nature of deformation</i>	<i>Description/location</i>	<i>Mineralisation</i>
Extension	Growth faulting associated with deposition of Rocky Cape Group	Outcrop-scale growth faulting near Temma coast	
Extension	Growth faulting associated with deposition of Togari Group	Block rotation during extension may account for unconformity between Rocky Cape and Togari groups	
D ₁	?Tyennan Orogeny	Foliation pre-dates chlorite porphyroblasts observed in thin sections of Rocky Cape Group rocks (e.g. southeast of Mt Franklin)	
D ₂	Tyennan Orogeny / Tabberabberan Orogeny	E-W trending folds and cleavage in Rocky Cape and Togari groups (e.g. southwest of Mt Frankland)	
D ₃	Tabberabberan Orogeny	NW-trending folds and thrusts. Reactivation of Roger River Fault	Copper mineralisation (Murrays Reward mine), Sn-W mineralisation (Specimen Hill)
D ₄	Tabberabberan Orogeny	Open upright north-trending folds (regionally developed)	

structure (322 590 mE; 5 433 760 mN) is an intensely brecciated and silicified zone separating older sandstone (Rocky Cape Group) in the hanging wall from younger chloritic siltstone (Togari Group) in the footwall. The along-strike continuation of this structure cropping out in Cassiterite Creek hosts the Murrays Reward copper deposit at Balfour and possibly other nearby copper deposits.

Northwest-trending reverse faults dissect the core of the northeast-verging anticline west of the Frankland River. The largest of these faults hosts the Specimen Hill Sn-W deposit at Balfour. Field observations and IP-based geophysical cross-sections show the faults dipping steeply both northeast and southwest, with the Specimen Hill Fault dipping moderately to the southwest (Menpes, 1995).

D₄ structures in the Balfour area are open upright folds, verging toward the west. Steeply east-dipping D₄ reverse faults have also been recognised along the Temma coast, overprinting D₃ structures.

Both D₃ and D₄ structures are interpreted to be Devonian in age.

Metamorphism

The area has been affected by regional greenschist facies burial metamorphism. Burial metamorphism is indicated by the lustrous bedding parting in pelitic rocks and also from isoclinally folded sandstone dykes. Recrystallisation associated with regional metamorphism is indicated by the occurrence of mica flakes with a slaty, bedding-parallel alignment. Bladed to tabular green chlorite, commonly forming aggregates up to 1 mm in diameter, is the most commonly preserved regional metamorphic mineral, but garnet has also been noted (Bottrill, 2004) and biotite may have been retrogressed to chlorite. Grey and green siltstone in different parts of the Balfour area also show metamorphic spotting, particularly where intense cleavages have developed (Turner, 1994).

Turner (1994) reported some "probable greisen" veinlets, which had been "thermally metamorphosed" near the junction of Blackwater Road and the Heemskirk Road. These are hosted by grey siltstone and mainly consist of quartz and chlorite. This is unconvincing evidence as the veinlets may have been metasomatically altered. The occurrence of greisens in this area appears to be unlikely, as the underlying granite surface is interpreted to occur at depths greater than six kilometres (Leaman and Richardson, 2003). The gravity data are coarsely spaced and there could be undetected cupolas of granite within the area.

Mineralisation and associated alteration

Mineralisation in the Balfour area has been described by Ward (1911) and many exploration geologists. A list of company reports describing the mineralisation in the Balfour and Temma area is included as Appendix 1. Two Honours theses describing the

mineralisation in the Murrays Reward mine area have also been written (Yaxley, 1981; Veska, 1993).

In general, the primary mineralisation in the Balfour area can be divided into two main types:

1. Numerous small copper lodes occurring along the 35 km long, NNW-trending Balfour belt. There are also some old copper prospects some 10 km to the south of the Toner River copper prospect, at the southern end of the copper belt (fig. 1) which may represent an extension of the copper belt. Copper mineralisation has been considered to be economically more significant than other types within the area. There are also a few copper lodes of similar nature to those observed along the copper belt in the Temma area.
2. Vein and stockwork-style tin and tungsten deposits lying in close proximity to the copper lodes, located approximately in the middle of the copper belt (fig. 1).

There are also some transgressive magnetite-dominated lodes, in addition to copper deposits, in the Temma area near the coast, 18 km west of Balfour. The deposits appear to show similar trends to the Balfour copper belt (fig. 1). They are up to 15 m thick and contain varying amounts of hematite, chalcopyrite, tetrahedrite, galena, sphalerite, pyrite, Fe-Mn-carbonates and silicate minerals.

Mineral deposits of secondary nature include alluvial tin, mostly in close proximity to some tin lodes, and subeconomic coastal sand dune deposits containing cassiterite, chromite, zircon and rutile.

Samples (rock chip and core) used for this study are described in Appendix 3.

Copper lodes

Mineralised rocks from outcrops, dumps and old workings along the belt are generally intensively weathered and leached (plates 4, 7 and 14), making it almost impossible to study the nature and mineralogy of mineralisation and associated alteration. Supergene alteration of chalcopyrite to covellite and digenite is evident in the Murrays Reward open cut where it has produced some secondary enrichment of the ore at or near surface. The leaching effect on sulphide minerals can be seen in the quartz samples on the Balfour South and Balfour Blocks prospect dumps where the samples commonly consist of porous quartz with remnants of sulphide minerals, mainly pyrite. Dolomite appears to have been completely leached, leaving cavities with a rhombohedral crystal shape.

The drilling programs undertaken by ACI in the early 1970s indicate that supergene alteration extends to depths greater than 150 metres. Extensive supergene alteration, together with brecciation and shearing, resulted in poor core recovery in some drill holes. As a result, the actual thickness and ore grade of some mineralised sections could not be accurately determined.

According to Jackaman (1972), quartz-dolomite occurs conformably within a sequence of carbonaceous siltstone, shale and sandstone, based on surface geology and costean geochemistry. This was not confirmed by our field observations, which found the lodes to cross-cut the stratigraphy.

The following are brief descriptions of mineralisation at three different deposits, including the Murrays Reward, Toner River, and Balfour South, where the actual copper lodes are exposed and their relationships with the host rocks can be studied. Other copper deposits, including The Clump, Waratah, Balfour Blocks, Balfour Central, Tatlows and Specimen Hill were also visited and have been briefly described in Appendix 4. All known mineral deposits and their locations in the Balfour-Temma area are listed in Appendix 2.

MURRAYS REWARD

Veska (1993) and Turner (1994) have described the mineralisation in the Murrays Reward mine, the largest copper deposit along the copper belt. Workings consist of four adits, an open cut (~30–15 m), shafts and trenches. The copper mineralisation in the open cut comprises numerous quartz-pyrite-chalcopyrite veins associated with a sheared zone that hosts some small, high-grade lenses of supergene-enriched copper (mainly covellite and digenite) ore. The sheared zone is related to a NNW-trending fault contact between carbonaceous slate to the west (hanging wall) and chloritic slate and siltstone to the east (footwall) (plate 1, 2). Hydrothermal alteration associated with mineralisation includes silicification, chloritisation and sericitisation. Silica and sericite content of the footwall chloritic slate commonly increases towards the mineralisation, whereas the carbonaceous hanging wall is chlorite enriched. The carbonaceous slate is copper-anomalous (up to 1100 ppm, Turner, 1994) and is rich in pyrite of possibly sedimentary origin (e.g. around 324–600 mE; 5–429–500 mN). No systematic regional sampling has been undertaken to compare the overall copper content of the carbonaceous slates to those occurring in the vicinity of the copper ore deposits. The mineralised zone at the Central Balfour prospect is also located at a boundary between the chloritic siltstone and slate and carbonaceous shale.

The mineralisation was probably introduced during a tensional phase and is characterised by quartz-sulfides-dolomite veining, extensive shearing, fracturing, and brecciation and occurring along hinges of small folds (plates 2–5, fig. 4). Carbonates are rare at the surface and in shallow workings (as at all the studied deposits) due to leaching, but are common at depth (McIntyre, 1973; Russell and Tear, 1997).

TONER RIVER

The Toner River prospect, located at the southern end of the copper belt, is one of the very few locations in the

belt where primary copper mineralisation can be seen *in situ*.

The main (mineralised) lode, exposed in an exploration trench, strikes NNW and is about 0.5 m wide with pyrite pods and narrow chalcopyrite veins of about 50 to 100 mm wide (plate 8).

The chalcopyrite and pyrite veins exhibit pinching and swelling along the lode (plates 9, 10). The mineralisation is hosted by a narrow zone (~3 m) of chloritised slate, changing into a highly silicified zone about seven metres wide. The silicification pre-dates the veining and mineralisation. This is shown by the occurrence of chloritic/silicified clasts within the lode. The silicified zone is not symmetrical relative to the copper lode and mainly occurs to the south of the lode (plate 8). There are a few thin barren quartz veins adjacent to the lode showing the same strike and these are cut by a late set of flat-lying, thin, barren quartz veins (plate 11). There is no identifiable dolomite zone within the mineralised section. The mineralogy of the ore samples is similar to that observed at the other copper prospects along the belt and is characterised by a simple primary mineralogy: pyrite, chalcopyrite and quartz-dolomite-chlorite. The quartz on the dumps and outcrops is mostly porous, due to leaching of sulfide minerals, mainly pyrite, from surface samples. The dump material is rich in chalcopyrite and can possibly have up to 20% chalcopyrite (plate 12). The mineralisation occurs within a fault/shear zone and is strongly cleaved, brecciated and sheared.

There are some two to three metre wide, white, barren quartz veins, striking northwest, located about 100 m northeast of the prospect. The quartz veins are hosted by siltstone and show sharp contacts with the country rocks with no visible wall rock alteration.

BALFOUR SOUTH

The Balfour South prospect consists of an adit and a shaft. The adit is driven east-west and is about 20 m long. The area is characterised by close folding where the weak zones (hinges) have acted as fluid conduits during deformation. This is shown by the occurrence of a small fold just outside the adit. The fold plunges at about 30° SSW and has been faulted in the hinge region (fig. 4). The eastern limb is dipping 80° SSE while the western limb is dipping about 60° WNW. The fault zone is about 2.5 m wide, striking SSW and dipping steeply southeast. It includes a mineralised zone, about one metre wide, on the eastern side (hanging wall) of the fault zone. The mineralised zone is extensively brecciated, containing some pyrite 'clasts' and porphyroblasts, which are rounded to elongated with rounded edges and vary in size, reaching up to about 200 mm. The clasts may represent an early, massive sulphide formation, pre-dating copper mineralisation and formed at deeper levels, that has been brecciated and pushed up along the fault to be cemented by later quartz. They may also represent remains of some pyrite veins that have been pulverised and recrystallised through extensive and multiple



Plate 1

Southern end of the Murrays Reward open cut showing the occurrence of the copper lode along a NNW-trending fault. The fault dislocated the eastern, vertical to overturned limb of a broad anticline, with axis trending NNW and plunging south. The lode occupies the contact between the carbonaceous and chloritic slate and siltstone. The grey (siliceous) zone to the right of the lode has been probably formed after dolomite, by leaching.



Plate 2

As for Plate 1, showing the details of the mineralisation. Note the location of the lode at the contact between the carbonaceous and chloritic slates and also the intensely fractured and brecciated nature of the host rocks. The green spots are copper sulfate minerals.

Plate 3



Plate 4



Plate 5



Plate 6

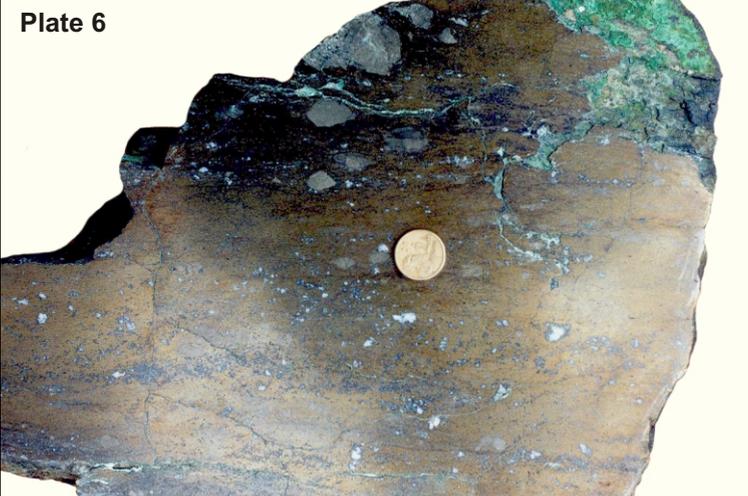


Plate 3

Silicified, sheared, boudinaged and mineralised carbonaceous slate. This is an early, probably pre-copper stage of mineralisation and is a common feature in copper deposits along the belt. Note that: (i) pyrite is the only sulfide; (ii) quartz veins show combined brittle and ductile deformations; (iii) pyrite with minor small quartz clasts is finely brecciated within the vein; (iv) more than one generation of barren quartz occurs within the rock; (v) the sheeted nature of the rock may represent the original cleavage in the rock; and (vi) the shear joints are characterised by the occurrence of thin layers of carbonaceous slate.

Murrays Reward open cut.

Plate 4

Intensely brecciated copper ore (chalcopyrite and minor pyrite) containing remnants of deformed carbonaceous slate clasts (black), Murrays Reward mine.

Plate 5

Leached, late-stage brecciation in a copper ore. Fragments include barren quartz, copper sulfides, pyrite, iron oxide and weathered country rock. Most fragments have already been brecciated in earlier phases of deformation. Balfour Blocks prospect.

Plate 6

Massive, mylonitised copper ore, Murrays Reward. Note the small clasts? (boudins) of pyrite and quartz in chalcopyrite. These clasts normally have higher sulfur isotope values than the hosting chalcopyrite.

Plate 7

Silicified rock veined by late, deformed, displaced, barren quartz veins. The porous nature of the rock is due to leaching of pyrite. This early silicification pre-dates copper mineralisation. Murrays Reward open cut.

Plate 7





Plate 8.

Copper lode (brown), consisting of quartz, chalcopyrite veinlets and pyrite pods. The mineralisation is hosted by silicified, chloritised slate. Note the barren quartz veins occurring next to the lode and showing a similar trend. Dolomite is absent in the mineralised zone. The width of the lode is about 0.5 metres. Toner River prospect.

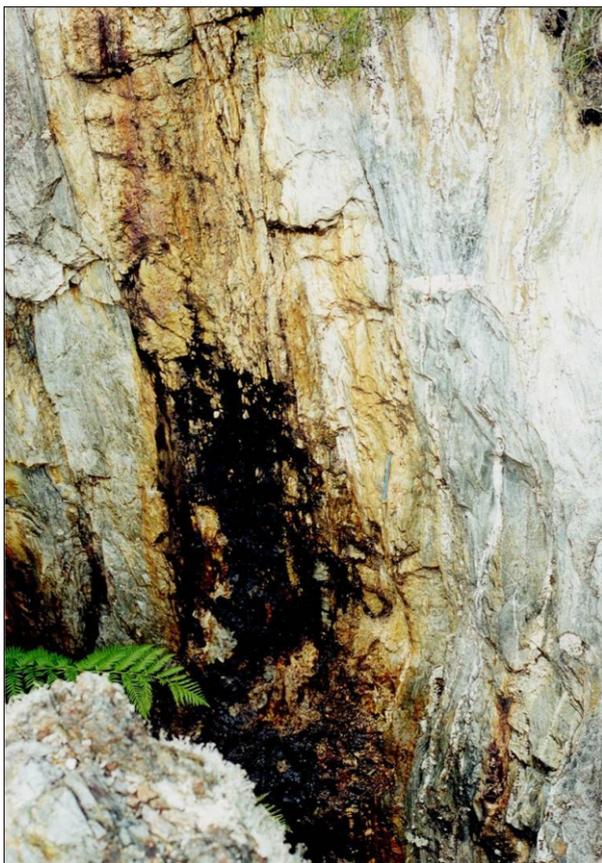


Plate 9

Toner River copper lode with the adjacent late barren quartz veins. The veins (fracture filling) pinch and swell and vary in dip from near-vertical to flat-lying. Note an elongated pyrite pod within the lode. Copper lode width is about 0.5 metres. Looking south.



Plate 10

A close up of Plate 9 showing the elongated pyrite pod within the lode. Note the pinching and swelling of a truncated quartz vein? in the same lode.



Plate 11

Early-formed silicified rock (adjacent to the copper lode), veined by near-vertical barren quartz veins (vq) which in turn are cut by late shallowly-dipping thin barren quartz veins (sq), Toner River prospect.



Plate 12

An old shaft sunk on the main copper lodes. The dump material may contain up to 20% chalcopryrite, Toner River prospect.

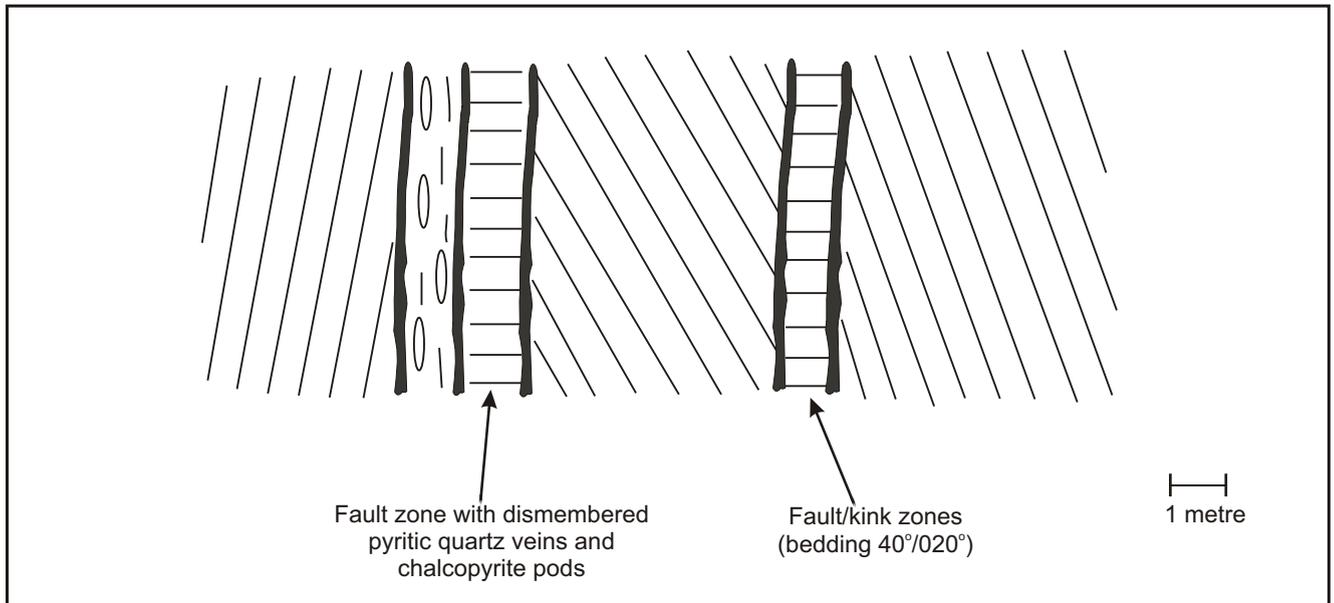


Figure 4

A sketch, showing the occurrence of copper lode along the fold hinge, Balfour South.

phases of deformation. Chalcopyrite occurs along the edges of the mineralised zone and appears to have been introduced late into the system. It is absent in pyrite clasts. Similar structures to that mentioned above, but at a smaller scale, were observed inside the adit. There is no evidence of quartz-dolomite in the area, but some quartz is apatite-rich. Apatite was not observed in any of the other prospects visited.

Different generations of brecciation can be observed in some rocks in the South Balfour mine dumps (plate 13), where breccia fragments can be seen within a later-formed breccia. Quartz veins, up to 50 mm wide, have been broken and in places folded. Porous quartz found in tailings probably represents leaching of pyrite from quartz. This is different to what is observed at the Balfour Blocks, where most quartz is also porous but the cavities largely exhibit rhombohedral shapes, indicative of pre-existing carbonate, probably dolomite (plate 14).

A very similar structure to that observed at the South Balfour can also be seen in the open cut at the Murrays Reward mine, where the major mineralised fault (the Balfour Fault) is formed along the axial plane of a broad anticline with axis trending northwest and plunging about 55°S. A similar structure, but at a very small scale, can also be seen on a track south of The Clump prospect, where a barren quartz vein is formed along an axial plane of a very small fold (plate 15).

SUMMARY OF FIELD OBSERVATIONS

Based on field observations, the characteristic of copper mineralisation along the belt from Toner River (far south) to The Clump prospect (far north) are summarised below:

- Copper mineralisation is structurally controlled and the lodes occur in dilation zones and are mainly fault related. Sheared/fault zones mostly acted as

the main conduits for the mineralising fluids. The rocks in all the mineralised areas show a complex history of deformation, including small-scale folds, small faults, vein deformation (both of ductile and brittle nature), extensive fracturing and multiple brecciation phases.

- The primary ore mineralogy mainly consists of chalcopyrite, pyrite, quartz, dolomite, and chlorite, with rare apatite in Balfour South. Chalcopyrite does not appear to be co-genetic with pyrite or quartz in most places and indicates a later phase of hydrothermal activity. Pyrite mainly occurs as clasts in quartz and chalcopyrite and thus clearly pre-dates the formation of both minerals.
- Quartz veins are of several different generations and are mostly barren. Mineralised quartz samples are commonly porous due to leaching of sulphide minerals (where cavities are irregular) and carbonate minerals (distinguished by rhombohedral cavities).

DRILL CORE

The nature of the associated hydrothermal alteration was studied in more detail by inspecting the available three drill cores from Murrays Reward prospect. There are also some core logs for 37 drill holes, with a total depth of more than 4100 m, drilled along the copper belt at eight different prospects. The holes were drilled by ACI in the early 1970s, but the wooden core trays were kept outside and eventually destroyed by time (M. Laan, pers. comm.).

The following observations are derived from the inspection of the available core from the Murrays Reward mine and the ACI core logs. It should be mentioned that the descriptions in these core logs are very general and the paragenetic relationships of the hydrothermally-formed minerals were not discussed.



Plate 13

Fault/sheared-related copper lode, South Balfour, consisting of quartz, pyrite and chalcopyrite. Chalcopyrite mainly occurs at the boundary between the country rock and the lode. Note the extensive fracturing, brecciation, pinching and swelling and leaching within the lode.



Plate 14

Porous quartz after carbonate which is characterised by rhombohedral cavities, Balfour Blocks.



Plate 15

Occurrence of quartz veins along the axial surface of kink bands near The Clump prospect.

The ACI core logs do indicate that the hydrothermal alteration and associated mineralisation for the drill-tested copper deposits along the belt are very similar to that observed in this study from the drill core at the Murrays Reward. This suggests that the ore-forming minerals from other copper deposits have also had similar paragenetic relationships to those observed from the Murrays Reward drill core.

In general, the mineralised sections of core are commonly intensively broken, sheared and, in places, brecciated, with puggy zones (faults) being common. They vary widely in thickness, copper content, mineral assemblages and alteration intensity. The contact between the country rocks and the mineralised sections are sharp and are probably fault contacts. Dark grey carbonaceous siltstone and slate commonly host the mineralised sections (e.g. The Clump prospect, Murrays Reward). At Balfour Blocks the common rock for mineralisation is deformed chloritic siltstone (ACI core log). The mineralised zones (dolomite quartz chalcopyrite pyrite chlorite) can be repeated over 40 m wide in some mineralised intervals. The mineralised zones vary in width from less than one to a few metres.

There are basically two different pervasive alteration types observed in drill core:

- (1) chloritisation, which is very common, formed very early in the alteration, replacing the original country rocks. It is often cut and replaced by later-formed minerals such as quartz and carbonate veins. Chlorite may also occur as a later hydrothermal product associated with quartz carbonate veins.
- (2) silicification, replacing (brecciated?) country rocks, mainly siltstone and slate and these form the margins of the mineralised sections (plates 16, 17, 20). This early silicification is commonly barren and in some places is cut by numerous thin (<20 mm) mineralised veins of quartz carbonate chlorite pyrite chalcopyrite. It may also occur in later stages replacing brecciated, chloritised slate and brecciated dolomite (plate 18).

Carbonate minerals (dolomite, siderite, magnesite) are also common in mineralised zones in drill core from different copper deposits (plate 19). They occur as veins and commonly show sharp contacts with the host rocks, which appear to be mostly fault/sheared contacts. Siderite is dark brown in colour and replaces the creamy-coloured dolomite. Magnesite is closely associated with siderite and was identified through XRD analysis. Both dolomite and siderite occur as massive masses and vary in width from a few centimetres to about one metre. There are also thin veinlets of carbonate minerals cutting early, massive dolomite. Dolomite selectively replaces the brecciated and chloritised rocks and is extensively veined by late, barren quartz (plate 20, 21, 22) and, to a lesser extent, by chalcopyrite and pyrite veins. It is important to

notice that the quartz and sulfide veins post-date the early, almost barren, dolomite.

There are some sections of the drill core where dolomite is massive and weakly veined and may contain only a few hundred ppm of copper. It is likely that the carbonate sections have been formed along fractures and faults and have been repeatedly veined and partially replaced by products of later hydrothermal activity. The source of the carbonate minerals is not known. ACI core log describes the occurrence of some thin "quartz-dolomite" bands (50-100 mm wide) which have been cut by chalcopyrite-bearing veins. The bands are likely to represent veined, early dolomite, a similar feature which can be seen in drill core from the Murrays Reward mine.

Quartz veins, the most common vein type, are mostly barren, commonly thin (200 mm or less) and are paragenetically of multiple generations (plate 16, 17, 18). Other vein types include pyrite quartz, quartz-chalcopyrite pyrite, and quartz-chlorite, all of which are narrow, ranging from less than 10 mm to 150 mm in width. The term 'quartz-dolomite', commonly used by exploration geologists, can be misleading as the quartz is a later phase cutting dolomite sections and can be barren.

Pyrite mainly occurs as an early-formed (sedimentary), disseminated, fine grained mineral in carbonaceous and chloritic siltstone and slate. Later (remobilised?) pyrite is seen in mineralised sections as fracture fillings, veinlets and in quartz veins. It appears (paragenetically) as an early phase relative to chalcopyrite in veins.

Chalcopyrite is a late-forming mineral and mainly occurs as fracture fillings, irregular and discontinuous stringers along incipient fractures, disseminations and small (10 to 20 mm diameter) patches in quartz, and as clots filling brecciated dolomite (plate 23, 24). Chalcopyrite may not be directly associated with the formation of dolomite, as there are some massive dolomite sections with no visible chalcopyrite and which are very low in copper content (Russell and Tear, 1997). Chalcopyrite is a later-formed mineral than pyrite, which may indicate its remobilisation from dolomite and subsequent precipitation in late-forming breccias and fractures in quartz, although there is no direct evidence from field observation and petrography to support this. There are also some 'quartz-dolomite' sections with no visible chalcopyrite in mineralised sections.

Trace amounts of galena and sphalerite, and to a less extent bornite and covellite, occur in some mineralised sections (e.g. The Clump prospect, ACI reports).

Minor magnetite associated with actinolite and chalcopyrite has been reported in a mineralised dolomite-rich zone in one drill hole (DDH6) from The Clump Prospect.

A generalised paragenesis for the hydrothermally-formed minerals along the copper belt is shown in Figure 5.



Plate 16

Silicified rocks with minor pyrite cut by later generations of barren quartz veins. This stage of silicification pre-dates copper mineralisation. DDH BC9, Murrays Reward.

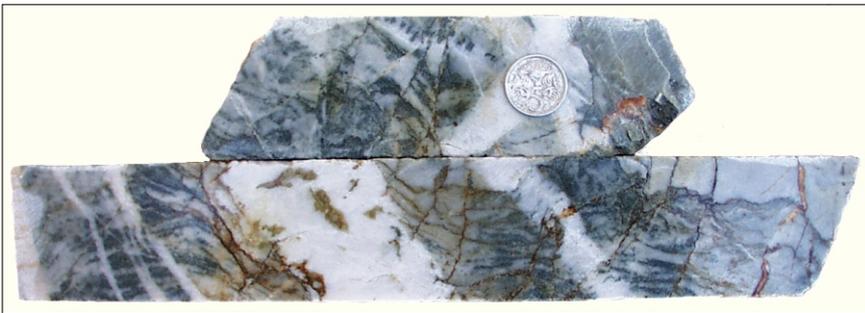


Plate 17

Silicified carbonaceous slate (sil) cut by barren quartz veins (qtz). DDH BC11, Murrays Reward.



Plate 18

Two styles of silicification, one resulting from the brecciation/replacement of carbonaceous slate (sil-carb) and the other formed from silicification of pre-existing dolomite (sil-dol). Both are unmineralised. DDH BC11, Murrays Reward.



Plate 19

Silicified dolomite vein with minor pyrite and chalcopyrite in carbonaceous slate. DDH BBC9, Murrays Reward.

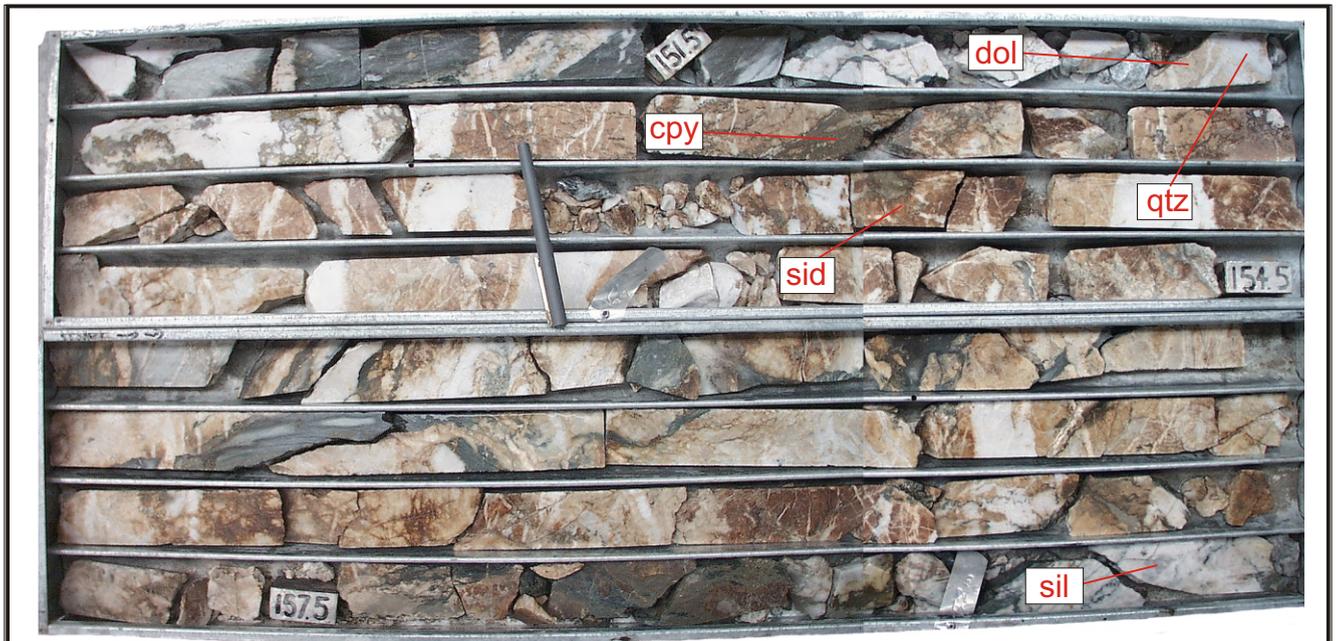


Plate 20

A general view of 'quartz-dolomite' alteration over eight metres of core from Murrays Reward. The figure shows: (I) the early dolomite (dol) that is unmineralised and is cut by quartz veins (qtz) of possibly different generations; (ii) replacement of dolomite by siderite (sid); (iii) early silicification (sil), probably formed as a result of replacing carbonaceous slate and may only contain pyrite; and (iv) chalcopyrite (cpy) and associated minor quartz are possibly the latest additions to the highly reactive, hydrothermally altered section, replacing carbonates and earlier-formed quartz. DDH BBC11, 150–158 m.

Mineral	Paragenetic stage	
	Early	Late
Quartz	-----	
Chlorite	-----	-----
Dolomite	-----	
Siderite		-----
Magnesite		-----
Pyrite	-----	
Apatite	-----	
Chalcopyrite		---
Sphalerite	-----	?
Galena	-----	?
Magnetite	-----	??
Actinolite	-----	?

?? Minor, reported by ACL geologists in core log

Figure 5

Generalised paragenesis for the hydrothermally-formed minerals along the Balfour copper belt.

Tin-tungsten deposits

Tin-tungsten mineralisation is mostly restricted to the area of Specimen Hill, one kilometre west of Balfour township, with a few minor, scattered occurrences to the south. Alluvial workings and old reports suggest that some more widespread tin mineralisation occurs within the area.

The mineralisation is hosted by siltstone, sandstone, quartzite and shale in the Specimen Hill area. The

dominant structure in the area is a broad open anticline, trending NNW and plunging south. There is also a major east-dipping, north-trending fault which separates west-facing siltstone, sandstone and a black shale unit on the western flank of Specimen Hill from the overlying east-facing siltstone units. The fault appears to have been the major conduit for hydrothermal activity. The known tin and tungsten mineralisation mainly occurs on the crest and western slopes of Specimen Hill, in the middle of the copper belt, in close proximity to the Murrays Reward mine (plate 25).

Mineralisation occurs as thin (10 to 500 mm), randomly orientated quartz veins containing cassiterite, wolframite and, in places, muscovite. Quartz veins in outcrop are porous, indicating the leaching of sulfide and/or carbonate minerals. This is demonstrated by mineralised zones which have been intersected by drill holes, where cassiterite and wolframite are associated with pyrite, chalcopyrite, arsenopyrite and pyrrhotite and minor carbonates. The proportions of minerals vary between deposits and drill holes within a deposit. Ward (1911) reported mineralised samples containing quartz, pyrite, siderite, galena, sphalerite and chalcopyrite and assaying about 7.5% Zn, 2.7% Pb, 0.23% Cu, 4 g/t Au and 80 g/t Ag.

At Tatlows mine, about one kilometre south of Specimen Hill, the mineralisation mainly consists of massive to semi-massive sulfides (pyrite, arsenopyrite, pyrrhotite) with quartz, cassiterite and wolframite. Sulfide-free quartz-cassiterite veins containing up to 70% cassiterite have also been

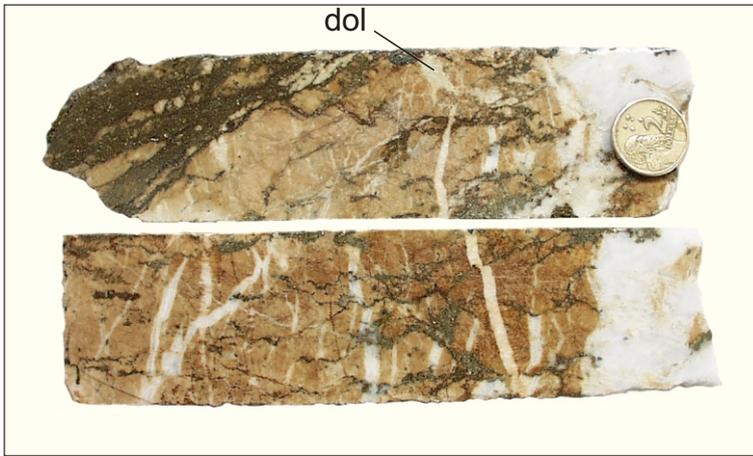


Plate 21

Early dolomite (dol), siderite-magnesite (brown) cut by late barren quartz veins. Note the remnants of dolomite (creamy colour) in siderite. Early dolomite is commonly unmineralised, indicating that copper is probably a later addition to 'quartz-dolomite'. Carbonates were probably more reactive and consequently formed better hosts for later mineralised fluids. DDH BBC11, Murrays Reward mine.

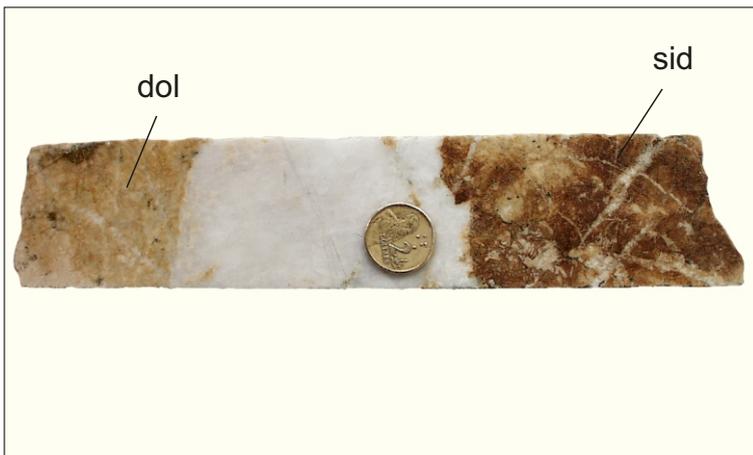


Plate 22

Dolomite (dol), siderite (sid) are cut by quartz and pyrite veinlets. DDH BBC11, Murrays Reward mine.



Plate 23

A typical form of quartz-chalcopyrite lode observed in drill core. Note pyrite is absent. DDH BC11, Murrays Reward mine.



Plate 24

Introduced late quartz-chalcopyrite replacing the earlier-formed, silicified carbonate (creamy colour). DDH BC11, Murrays Reward mine.



Plate 25

A network of quartz-cassiterite-wolframite veins hosted by siltstone in the Specimen Hill area.

reported within the area (e.g. Langsford, 1977). At Robbies workings, about 300 m south of Tatlows, thin quartz-cassiterite veins occur in shallow workings. Quartz-cassiterite veins with minor chalcopyrite are also exposed in sluiced areas.

Cassiterite was also recorded as finely disseminated (<0.5 mm) grains in altered, laminated shale in the Specimen Hill area (Langsford, 1977), but was not observed in this study.

The veins in all cases show sharp contacts with the country rocks.

Wall rock alteration is limited to tourmalinisation, minor sericitisation and silicification, with tourmalinisation being the most pervasive type. The veins appear to have been formed along shear and tension joints and pre-existing faults. They are erratic both in terms of tin and tungsten content, widths and directions.

Veins intersected by drill holes average about 10 mm in thickness with some larger veins reaching up to 300 mm in width.

Fluid Inclusions

A fluid inclusion study was undertaken on quartz from nine different prospects (Waratah, Balfour South, Murrays Reward, Premier, Balfour Blocks, Clump, Couta, Specimen Hill, Strickland) along the tin-copper belt and in the Temma area. Two quartz samples from barren quartz veins from Temma Farm and southwest of The Clump prospect (samples C108470, C108489) were also used for this study.

Initially, numerous quick plates were made for samples from most of the prospects but it was found that only a few samples contained workable fluid inclusions. Most of the quartz samples have been affected by several phases of deformation, recrystallisation and brecciation to various degrees. As a result, only rare, smaller fluid inclusions (<5 μm), particularly those occurring immediately adjacent to small patches of sulfides, have been protected from the effects of tectonic deformation.

Microthermometric data were obtained on a modified Fluid Inc. gas-flow type heating-freezing stage. The stage was calibrated with synthetic H₂O and CO₂ inclusions and inclusions with known salinities. The measurements have errors of about ±0.2°C.

This study is of a preliminary nature but showed that a comprehensive fluid inclusion study on tin-tungsten and copper prospects along the belt, and in the Temma area, would require a considerable amount of time and sample preparation. This is because of the scarcity of workable fluid inclusions and the occurrence of several generations of fluid inclusions in some localities. The small size of fluid inclusions severely restricted the freezing experiments. Consequently, the data presented here may not be representative of all fluid inclusion types that formed in quartz from these localities. It should be emphasised that a detailed fluid inclusion study can be of particular importance as it should provide more information on the:

- compositions and formation temperatures of the ore-forming fluids for the copper and Sn-W mineralisation;

- origins of the fluids (magmatic vs metamorphic);
- temperature zonation along the belt; and
- temperature-composition differences/similarities in the ore-forming fluids between prospects in the Temma area and those along the copper belt.

Every attempt was made to use primary or primary-looking fluid inclusions for microthermometric measurements. This assumption needs to be taken cautiously as later-formed (secondary) fluid inclusions may not always be distinguishable from primary inclusions, especially if quartz samples have been affected by different phases of deformation.

The microthermometric results are shown in Appendix 5.

In general, fluid inclusions in quartz from both the copper prospects along the Balfour belt and the Temma area are dominantly two phase (liquid H₂O and vapour) inclusions with a very small proportion containing CO₂ + CH₄ in addition to water.

The size of fluid inclusions ranges from 3 to 15 μm and they vary in shape from negative crystal to irregular. Only randomly distributed or isolated fluid inclusions within grains and those occurring immediately next to sulfides were used for the microthermometric measurements. Liquid-vapour ratios may vary widely within a sample, mainly due to the presence of different generations of fluid inclusions observed in some samples. Vapour-rich and liquid-rich fluid inclusions coexist in some samples (e.g. Specimen Hill and Strickland prospects).

The fluid inclusions in quartz from the Specimen Hill prospect vary from water-rich to vapour-rich. There are also some vapour-only inclusions which may or may not be associated with vapour-rich inclusions. No daughter minerals were observed in the fluid inclusions. The fluid inclusions from Specimen Hill are distinctly larger and the quartz is clearer and much less deformed than those observed in the copper deposits. The homogenisation temperatures appear to be bimodal in that a smaller population is in the range of around 200 to 240°C whereas the other group is characterised by higher homogenisation temperatures ranging from around 300° to over 400°C (fig. 6). The lower temperature fluid inclusions contain lower vapour-liquid ratios (20–30% by volume) than those showing higher homogenisation temperatures (40–70%).

Compositionally, fluid inclusions vary from H₂O only to H₂O + CO₂ + CH₄ (first melting point of -62 to -63°C). The former vary in composition from almost pure H₂O to containing almost 9 wt% equivalent NaCl. The final melting points of clathrate for CO₂-bearing fluid inclusions were estimated to be between +5 to +7°C from which a salinity of around 7 wt% equivalent NaCl can be estimated (Collins, 1979). CO₂ + CH₄-bearing fluid inclusions are characterised by high vapour to liquid ratios (>40% by volume) and homogenisation temperatures of more than 300°C. There are also some

CO₂-free (or undetectable) fluid inclusions that are very similar in size, vapour-liquid ratios and appearance to those containing CO₂ + CH₄. These two types of fluid inclusion are found in the same section but their relationships are not known. The onset of final melting of most fluid inclusions was very gradual and this made it very difficult to accurately determine salinities. Much more systematic work is needed to define timing and compositions of the different fluid inclusions.

Fluid inclusions from the copper deposits, including Premier, Balfour Block, Balfour South, Murrays Reward and Waratah, and also barren quartz veins, are mostly small (<5 μm) and rare and are commonly low in vapour-liquid ratios (25–35% by volume).

The homogenisation temperatures range from 167 to 268°C, but the majority fall within a narrow range of 180 to 220°C. The exception is the high temperature fluid inclusions in quartz from Balfour Blocks, where the temperatures range from 246 to 361°C, but mostly show a narrow range of 290 to 330°C. Two fluid inclusions also show critical behaviour at temperatures of 420 and 430°C. Only one small (3 μm) CO₂-bearing fluid inclusion consisting of liquid water, liquid CO₂ and vapour CO₂ + H₂O was observed.

The fluid inclusions from The Clump prospect show similar features to those from Premier and Balfour South but exhibit higher homogenisation temperatures ranging from 175 to 330°C, with most being in the range of 240 to 330°C (fig. 6).

A salinity of around 9 wt% equivalent NaCl is estimated for the fluid inclusions in quartz from the Balfour Blocks and Clump prospects. Fluid inclusions from Waratah show a salinity range of 5 to 15 wt% equivalent NaCl (Appendix 5).

Based on a few freezing measurements, the fluid inclusions from barren quartz (Sample 7204) appear to be of low salinity, ranging from 0 to 5 wt% equivalent NaCl. The freezing points of a few fluid inclusions with higher vapour-liquid ratios (>30%) could not be determined in this sample.

The fluid inclusions from the Temma area (Couta and Strickland prospects) are two phase (liquid water and vapour) and the homogenisation temperatures range from 251 to 420°C, with more than 80% of the data falling within the range of 280 to 320°C. The salinities for these fluid inclusions are estimated to be in the range of 12 to 17 wt% equivalent NaCl. The fluid inclusions from a barren quartz vein in Temma Farm have relatively low homogenisation temperatures from 162 to 224°C. A salinity of around 15 wt% equivalent NaCl is indicated from these fluid inclusions.

The initial melting points for all the fluid inclusions, with the exception of the few containing CO₂, range from -32 to about -25°C, indicative of the existence of other salts such as calcium and magnesium chlorides in addition to NaCl and KCl.

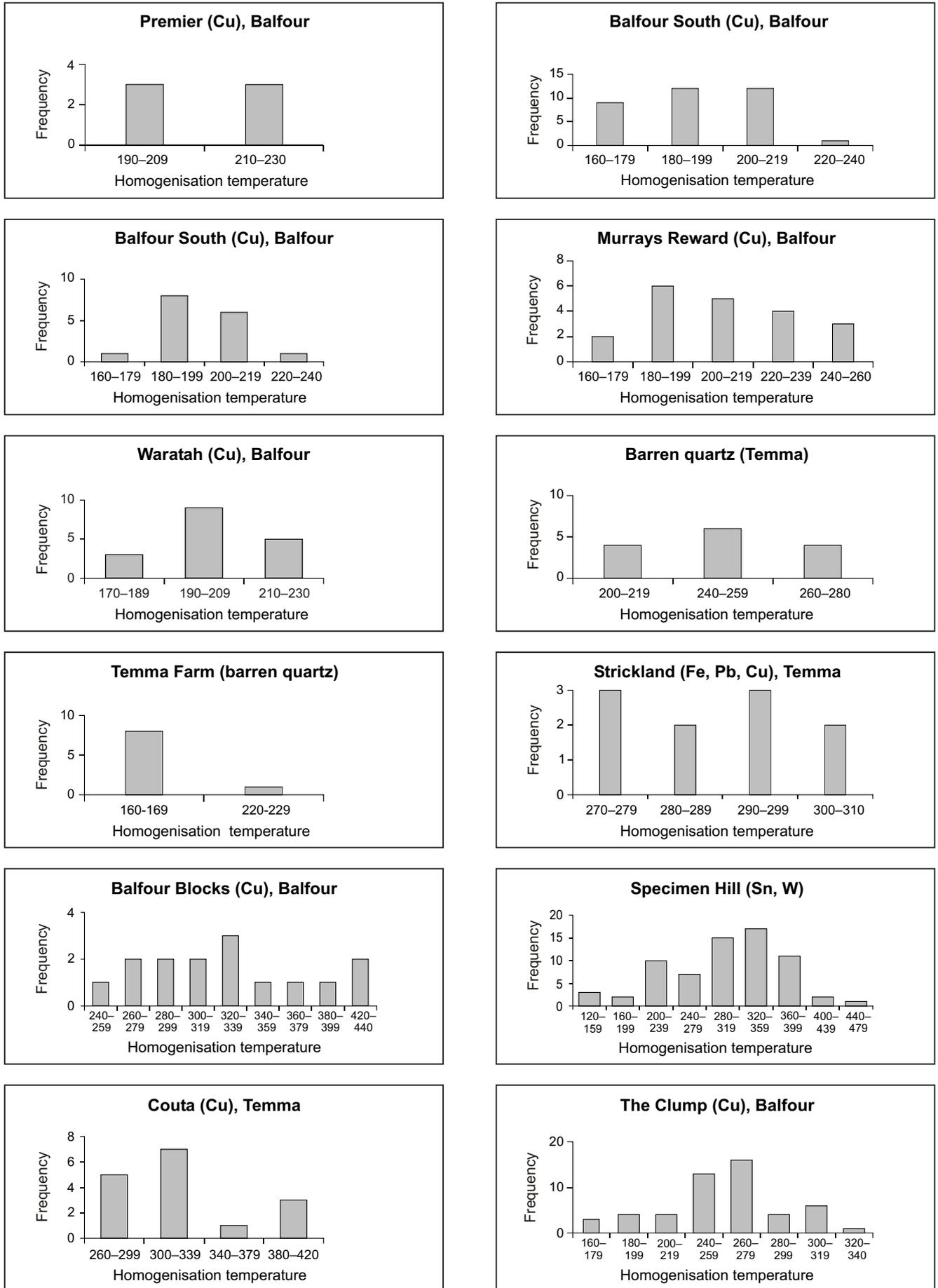


Figure 6

Frequency distributions of homogenisation temperatures (°C) in quartz from the Balfour copper belt, Specimen Hill and Temma areas

Summary

Although this fluid inclusion study is of a preliminary nature, it has still provided the following information:

- The hydrothermal fluids responsible for the formation of quartz, in the copper deposits throughout the copper belt, appear to be of low salinity and are possibly of metamorphic origin.
- CO₂ + CH₄-bearing fluid inclusions are rare and were only observed in quartz from the Specimen Hill tin-tungsten prospect.
- Homogenisation temperatures vary considerably within different deposits.
- Temperatures and fluid compositions obtained from fluid inclusions do not show any correlations with the estimated depths of the interpreted underlying granite (fig. 7). Therefore the fluid inclusions and geophysical data are inconsistent with a granitic origin for the fluids responsible for copper mineralisation along the belt and in the Temma area. For example, the granite surface at the Balfour South and Waratah prospects is at a depth of only about one to two kilometres and yet the primary-looking fluid inclusions in quartz show very low homogenisation temperatures of around 200°C. In contrast The Clump is positioned nearly four kilometres above the surface of the underlying granite, but the fluid inclusions have high homogenisation temperatures of up to 400°C. Similar high temperature fluid inclusions are found in copper deposits in the Temma area (e.g. Strickland and Couta prospects) where the top of the granite is inferred to lie at depths of more than nine kilometres (Leaman and Richardson, 2003). The high homogenisation temperatures recorded from the Balfour Blocks prospect may indicate the involvement of a high temperature fluid source (e.g. from the underlying granite) in the formation of some quartz in these deposits. Quartz is not always associated with the copper sulphides, so the fluids involved in the formation of the quartz veins may not necessarily represent the ore-forming solutions or the estimated formation temperatures for the copper mineralisation. More detailed petrological and fluid inclusion studies are required to establish the paragenetic relationships of different quartz types and the nature of their fluid inclusions.
- There is a possible trend to suggest a general increase in the homogenisation temperatures of the fluid inclusions from south to north along the copper belt. This needs to be confirmed by more detailed work.
- There appears to have been pulse(s) of hydrothermal fluids of low salinities introduced during deformation at higher temperature than the original temperature of formation of the quartz. This is indicated by some secondary fluid inclusions with homogenisation temperatures

exceeding those considered to be primary inclusions (e.g. The Clump prospect).

- On the basis of all the evidence, it is considered most likely that the fluids responsible for copper mineralisation have a metamorphic origin. This is further discussed in the *Oxygen isotopes* and *Sulfur isotopes* sections.
- Fluid inclusions found in quartz from the Specimen Hill Sn-W deposit are larger and have much higher homogenisation temperatures than those found in nearby copper deposits (e.g. Murrays Reward). The quartz is also less deformed in the Specimen Hill area. The quartz-cassiterite and/or wolframite veins used for the fluid inclusion study contain quartz and tin-tungsten minerals paragenetically belonging to the same stage of formation. The fluid inclusions at Specimen Hill are of high temperature and are low in salinity. This is in contrast to fluid inclusions found in most other Sn-W deposits in Tasmania, which are characterised by high temperature and high salinity fluid (e.g. Patterson *et al.*, 1981; Taheri, 1985; Halley, 1982; Collins, 1981). Despite the limited data, the distribution of fluid inclusions and their behaviour upon heating in Specimen Hill samples may be explained by fluid immiscibility in the CO₂-H₂O system. The criteria used for this interpretation are:
 - Variability in vapour-liquid ratios and possibly water-CO₂ ratios.
 - Co-existence of CO₂-free (or poor) and CO₂-rich fluid inclusions in the same grain.
 - Homogenisation of fluid inclusions to liquid or vapour.

If this is the case, then no fluid inclusions were found that could be related to the parent (magmatic) fluids from which the CO₂-H₂O immiscible fluid has been derived. Tin mineralisation has been shown to be associated with the low salinity fluid exsolved from a more saline parent magmatic fluid (e.g. Lakeside deposit, western Tasmania, Taheri and Green, 1990).

- Fluid inclusions from barren quartz veins are of low temperatures and low salinities. They are similar to fluid inclusions found in quartz veins along the copper belt and in the Temma area.

Oxygen isotopes

Twelve quartz samples from different copper and tin-tungsten prospects, and one from a barren quartz vein located northeast of The Clump prospect (sample 108489) were analysed for oxygen isotope. The results, together with the oxygen isotope compositions of water in equilibrium with the quartz at minimum temperature of formations determined by the fluid inclusions study, are shown in Table 2. The exceptions are samples C108226, C108205 and C108460 where no workable fluid inclusions were found. In general, the oxygen isotope values exhibit a narrow range of 12.3 to 14.5‰, irrespective of the deposit types/locations.

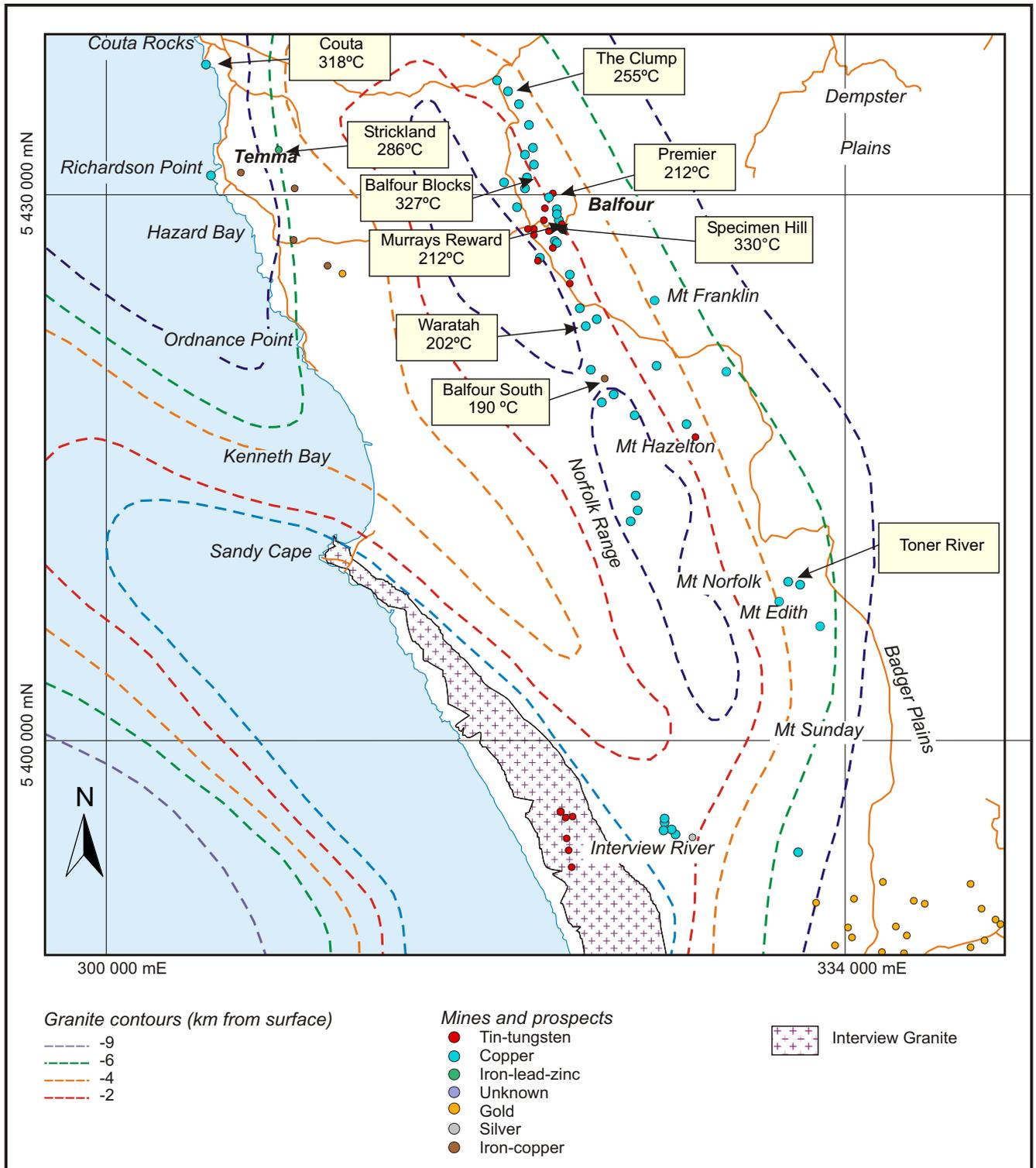


Figure 7

Relationships between the distribution of homogenisation temperatures in different copper-tin-tungsten deposits and the underlying granite, Balfour-Temma area.

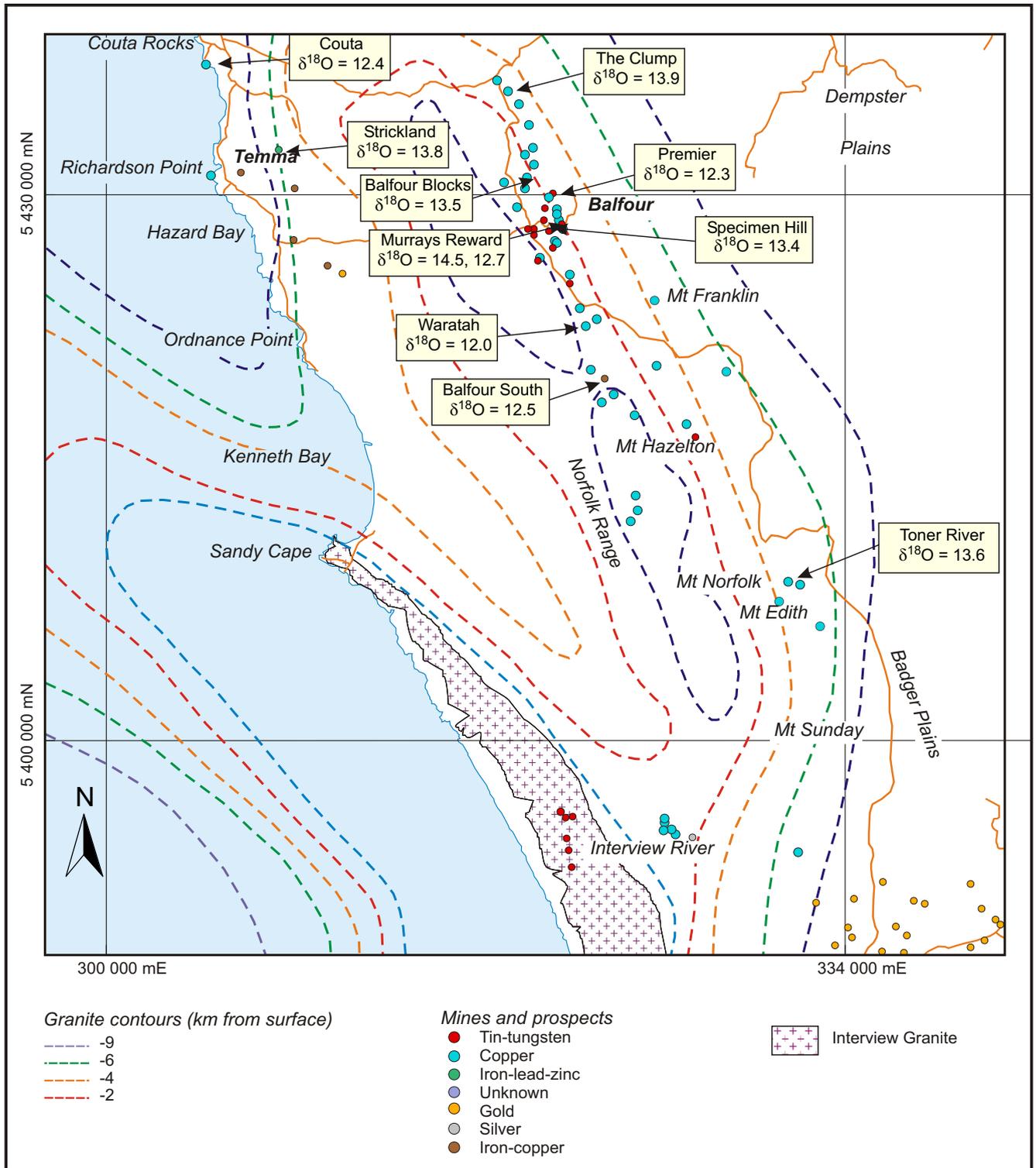


Figure 8

Distribution of oxygen isotope values in different copper and tin-tungsten deposits relative to the underlying granite.

Table 2

Oxygen isotope values of the quartz samples from the Balfour, Temma and Specimen Hill areas. Average homogenisation temperatures were used for calculation of isotopic compositions of water with quartz samples.

Sample	Mineral location/ mineralisation	Calculated		T (°C)
		¹⁸ O (‰) Mineral	¹⁸ O (‰) Water	
C108489	Quartz, NE of Clump (Cu)	12.5	2.9	245
C108202	Quartz, Murrays Reward (Cu)	14.5	2.4	212
C108205	Quartz, Murrays Reward (Cu)	12.7	-	-
C108240	Quartz, Waratah (Cu)	12.0	0.1	202
C108242	Quartz, Premier prospect (Cu)	12.3	0.9	211
C108245	Quartz, Balfour Blocks (Cu)	13.5	7.0	327
C108258	Quartz, Clump prospect (Cu)	13.9	5.5	272
C108409	Quartz, Balfour South (Cu)	12.5	-0.1	191
C108254	Quartz, Couta prospect (Cu)	12.4	5.0	301
C108415	Quartz, Strickland (Cu)	13.8	5.9	286
C108286	Quartz, Specimen Hill (Sn-W)	13.0	8.1	360
C108289	Quartz, Specimen Hill (Sn-W)	13.6	6.1	313
C108222	Quartz, Specimen Hill (Sn-W)	14.0	7.7	334
C108226	Quartz, Tatlows (Sn-W)	13.6	-	-
C108460	Quartz, Toner River (Cu)	13.2	-	-

Discussion

The following discussion is based on the limited number of oxygen isotope values in Table 2 and Figure 8 and the assumption that the fluid inclusions were of primary origin and represent minimum formation temperatures (see *Fluid Inclusion* section for details).

Although the oxygen isotope compositions of the quartz are similar for most of the deposits along the copper belt, the calculated isotopic compositions of water in equilibrium with quartz are vastly different for different prospects, ranging from -0.1 to 8.1‰. This is mainly due to the wide variations observed in the homogenisation temperatures of the fluid inclusions in quartz samples from different prospects. The calculated oxygen isotope compositions of water for the different quartz samples (Table 2) are based on average homogenisation temperatures for each sample. If the minimum and maximum temperatures are considered for each sample, then the oxygen isotope composition of water could vary up to 11‰ between different prospects.

A magmatic-dominated source is indicated from the oxygen isotope compositions of water in equilibrium with quartz from Specimen Hill (Taylor, 1979). This is expected, considering the hydrothermal alteration mineralogy (see *Mineralisation* section for details) and the geophysically-predicted occurrence of an underlying granite at shallow depth (Leaman and Richardson, 2003) in the area (fig. 8).

Oxygen isotope compositions of water in equilibrium with quartz along the copper belt are low and show little variation in the southern half of the belt, but they are mostly higher in the northern half of the belt. This resulted from the general increase in the formation temperatures (as determined from fluid inclusions) of quartz associated with copper mineralisation towards

the northern half of the belt. The oxygen isotope values of water in equilibrium with quartz from the Balfour Blocks prospect are, surprisingly, very similar to those obtained from the granite-related Specimen Hill prospect. As discussed in the *Fluid Inclusion* chapter, at least one generation of quartz in the Balfour Blocks deposit may have been derived from granitic fluid, as the oxygen isotope values and homogenisation temperatures are very similar to those from the Specimen Hill tin-tungsten prospect. The recent gravity interpretation of the area (Leaman and Richardson, 2003) shows the underlying granite in this area to be located at a very shallow depth of around two kilometres. There is little definite evidence linking the formation the quartz and the chalcopyrite bodies in these deposits, excepting the spatial association with fault zones.

Oxygen isotope compositions of water in equilibrium with two quartz samples from the Temma area (Strickland, Couta) are similar and resulted from similar homogenisation temperatures obtained in quartz from both prospects.

Oxygen isotope data, together with the ore mineralogy and the compositions and temperature of ore-bearing fluid inclusions, suggest various metamorphic fluids of different temperatures and probably different compositions are responsible for the formation of the copper deposits along the belt. The effect of the underlying, postulated very shallow (1 to 3 km) granite along most of the belt cannot be evaluated, and in particular there are no obvious alteration assemblages or mineralogical evidence to support a direct relationship between the granitic fluid and the formation of the copper deposits. The deposits have probably formed from the sporadic introduction of different fluids into long-active existing fluid conduits (faults, thrusts and shear zones) during various stages of deformation and tectonic activity. Thus some deposits may show indications of multiple hydrothermal events. The data are also consistent with the involvement of isotopically shifted meteoric water.

Hydrothermal fluids responsible for the formation of the copper mineralisation along the belt and in the Temma area are discussed further in the last chapter of this report.

Sulfur isotopes

A total of twenty-three sulfide samples, including pyrite, chalcopyrite, arsenopyrite and galena, were selected for sulfur isotope analysis. The results are shown in Table 3. The samples have been taken from twelve different prospects along the copper belt covering some 35 kilometres. A few sulfides were also analysed from the Temma area for comparison. Yaxley (1981) and Veska (1993) have also analysed some sulfide samples from the Specimen Hill (Sn, W) and Murrays Reward (Cu) areas. Their results are also included in Table 3 and Figure 9.

In general, the sulfide minerals from the tin-tungsten deposits have lower sulfur isotope values than those

Table 3
Sulfur isotope data for the Balfour and Temma deposits, northwest Tasmania

<i>Sample</i>	<i>Prospect/mine</i>	<i>Sulfide mineral</i>	<i>Description</i>	$\delta^{34}\text{S}$ (‰)
108229	Tatlows	Arsenopyrite	Quartz-sulfides	13.4
108229	Tatlows	Chalcopyrite	Quartz-sulfides	14.4
108234	Balfour Central	Chalcopyrite	Quartz-chalcopyrite-pyrite (oxidised)	20.3
108238	Balfour South	Pyrite	Quartz-pyrite	19.9
108239	Balfour South	Pyrite	Quartz-pyrite	20.6
108243	Premier Prospect	Pyrite	Quartz-pyrite	23.4
108246	Balfour Blocks	Pyrite	Quartz-pyrite	23.4
108247	Balfour Blocks	Chalcopyrite	Semi-massive chalcopyrite-pyrite quartz (oxidised)	20.9
108248	Balfour Blocks	Pyrite	Chloritised siltstone with disseminated pyrite	19.9
108249	Balfour Blocks	Chalcopyrite	Semi-massive chalcopyrite-pyrite (oxidised)	18.1
108253	Balfour Blocks	Chalcopyrite	Quartz-chalcopyrite-pyrite (oxidised)	19.8
108256	Couta	Chalcopyrite	Fractured-filled chalcopyrite in shale	20.4
108259	The Clump	Pyrite	Breccia	21.8
108260	The Clump	Pyrite	Quartz-pyrite veins in pyritised shale	22.2
108261	The Clump	Chalcopyrite	Quartz-chalcopyrite	20.6
108285	Specimen Hill	Arsenopyrite	Quartz-sulfides	15.2
108416	Strickland	Galena	Magnetite-sulfides	20.6
108420	Strickland	Pyrite	Quartz-sulfides	23.6
108438	The Clump	Chalcopyrite	Breccia, quartz-chalcopyrite-pyrite	13.7
108438	The Clump	Pyrite	Breccia, quartz-chalcopyrite-pyrite	22.7
108460	Toner River	Pyrite	Quartz pyrite	14.8
SI 1*	Murrays Reward	Chalcopyrite		20.0
SI 2*	Murrays Reward	Chalcopyrite		20.9
SI 3*	Tatlows Shaft	Arsenopyrite		14.8
SI 4*	Tatlows Shaft	Pyrite		14.6
SI 5*	Murrays Reward	Chalcopyrite		20.6
SI 6*	Murrays Reward	Chalcopyrite		20.9
SI 7*	Murrays Reward	Chalcopyrite		21.1
SI 8*	The Clump	Pyrite		1.5
SI 9*	Development	Chalcopyrite		20.1
SI 10*	Murrays Reward	Chalcopyrite/pyrite		21.5
105443**	Specimen Hill	Pyrite ('sedimentary')		15.9
105442?*	Cassiterite Creek	Pyrite ('sedimentary')		18.1
105442?*	Specimen Hill	Pyrite		12.6
105444**	Tatlows Shaft	Pyrite		9.1
105445**	Cassiterite Creek	Sphalerite		7.4

* Veska (1993) ** Yaxley (1981)

from copper mineralised areas along the belt and from the Temma area. The sulfur isotope values in sulfides from the former range from 7.4 to 15.2‰ with majority between 12‰ and 15‰, whereas those from the copper prospects mostly show values between 20‰ and 23‰. The exceptions are two relatively low values from The Clump and Toner River of 13.7‰ and 14.8‰ respectively. Veska (1993) also reported an unusually low value of 1.5‰ from The Clump prospect.

Discussion

The present data, together with those obtained by Yaxley (1981) and Veska (1993), indicate that:

- Sulfur isotope values for sulfides from the Sn-W deposits (7-15‰) are mostly distinctly lower than for those sulfides in copper deposits occurring along the copper belt (18-24‰). The few sulfur

isotope results determined from the Temma area also indicate a marked similarity to those obtained along the copper belt (20-24‰).

- The sulfur isotope values are fairly consistent for copper deposits over 35 km along the copper belt and do not show any regional zonation, or obvious relationship with depth from the underlying granite. Two inconsistencies are one pyrite sample from the Toner River and one chalcopyrite sample from The Clump prospect, both with sulfur isotope values markedly lower (14.8‰ and 13.7‰ respectively) than in other copper deposits along the belt or in the Temma area. A sulfur isotope value for a pyrite sample from The Clump prospect is also distinctly lower than all others along the copper belt (1.5‰; Veska, 1993). The sulfur source and the reliability of the analysis for this sample cannot be evaluated without obtaining more data.

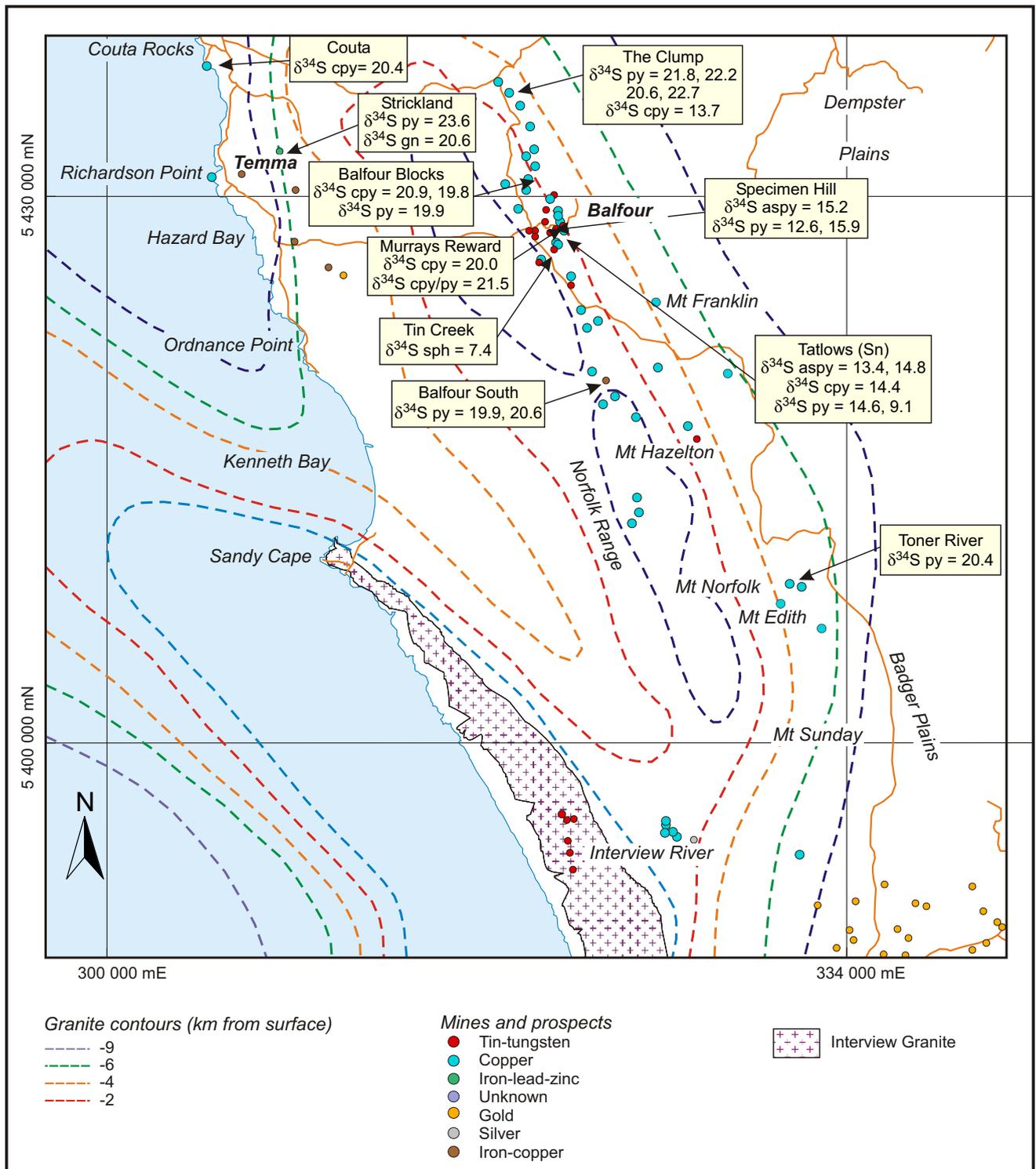


Figure 9

Distribution of sulfur isotope values in different copper and tin-tungsten deposits relative to the underlying granite

- Values for copper deposits from the Temma area show a marked similarity to those along the copper belt (fig. 9).
- In general, chalcopyrite is characteristically consistent in sulfur isotope values throughout the copper belt and at Temma and mostly lower, by up to 2.5‰, than values for pyrite.

The sulphur isotopes, geochemistry and mineralogy of the tin-tungsten deposits and associated quartz + sulfides muscovite tourmaline in the Specimen Hill

area are indicative of a close genetic link with a shallow underlying granite (fig. 9; Leaman and Richardson, 1992; 2003). The position of nearby copper deposits (e.g. Murray's Reward) relative to the depth of the underlying granite is identical to those of tin and tungsten deposits (fig. 9) yet, surprisingly, the deposits are mineralogically, chemically and isotopically very different.

In summary, the positions of the copper deposits relative to the underlying granite vary from less than two (e.g. South Balfour) to greater than nine

kilometres (e.g. the Temma area). The sulfur isotope values from the sulfides along the copper belt and from the Temma area are relatively consistent and distinctly different from those of the Sn-W deposits. These observations indicate that:

- magmatic sulfur (i.e. granite-derived) did not play a major role in the formation of the sulfides in the copper deposits, including those in the Temma area;
- the copper deposits have generally formed under different conditions to the Sn-W deposits;
- the sulfur isotope values from the Sn-W deposits are generally high for granitic fluids. ($^{34}\text{S}_{\text{Igneous sulfur}} = 0 - 5\%$; Ohmoto, 1986); and
- the high and consistent sulfur isotope values of pyrite from the copper deposits (up to 23.4‰) may represent the original (or very close to) sulfur isotope compositions of sedimentary pyrite from which the sulfur isotope compositions of chalcopyrite have been derived.

The high sulfur isotope values from the Sn-W deposits at Balfour may indicate partial leaching and/or remobilisation of heavy sedimentary sulfides in the formation of sulfide minerals in the Sn-W deposits. They are comparable with the high sulfur isotope values (up to 15‰) reported by Taheri (1985) from the Sweeney mine in western Tasmania. The Devonian Heemskirk Granite hosts Sweeney's tin mine and the high sulfur isotope values were interpreted to have been derived by the circulation of hydrothermal fluids through Precambrian rocks (with high sulfur isotope values) overlying the granite.

The very high sulfur isotope values from the Balfour-Temma copper deposits strongly suggests that the sulfide minerals were derived from an existing stratiform deposit at depth. This will be further discussed in the *Genetic Models* section.

Geochemistry

Some sixty mineralised samples from different prospects in the Balfour-Temma area were analysed for base metals, nickel, cobalt, tin, tungsten, bismuth and gold (Appendix 6). The aims were to investigate:

- geochemical signatures that can possibly relate the tin-tungsten, granite-related mineralisation to the copper mineralisation; and
- the involvement of Devonian granitic bodies in the formation or the remobilisation of the copper mineralisation within the area.

The copper mineralisation is geochemically simple and is characterised by low (<200 ppm) lead, zinc, bismuth, arsenic and other metals. Because of low concentrations of metals other than copper and iron, no reliable correlations between most metals can be established. The exceptions are Co and Ni concentrations which generally show positive correlations with copper content. This may either suggest that the copper has been remobilised from

basic rocks (e.g. Spinks Creek Volcanics), rich in copper, nickel and cobalt, or that it has been remobilised from an existing copper deposit enriched in these elements. The former is unlikely as the simple ore mineralogy persists throughout 35 km long copper belt. This requires an extensive continuation of the volcanic rocks along the belt, which in turn would require major thrusting, as the only known significant body of mafic rocks in the area, the Spinks Creek Volcanics, is younger than the Mesoproterozoic Rocky Cape Group host rocks.

Based on drill core geochemistry, tin-tungsten prospects are characteristically polymetallic, containing substantial amounts of Fe, As, Bi, Zn, Cu and Pb (Russell and Tear, 1997). The tin-tungsten deposits are also characteristically very low in nickel and cobalt contents and their concentrations remain almost the same, even in highly mineralised sections (Russell and Tear, 1997).

Bismuth and arsenic are only anomalous in the tin-tungsten prospects. Tatlow is especially high in Bi with a maximum value of 800 ppm observed in one sample (Appendix 6).

Gold is low even in highly mineralised zones, commonly less than 0.05 ppm, but with values up to 0.1 ppm having been reported in some copper deposits (Russell and Tear, 1997).

Tin contents of mineralised rocks from the copper prospects are generally very low, with the exception of a few samples from Murrays Reward where values of up to 250 ppm have been recorded.

The geochemical data clearly show that the Balfour-Temma copper deposits are formed from different sources and by different processes than the tin-tungsten deposits. This is despite the fact that the main tin-tungsten deposits are less than two kilometres from some copper deposits along the belt (e.g. Murrays Reward). The data do not support any major involvement of the underlying granite in the formation of the copper deposits.

Ore genesis

Introduction

The possible origins of the mineralisation at Balfour have been discussed by different exploration geologists and vary from stratabound to granite-related models. In general, the underlying granite has been assumed to be a principal factor in the formation and/or remobilisation of the copper deposits along the belt.

Based on surface mapping, costean geochemistry and diamond drilling at The Clump, ACI Limited (Jackaman, 1972) suggested that the copper mineralisation is associated with 'dolomitic quartzite' which conformably occurs within a sequence of carbonaceous siltstone, shale and sandstone. The mineralisation extends over a strike length of two kilometres at The Clump prospect. No wall rock

alteration was identified. Based on field and drill core observations, it was suggested that pyrite and chalcopyrite were formed by diagenetic and microbiological sulfidation of syngenetic, syn-sedimentary iron hydroxides and oxides and cupriferous material. Later tectonism mobilised and concentrated some of the disseminated chalcopyrite along the shear zones as quartz-carbonate-sulfide veinlets.

ACI geologists proposed a similar genetic model for the copper mineralisation at Murrays Reward after detailed surface and underground mapping. It was suggested that the present mineralised zone resulted from the remobilisation of originally stratabound deposits into faults and similar structures (McIntyre, 1974).

If the occurrence of 'concordant dolomitic quartzite' containing fine disseminated chalcopyrite can be verified, then this would be genetically and economically very significant as discussed later in this section. Our fieldwork could not locate any 'dolomitic quartzite' units, despite checking some 'dolomitic quartzite' outcrops mentioned by ACI geologists in their reports. Based on our observations, the 'dolomitic quartzite' was grey to dark grey siltstone and shale with no traces of carbonate (confirmed by HCl tests and XRD analyses). All drill core appears to have been destroyed or lost and most trenches are overgrown or hard to locate. As a result, the observations noted by ACI geologists in The Clump area, although genetically and economically important, remain unverified.

According to the regional studies of CRAE (Parkinson, 1994; Menpes, 1995) three areas within the Precambrian sequences in northwest Tasmania were considered to be prospective for stratiform/stratabound copper deposits, namely the Balfour copper belt, the Arthur Lineament, and the Smithton Trough. Within the Balfour copper belt, CRAE geologists identified some lithological contacts considered to be prospective for sediment-hosted copper deposits. They also considered that the major structures, such as the WNW-trending faults in the Murrays Reward area and the NNE-trending Roger River fault, could have played a major part in ore genesis.

Rio Tinto (Tear and Russell, 1997) considered the combination of Neoproterozoic basalt-derived copper and granite-driven hydrothermal fluids was capable of producing a large scale bulk mineable disseminated copper orebody. The aim was to identify areas where diamond drilling could intersect such an ore body. Rio Tinto considered that there was good potential for the existence of such economic ore bodies within the area, but the company prematurely stopped its exploration program in northwest Tasmania.

Genetic models

There are probably direct links between the formation of the Balfour tin and tungsten deposits and a

shallowly underlying granite (1–4 km, Leaman and Richardson, 2003), as has been mentioned by previous geologists (e.g. Veska, 1993). Evidence includes:

- (1) the occurrence of greisens in Tatlows prospect (Yaxley, 1981);
- (2) the close association of cassiterite and wolframite with typical granite-related hydrothermal minerals such as tourmaline, muscovite, pyrrhotite, and arsenopyrite; and
- (3) the lodes are anomalous in bismuth and arsenic.

Similar hydrothermal alteration and mineral assemblages are also associated with many other Devonian granite-related tin-tungsten deposits in Tasmania (Taheri, 1985; e.g. Collins, 1981; Patterson, 1980).

The copper deposits do not show any apparent genetic relationship with the underlying granite in the area. The only possible involvement of the underlying granite with the copper deposits can be seen in the Balfour Blocks prospect, where the oxygen isotope values and fluid inclusions of one quartz sample show very similar features to those from the local tin-tungsten deposits (see *Fluid Inclusion* and *Oxygen Isotope* sections). This may indicate that at least one generation of quartz in the Balfour Blocks deposit has been formed largely from granitic fluids. The sulfur isotope values of this prospect are distinctly higher than those determined in the tin-tungsten deposits. The copper deposits and associated quartz veins may be genetically unrelated, and the possibility of different generations of quartz in the copper deposits was not studied in detail. Copper deposits are generally very different in many ways from tin-tungsten deposits, as:

- The mineralogy is simple (pyrite, chalcopyrite quartz carbonate chlorite), and lacks the typical low pH, low fO_2 magmatic hydrothermal mineral assemblages associated with tin-tungsten deposits (e.g. tourmaline, muscovite, topaz, bismuthinite and arsenopyrite).
- Hydrothermally-formed mineral assemblages are consistent throughout the 35 km long copper belt. This is despite the fact that the depth of the underlying granite can vary from around one kilometre (e.g. South Balfour area) to greater than five kilometres (e.g. Toner River).
- The sulfur isotope values of sulfide minerals throughout the copper belt and those from Temma are similar but are characteristically higher than those observed from the tin-tungsten deposits within the area.
- Fluid inclusions in quartz from the Specimen Hill tin-tungsten prospect characteristically exhibit higher homogenisation temperatures (up to 400°C) than those found in nearby copper deposits such as Murrays Reward and Waratah (homogenisation temperatures of around 200°C).

- The copper mineralisation along the belt is characterised by high concentrations of copper and iron with traces of nickel and cobalt, but is very low in other metals such as As, Zn, Pb, Sn and W. This is distinctly different to the tin-tungsten deposits where the mineralised sections are high in As, Zn, Pb, Fe, Cu, Sn and W with traces of Bi being common, but is characteristically free from Co and Ni.

These observations suggest that the Balfour copper deposits have been formed from different ore-bearing solutions to the tin and tungsten deposits. They may have been formed from the circulation of low metal, low sulfur, late meteoric fluids through existing copper-rich source rocks (disseminated ores?). There is no apparent evidence to support the direct involvement of magmatic (granite-dominated) fluids in the formation of the copper deposits along the copper belt or in the Temma area.

The overall features of the copper mineralisation, especially the simple mineralogy and semi-massive to massive nature of chalcopyrite, located mainly in faults and shear zones, suggest that the copper deposits have been derived by hydrothermal remobilisation of existing low grade copper deposits at a deeper level. The copper mineralisation, exhibiting consistent mineralogical and geochemical signatures, can be seen in many copper deposits along the belt over 35 kilometres. Similar copper prospects, located at Interview River about 10 km south of the Toner River, could be considered to be the far south end of the copper belt.

Considering the above features, it is suggested that the copper source is underlying, low-grade stratiform copper deposit. These deposits are characteristically laterally extensive in relatively thin (measured in metres) stratigraphic units. Other features that potentially support this concept are:

- (1) the relatively high ore grade of stratiform copper deposits, being in the range of 1 to 5% copper, which may explain the local, very high grade copper ore along the copper belt, as the early mining records indicate that only ores containing 35% or more copper were processed;
- (2) the elevated content of cobalt and nickel in mineralised zones throughout the belt which are also a characteristic feature of the stratiform copper deposits (e.g. *Zambian Copper Belt*); and
- (3) the presence of early pyrite clasts with high (sedimentary) sulfur isotope values in cupriferous zones. This may represent some of the original reduced sedimentary pyrite from anoxic formations which has been tectonically remobilised into the sheared fault zones.

Sediment-hosted copper deposits are the second most important group of copper worldwide after porphyry copper deposits. They are characterised by lateral continuity and consistent grades, which make them

very attractive exploration targets. They are typified by giant deposits such as the Late Proterozoic copper belt of Central Africa, White Pine in America, and Permian Kupferschiefer in north-central Europe. The pre-mining reserves and resources for the Central African Belt have been estimated to be around 4.9 10⁹ t at 3.37% copper (Freeman, 1986).

The sediment-hosted copper deposits locally contain Co of economic significance and may also contain minor quantities of gold, uranium, platinum-group and rare earth elements (Kucha, 1982). The host rocks are not related to a single favourable sedimentary environment, because in stratiform deposits the introduction of copper post-dates the formation of host rocks. They must be able to precipitate the introduced copper and other metals by having a reductant, typically carbonaceous matter, and having pre-ore stage pyrite, or sulfates such as gypsum and anhydrite that can be reduced to form sulfides, possibly by reaction with brine fluids (Brown, 1997). The associated sequences are commonly red-bed sedimentary rocks or sometimes volcanic rocks. The carbonaceous (reduced) host rocks overlie oxidised (red bed) sedimentary rocks.

A post-sedimentary (diagenetic) genetic model for the formation of sediment-hosted deposits is widely accepted (e.g. Brown, 1997; Davidson, 1965; Garlick, 1989; Rowlands *et al.*, 1978). In this model, reduced rocks become mineralised by ascending aqueous brines leaching copper while passing through the red bed and reaching the red oxcline (the top of carbonaceous, pyritic strata) from where the brine could precipitate metals mainly in the form of sulfides. At the White Pine sediment-hosted copper deposit, there is also later, economically significant copper mineralisation which is structurally controlled (Mauk, 1993).

There are some geological settings which can potentially fulfil the requirements for the formation of sediment-hosted copper deposits in northwest Tasmania. Carbonaceous and pyritic shales are common within the Cowrie Siltstone and parts of the Balfour Subgroup of the Rocky Cape Group rocks, and also within the Black River Dolomite of the Togari Group. Evaporitic environments are indicated by the presence of some possible anhydrite casts, formed during the deposition of the Cowrie Siltstone (J. Everard, pers. comm.). There is some local development of ironstones in some formations (e.g. Keppel Creek Formation) that may act as red beds within the area. Based on two available analyses, these rocks could act as an excellent mineralising horizon for the formation of sediment-hosted deposits as they appear to be highly anomalous in copper (up to 92 ppm), nickel (up to 150 ppm), and cobalt (up to 80 ppm).

Although the red beds are considered to be the main immediate sources of copper for most sediment-hosted copper deposits, other sources of copper such as deep metamorphic fluids or magmatic

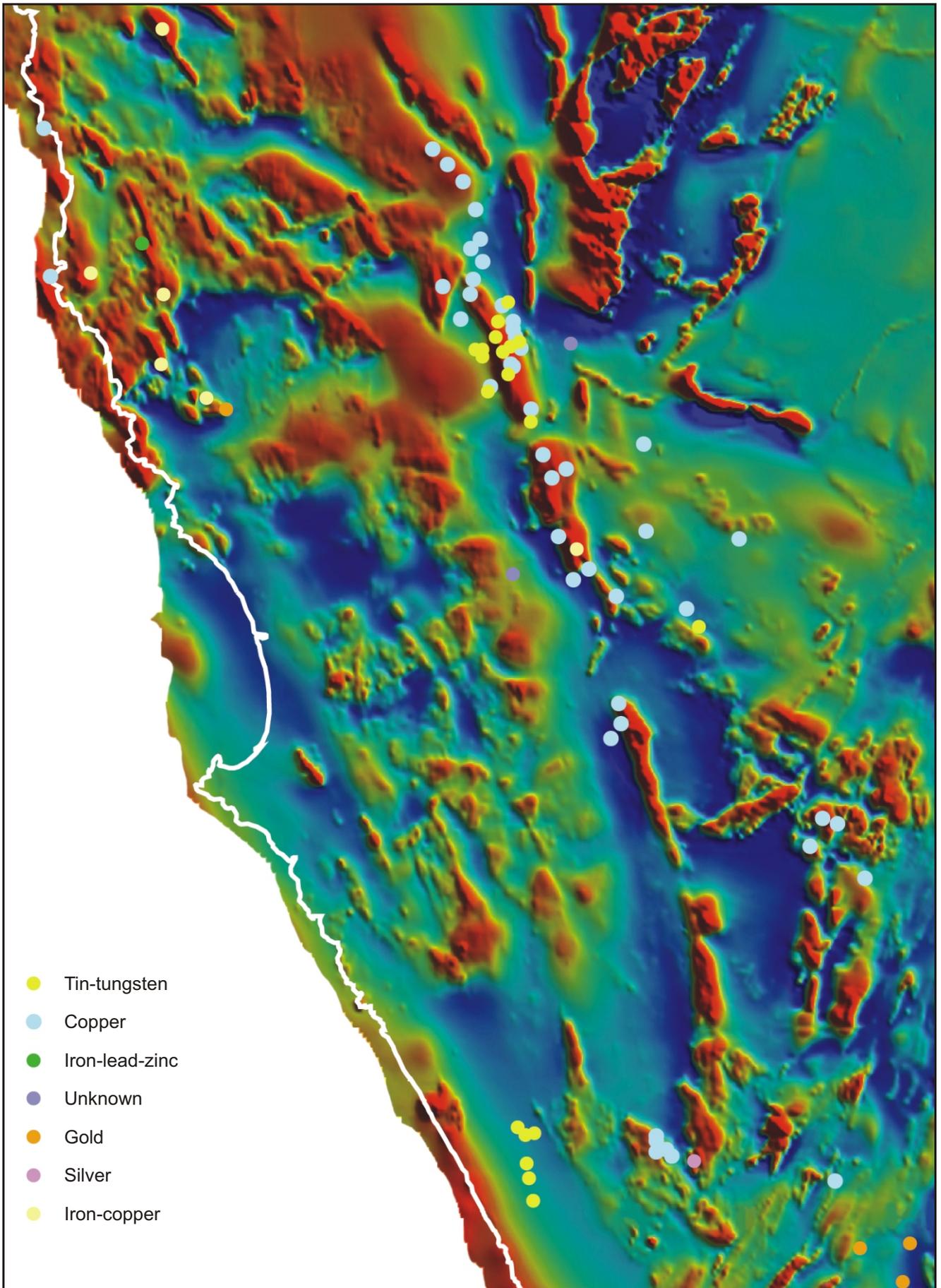


Figure 10

Magnetic image showing the relationship between the underlying magnetic bodies and the locations of copper deposits in the Balfour-Temma area.

fluids have been suggested (e.g. Annels, 1974). These models are more conceptual than confirmed.

The Balfour area is particularly prospective for stratiform copper deposits. CRA (Parkinson, 1994; Tear, 1996) identified two sedimentary boundaries between the oxidising and reducing sedimentary rocks, which could be potentially favourable for the formation of stratiform copper deposits. The first is the contact between the Lagoon River Quartzite and the overlying carbonaceous siltstone of the Balfour Subgroup. The contact is marked by a strongly magnetic siltstone unit extending for some 60 kilometres. The siltstone in the vicinity of the Murrays Reward mine is locally pyrrhotite-rich. This boundary is strongly conductive (IP and DigHEM surveys), suggesting it is graphitic or sulphidic in the Specimen Hill area.

The second contact occurs between the carbonaceous and pyritic siltstone and chloritic siltstone with a strike length of eight kilometres between Murrays Reward and The Clump. East of The Clump prospect some pyrite-rich chloritic rocks, which are copper and gold anomalous with values up to 1100 ppm copper and 0.034 ppm gold (435 900 mE; 5 322 700 mN), have been reported by Turner (1994). There is also a contact between a dark grey, black carbonaceous siltstone and pale grey siltstone on Frankland Road. The pyritic siltstone is commonly copper, gold, and arsenic anomalous and is chemically and lithologically consistent along the belt from Murrays Reward to The Clump prospects (Turner, 1994). This indicates that the pyritic siltstone unit is regionally extensive and can potentially be considered as a source of sulfur and possibly partially contributed to the formation of copper deposits within the area.

The regionally extensive, copper-anomalous carbonaceous units represent stratiform copper targets in northwest Tasmania. They are also potential source rocks for the copper veins along the belt and possibly in the Temma area.

Another potentially important source of copper is the basalt of the Spinks Creek Volcanics which is generally anomalous in copper, reaching to nearly 600 ppm (Everard *et al.*, 2002). The volcanic rocks are part of the Togari Group and are younger than the Cowrie Siltstone and the Balfour Subgroup (Rocky Cape Group) which host the mineralisation. There is geological (Everard *et al.*, 2003) and geophysical evidence (gravity interpretations, Leaman and Richardson, 2003) which suggest that the Rocky Cape Group has been thrust over the younger sedimentary rocks and basalts of the Togari Group. This model requires:

- (1) a very efficient system where copper could have been leached from the basalts, transported, concentrated, reduced, and finally deposited in the main conduits (faults, sheared zones, fractures);

- (2) very extensive subsurface continuity of the basalts over some 40 km;
- (3) the basalts to have been uniformly high in copper content; and
- (4) extensive and pervasive alteration of the basalts to facilitate the release of copper.

The Spinks Creek Volcanics contain numerous copper anomalies throughout their known distribution but are very erratic in copper content, and in outcrop show only regional metamorphism rather than distinct hydrothermal alteration. There is no definitive field evidence to support the required subsurface continuity.

There are also some NNW-trending, elongated, shallow magnetic bodies along the copper belt and in the Temma area which directly underlie most of the copper deposits. Figure 10 is a qualitative interpretation of the aeromagnetic data from the Balfour and Temma areas. The images were derived from the 1996 Arthur-Pieman aeromagnetic survey (flown as part of studies undertaken for the Regional Forests Agreement by MRT and AGSO).

In the Balfour belt, copper deposits from The Clump to the South Balfour area are all closely associated with a shallow, 20 km long, narrow NNW-trending magnetic anomaly (possibly dipping east and deepening to the north?). There is a four kilometre break in both the magnetic anomaly and copper trend before a group of deposits occur around the Poseidon mine, on the same trend. The magnetic trend to the south of this group appears unmineralised. The Toner River prospect appears to have been related to magnetic bodies striking NNE (possibly the same unit repeated by folding?). There is also a group of deposits near the Pieman River (~35 km south of Balfour) which overlie another magnetic anomaly of unknown source.

The Temma deposits are known to be associated with magnetite-rich ironstones, represented by large magnetic anomalies. The direct spatial association between some linear magnetic bodies and copper deposits in the Balfour area may indicate that similar magnetite-rich units underlie and may have been the main sources for the copper deposits. These ironstone bodies may represent large, low-grade mineralised (magnetite and/or pyrrhotite-rich) sedimentary or epigenetic deposits from which later, structurally-controlled copper deposits have been derived through remobilisation of the original copper and fluid focussing into active dilant structures.

The magnetic nature of the copper-rich pelitic units identified at Balfour is uncertain (the weathered sections are non-magnetic), but may be pyrrhotite-bearing at depth and thus a potential source of a magnetic anomaly. but is a potential source of an anomaly. Alternatively the magnetic anomalies may represent unidentified mafic or ultramafic rocks, representing another potential source for the copper deposits within the area.

Dolerite dykes are known in the Toner River area, possibly causing the complex magnetic patterns displayed in that area. Such rocks may contain copper, but are probably too limited in extent to be a significant source.

The mineralisation along the copper belt, in the Temma area, and in the Specimen Hill area all occupies structures broadly similar in age (A. Reed, pers. comm.). The copper deposits are related to a regionally extensive hydrothermal system where the ore-bearing fluids of possibly metamorphic/late granitic origin have probably remobilised copper from an existing copper deposit. In contrast, the granite-related tin-tungsten deposits are mainly restricted in and around the Specimen Hill area. The contrast between the two types of deposits, despite close proximity in the Balfour area, strongly suggests that they are the products of different hydrothermal events.

Further work

In order to enhance our understanding of the genesis of the copper mineralisation and to more reliably evaluate the economic potential of the area, it is necessary to:

- Apply a detailed fluid inclusion study to more conclusively characterise the compositions of hydrothermal fluids responsible for the formation of the tin and tungsten deposits in comparison to the copper prospects.
- Study the oxygen and carbon isotope ratios of the carbonate rocks along the copper belt to compare with the Precambrian dolomite. This could provide some information on the origin of the carbonate rocks which are commonly associated with the mineralised sections.
- More detailed petrological studies to establish different generations of quartz and their association with copper mineralisation along the belt and in the Temma area. The likely fluid sources can then be evaluated through fluid inclusion and oxygen isotope studies.
- Establish the sulfur isotope ratios of Precambrian sedimentary pyrite.
- Analyse the mineralised rocks for other elements commonly found in sediment-hosted deposits, such as uranium, platinum-group and rare-earth elements.
- Investigate the lead-zinc anomaly found in rock chip samples from beside the Heemskirk Road, south of The Clump prospect (Turner, 1994), as there may be potential for sediment-hosted stratiform lead-zinc deposits.
- Investigate the full potential of the copper mineralisation at The Clump as it is not yet known. This will require a drilling program on areas of economic significance, as intersections up to 1.5% Cu over 20 m have been reported by ACI geologists.

- Further investigate the copper anomalous 'chlorite/pyrite' rocks, east of The Clump workings, which contain up to 1100 ppm copper (Turner, 1994; e.g. along the Franklin River, around 435 900 mE, 5 322 700 mN). These rocks may represent a different style of mineralisation or can represent a potential redox trap (carbonaceous) within the area. These rocks can also potentially represent a low-grade sediment-hosted copper deposit within the area.
- Study the extent of the ironstones and their association with carbonaceous units and establish their range of chemical compositions within the Rocky Cape region. This is to investigate the possibility of ironstones as source horizons for the formation of sediment-hosted copper deposits within the area.
- Investigate the extent and chemistry of the copper-anomalous carbonaceous rocks through a detailed mapping and geochemical program.
- Verify the occurrence and nature of gold mineralisation at Balfour South, as reported by CRAE (e.g. Russell and Tear, 1997).
- Drill test the strong Zn anomalies, identified by CRAE in the Nelson prospect, Temma area. This exploration program was left incomplete and warrants much more attention, as there is potential for Zn-Pb sediment-hosted deposits in this area.

Summary

There are basically three different styles of mineralisation in the Balfour-Temma area of northwest Tasmania. These include:

- (1) copper lode deposits along a 35 km long, NNW-trending belt through Balfour and in the Temma area, 18 km west of Balfour;
- (2) vein and stockwork style tin and tungsten deposits lying in close proximity to the copper lodes, and located approximately in the middle of the copper belt; and
- (3) transgressive magnetite-dominated lodes with copper, lead and zinc in the Temma area.

Copper mineralisation is structurally controlled as the lodes occur in fault related dilation zones. Shear and fault zones acted as the main conduits for mineralising fluids. The rocks in the mineralised areas have been affected by small-scale folds and faults, vein deformation (both of ductile and brittle nature), extensive fracturing and several phases of brecciation.

The mineralised rocks throughout the copper belt have been strongly affected by supergene leaching of sulfides and dolomites. This is demonstrated by the formation of lode quartz exhibiting irregular cavities (sulfide leaching) and rhombohedral cavities (carbonate leaching), and formation of covellite-digenite rich ores.

The primary ore mineralogy is simple and consistent throughout the copper belt, mainly consisting of chalcopyrite, pyrite, quartz, dolomite and chlorite. Pyrite occurs as early-formed (sedimentary?), fine grained disseminations, in carbonaceous and chloritic siltstone and slate. Later (remobilised?) pyrite occurs as fracture filling veinlets and clasts in quartz veins in mineralised sections. Chalcopyrite does not appear to be co-genetic with pyrite or quartz in most places and is a product of a later phase of the hydrothermal activity.

The primary ore mineralogy in the Temma deposits is more complex (Bottrill, 2004b), with large amounts of iron oxides (magnetite and hematite) and significant amounts of Fe-Mn carbonates, amphiboles, stilpnomelane, galena, sphalerite and other minerals.

Based on drill core observations, silicification and chloritisation are the two main pervasive styles of hydrothermal alteration in the copper belt. Both are of an early stage and are commonly unmineralised. The silicified and chloritised rocks are cut by mineralised veins of quartz carbonate (dolomite, siderite, and magnesite) chlorite pyrite chalcopyrite. Quartz veins are the most common vein type; these are mostly barren, and are paragenetically of different generations.

Dolomite is a common hydrothermal mineral and can only be observed in drill core from the copper deposits. It is massive and shows sharp, mostly faulted contacts with the host rocks. Dolomite selectively replaces the brecciated, chloritised rocks and is extensively veined by late-formed barren quartz and, to a lesser extent, by chalcopyrite and pyrite veins. Quartz and sulfide minerals are late additions to the early-formed, unmineralised dolomite.

The granite-related tin-tungsten deposits are commonly polymetallic, consisting of quartz, muscovite, cassiterite, wolframite, pyrite, chalcopyrite, arsenopyrite and pyrrhotite with minor carbonate minerals. Wall rock alteration is limited to tourmalinisation, minor sericitisation and silicification, with tourmalinisation being the most pervasive type in the Specimen Hill area.

A fluid inclusion study indicates that the hydrothermal fluids responsible for the formation of the quartz, and presumably the associated copper deposits throughout the copper belt, were of low salinity and were probably of metamorphic and/or late granitic-meteoritic origin. There is a trend to suggest a general increase in the homogenisation temperatures of the fluid inclusions from south to north along the copper belt but these do not show any correlation with the depth of a postulated shallow underlying granite. Homogenisation temperatures are generally low (~200°C), but temperatures up to 400°C have been measured from the Balfour Blocks prospect. Fluid inclusion and oxygen isotope data, with the exception of one sample from the Balfour Blocks prospect, do not support the involvement of granitic fluids in the formation of copper deposits along the

belt. The oxygen isotope data are also permissive of formation of the copper deposits from isotopically shifted meteoric hydrothermal fluids.

Fluid inclusions found in quartz from the Specimen Hill Sn-W deposit contain CO₂ + CH₄ with low salinity and have much higher homogenisation temperatures (>400°C) than those found in nearby copper deposits (e.g. Murrays Reward). The distribution of fluid inclusions and their behaviour upon heating can be explained by fluid immiscibility in the CO₂-H₂O system.

Despite the variations in the depths to the granite underlying the copper deposits (Leaman and Richardson, 2003), the sulfur isotope values from the sulfide minerals along the belt are relatively consistent and isotopically higher than those of the Sn-W deposits. The high and consistent sulfur isotope values of pyrite from the copper deposits (up to 23.4‰) may represent the original (or very close to) sulfur isotope compositions of sedimentary pyrite from which the sulfur isotope compositions of chalcopyrite have been derived. The very high sulfur isotope values from the copper deposits strongly indicate that igneous sulfur has had very little input into the sulfur isotope composition of the sulfide minerals along the copper belt. The relatively high sulfur isotope values of sulfide minerals from the tin-tungsten deposits, being around 15‰, indicate partial leaching and incorporation of heavy sedimentary sulfur during the formation of sulfide minerals. The overall results suggest that the copper deposits have formed under different conditions relative to the formation of Sn-W deposits, and possibly earlier given the more deformed nature of the quartz veins hosting the former.

The copper mineralisation is geochemically simple and is characterised by low (<200 ppm) lead, zinc, tin, tungsten, bismuth, arsenic and other metals, but is generally anomalous in Co and Ni. The tin-tungsten prospects are polymetallic, containing substantial amounts of Fe, As, Bi, Zn, Cu and Pb, but are characteristically low in Ni and Co. The geochemical data clearly show that the copper deposits are formed from different sources and/or by different processes to the tin-tungsten deposits. The data do not support any major involvement of the underlying granite in the formation of the copper deposits.

The overall features of the copper mineralisation, especially the simple mineralogy and the commonly massive nature of chalcopyrite, located mainly in faults and shear zones, suggest that copper deposits may have been derived from an existing low-grade copper deposit (of sediment-hosted type) at a deeper level. The tin tungsten deposits are typical granite-related deposits and are restricted to the middle of the copper belt.

The preliminary fluid inclusion and stable isotope studies from the deposits in the Temma area strongly suggest a related origin to those along the Balfour copper belt, despite some significant differences in mineralogy and geochemistry.

Some elongated magnetic bodies at shallow depth (~1 km), extending along the copper belt from The Clump in the north to the Toner River prospect area in south, may be the potential source for the formation of the copper deposits. Magnetic bodies with similar strike also exist in the Temma area and may have played a similar role in the formation of the magnetite-copper deposits.

The Balfour and Temma areas are particularly prospective for stratiform copper deposits as there are sedimentary redox boundaries between oxidising and reducing sedimentary rocks that could be potentially favourable for the formation of stratiform copper deposits.

References

- ANNELS, A. E. 1974. Some aspects of the stratiform ore deposits of the Zambian copperbelt and their genetic significance, in: BARTHOLOME, P. (ed.). *Gisements stratiformes et provinces cuprifères*. 235–254. Société Géologique de Belgique.
- ANON. 1972. *Geology of the Specimen Hill area, Balfour*. Australian Consolidated Industries Limited [TCR 74-1070].
- BELL, D. H. 1972. 1971–72 Annual Report, EL48/70 and EL49/70, north-western Tasmania, joint venture exploration. Australian Consolidated Industries Limited [TCR 72-876].
- BOTTRILL, R. S. 2004a. Garnet-bearing and other spotted porphyroblastic metasedimentary rocks from the Balfour area. *Record Tasmanian Geological Survey* 2004/02.
- BOTTRILL, R. S. 2004b. Miscellaneous mineral analyses from near Balfour and Temma. *Record Tasmanian Geological Survey* 2004/06.
- BRITTON, A. M. 1997. *Structure, stratigraphy and mineralisation of the Temma area, northwest Tasmania*. B.Sc. (Hons) thesis, University of Tasmania.
- BROWN, A. C. 1984. Alternative sources of metals for stratiform copper deposits. *Precambrian Research* 25:61–74.
- BROWN, A. C. 1997. World-class sediment-hosted stratiform copper deposits: characteristics, genetic concepts and metallotects. *Australian Journal of Earth Sciences* 44:317–328.
- BROWN, A. V. 1985. Preliminary report on the Forest No. 1 diamond-drill hole and chemical analyses of associated tholeiitic basalts in the Smithton and Woolnorth quadrangles. *Unpublished Report Department of Mines Tasmania* 1985/62.
- BROWN, A. V. 1989. (comp.) Geological Atlas 1:50 000 Series. Sheet 21 (7916S). Smithton. *Explanatory Report Geological Survey Tasmania*.
- CHESNUT, W. S. 1964. *Report on Balfour, Tasmania – Prospecting 1963–1964*. Broken Hill Proprietary Company Limited [TCR 64-0373].
- CHESNUT, W. S. 1964. *Report on Balfour, Tasmania – Prospecting 1964–1965*. Broken Hill Proprietary Company Limited [TCR 65-0394].
- COLLINS, P. L. F. 1979. Gas hydrates in CO₂-bearing fluid inclusions and the use of freezing data for estimation of salinity. *Economic Geology* 74:1435–1444.
- COLLINS, P. L. F. 1981. The geology and genesis of the Cleveland tin deposit, western Tasmania: Fluid inclusion and stable isotope studies. *Economic Geology* 76:365–392.
- CROMER, W. C. 1988. *Exploration Licence 21/87 – Balfour. Annual report : year 1 (20 January 1988–19 January 1989)*. Aureole Resources Pty Ltd [TCR 88-2900].
- DAVIDSON, C. F. 1965. A possible mode of origin of strata-bound copper ores. *Economic Geology* 60:942–954.
- DAVIES, H. G. 1969. *Progress Report R.9039 – corporate exploration of Tasmanian mineral resources*. ACI Operations Limited [TCR 69-599].
- EVERARD, J. L.; SEYMOUR, D. B.; BROWN, A. V. 1996. *Geological Atlas 1:50 000 Series. Sheet 27 (7915N). Trowutta*. Mineral Resources Tasmania.
- EVERARD, J. L.; SEYMOUR, D. B.; REED, A. R.; MCCLENAGHAN, M. P.; GREEN, D. C.; CALVER, C. R.; BROWN, A. V. 2002. *Regional geology of the southern Smithton synclinorium. Explanatory Report for the Roger, Sumac and Dempster 1:25 000 map sheets, far northwestern Tasmania*. Mineral Resources Tasmania (unpublished).
- FREEMAN, P. V. 1986. *Some statistics of Zambian (and Zairean) copper and cobalt*. Note for file, Zambia Consolidated Copper Mines Limited, Lusaka.
- GARLICK, W. G. 1989. Genetic interpretation from ore relations to algal reefs in Zambia and Zaire, in: BOYLE, R. V. (ed.). *Sediment-hosted stratiform copper deposits. Special Paper Geological Association of Canada* 36:471–498.
- GEE, R. D. 1968. A revised stratigraphy for the Precambrian of north-west Tasmania. *Papers and Proceedings Royal Society of Tasmania* 102:7–10.
- GEE, R. D.; GULLINE, A. B.; BRAVO, A. P.; LEGGE, P. J.; GROVES, D. I. 1969. *Geological Atlas 1:63,360 Series. Sheet 42 (7814N). Pieman Heads*. Department of Mines, Tasmania.
- GROVES, D. I.; SOLOMON, M.; RAFTER, T. A. 1970. Sulfur isotope fractionation and fluid inclusion studies at the Rex Hill Mine, Tasmania. *Economic Geology* 65:459–469.
- HALLEY, S. W. 1982. A fluid inclusion study of the Lutwyche vein system, Rossarden. B.Sc. (Hons) Thesis, University of Tasmania.
- JACKAMAN, B. 1972. *The geology of the Clump Prospect, Balfour, northwest Tasmania*. Australian Consolidated Industries Limited [TCR 74-1070].
- KUCHA, H. 1982. Platinum-group metals in the Zechstein copper deposits, Poland. *Economic Geology* 77:1578–1591.
- LANGSFORD, N. R. 1977. *Report on exploration on SPL 762, Balfour, Tasmania, January–June 1977*. Tico Mines Pty Ltd [TCR 77-1218].
- LEAMAN, D. E. 1988a. *Balfour–Trowutta area, north west Tasmania. Evaluation of regional geophysics, implications specific to EL 21/87*. Leman Geophysics [TCR 88-2900].
- LEAMAN, D. E. 1988b. *EL26/87, North Pedder River. Regional geophysical review for New Holland Mining NL*. Leman Geophysics [TCR 88-2892].
- LEAMAN, D. E. 1992. *Review of geophysical data, EL 53/88 Mt Frankland*. Leman Geophysics [TCR 92-3403].
- LEAMAN, D. E.; RICHARDSON, R. G. 1992. A geophysical model of the major Tasmanian granitoids. *Report Department of Mines Tasmania* 1992/11.
- LEAMAN, D. E.; RICHARDSON, R. G. 2003. A geophysical model of the major Tasmanian granitoids. *Record Geological Survey Tasmania* 2003/11.
- LEGGE, P. J. 1980. *The lead zinc potential of younger rocks (Precambrian) of North West Tasmania*. CRA Exploration Pty Ltd [TCR 85-2349].

- LENNOX, P. G.; CORBETT, K. D.; BAILLIE, P. W.; CORBETT, E. B.; BROWN, A. V. 1982. *Geological Atlas 1:50 000 Series. Sheet 21 (7916S)*. Smithton. Department of Mines, Tasmania.
- MAUK, J. L. 1993. *Geological and geochemical investigations of the White Pine sediment-hosted stratiform copper deposit, Ontonagon County, Michigan*. Ph.D. thesis, University of Michigan, Ann Arbor.
- MCINTYRE, M. H. 1972. *Mineral exploration in EL 16/68, Balfour, Tasmania. Summary report for field season, 1971-72*. ACI Minerals Proprietary Limited [TCR 74-1070].
- MCINTYRE, M. H. 1973. *Mineral exploration in EL 16/68, Balfour, Northwest Tasmania, 1972-73*. ACI Minerals Proprietary Limited [TCR 73-0948].
- MCINTYRE, M. H. 1974. *Summary report on regional geological mapping in EL 16/68, Balfour, Tasmania*. ACI Minerals Proprietary Limited [TCR 74-1070].
- MENPES, S. A. 1995. *Balfour EL4/94. Report on exploration for the first year of tenure 3/6/94 to 3/5/95*. CRA Exploration Pty Ltd [TCR 95-3734].
- MORRISON, K. 1991. *Exploration Licence 53/88 Mount Frankland. Annual report : Year 3 (6 January 1991-5 January 1992)*. Soloriens Mining Pty Ltd [TCR 91-3315].
- MORRISON, K. 1992. *EL53/88 Mount Frankland. Annual report: Year 4 (6 Jan 1992-5 Jan 1993)*. Soloriens Mining Pty Ltd [TCR 92-3403].
- OHMOTO, H. 1986. Stable isotope geochemistry of ore deposits, in: VALLEY, J. W.; TAYLOR, H. P.; O'NEIL, J. R. (ed.). Stable isotopes in high temperature geological processes. *Reviews in Mineralogy* 16:491-559.
- PARKINSON, R. G. 1994. *Mount Frankland EL 18/92. Report on exploration for the second year of tenure 6/10/93 to 5/10/94*. CRA Exploration Pty Ltd [TCR 94-3644].
- PATTERSON, D. J. 1980. *Geology and mineralization at Renison Bell, western Tasmania*. Ph.D. thesis, University of Tasmania.
- PATTERSON, D. J.; OHMOTO, H.; SOLOMON, M. 1981. Geologic setting and genesis of cassiterite-sulfide mineralisation at Renison Bell, Western Tasmania. *Economic Geology* 76:393-438.
- ROWLANDS, N. J.; DRUMMOND, A. J.; JARVIS, D. M.; WARIN, O. N.; KITCH, R. B.; CHUCK, R. G. 1978. Geological aspects of some Adelaidean stratiform copper deposits. *Mineral Science and Engineering* 10: 258-277.
- RUSSELL, S. A. J.; TEAR, S. J. 1997. *EL 4/94 Balfour. Third annual and final report for the period 3 May 1996 to 11 November 1997, Tasmania, Australia*. Rio Tinto Exploration Pty Ltd [TCR 98-4115].
- SCHMIDT, R. D. 1968. *Marrawah Beach heavy mineral sands*. Pickands Mather & Co. International [TCR 68-0533].
- SEYMOUR, D. B.; BAILLIE, P. W. 1992. *Geological Atlas 1:50 000 map series. Sheet 20 [7816S]*. Woolnorth. Department of Mines, Tasmania.
- SPRY, A. H. 1957. The Precambrian rocks of Tasmania, Part I, Dolerites of the north-west coast of Tasmania. *Papers and Proceedings Royal Society of Tasmania* 91:81-93.
- SPRY, A. H. 1962. The Precambrian rocks, in: SPRY, A.; BANKS, M. R. (ed.). The geology of Tasmania. *Journal Geological Society of Australia* 9(2):107-126.
- TAHERI, J. 1985. *Origin of mineralisation in south Heemskirk Granite*. Ph.D. thesis, University of Tasmania.
- TAHERI, J.; GREEN, G. R. 1990. The origin of gold-tin-copper mineralisation at the Lakeside deposit, western Tasmania. *Geological Report Mt Read Volcanics Project Tasmania* 5.
- TAYLOR, C. P. 1965. *Ground magnetic survey Balfour, Tasmania*. Broken Hill Proprietary Company Limited [TCR 65-0383].
- TAYLOR, H. P. 1979. Oxygen and hydrogen isotope relationships in hydrothermal mineral deposits, in: BARNES, H. L. (ed.). *Geochemistry of hydrothermal ore deposits*. 236-277. Wiley : New York.
- TEAR, S. J. 1996. *Fourth annual report for the period ending 5 October 1996. EL18/92 Mt Frankland, Tasmania*. CRA Exploration Proprietary Limited [TCR 96-3931].
- TEAR, S. J.; RUSSELL, S. A. J. 1997. *EL18/92 Mt Frankland. Fifth and final annual report for the period from 6 October 1996 to 11 November 1997, Burnie SK55-03, Tasmania, Australia*. Rio Tinto Exploration Proprietary Limited [TCR 96-4121].
- THOMAS, D. E.; HENDERSON, Q. J. 1943. Balfour mining field. *Unpublished Report Department of Mines* 1943:154-162.
- TURNER, N. J. 1989. Precambrian, in: BURRETT, C. F.; MARTIN, E. L. (ed.). Geology and mineral resources of Tasmania. *Special Publication Geological Society of Australia* 15:5-46.
- TURNER, N. J. 1994. Report on geological mapping and rock chip sampling around The Clump, Murrays Reward and other localities in EL18/92, Balfour district, north western Tasmania, in: MENPES, S. A. *Balfour EL4/94. Report on exploration for the first year of tenure 3/6/94 to 3/5/95*. CRA Exploration Pty Ltd [TCR 95-3734].
- VESKA, L. T. 1993. *Geology, mineralisation and structure of the Balfour copper occurrence, north-western Tasmania*. B.Sc. (Hons.) thesis, University of Tasmania.
- WARD, L. K. 1911. The Mount Balfour mining field. *Bulletin Geological Survey Tasmania* 10.
- WHITEHEAD, S. 1965. *Petrological Report No. M.9/65 Specimens from DDB 5 - Balfour, Tasmania*. Broken Hill Proprietary Company Limited [TCR 65-0388].
- WHITEHEAD, S.; APHORPE, M. 1964. *Petrological Report No. M.19/64. Specimens from Balfour, Tasmania*. Broken Hill Proprietary Company Limited [TCR 64-0374].
- YAXLEY, G. 1981. *Geology and mineralisation of the Balfour district*. B.Sc. (Hons.) Thesis, University of Tasmania.

[25 October 2005]

APPENDIX 1

Reports issued by exploration companies involved in the Balfour area (1955-2001)

<i>Report No</i>	<i>Tenement</i>	<i>Company</i>	<i>Author</i>	<i>Date</i>	<i>Title</i>
55_0116	SPL252	Mining and Prospecting Services Proprietary Limited	Elliston, J.	1955	Interim report on an area of 176,000 acres – Special Prospectors Licence No. 252. Nelson Bay area Tasmania.
58_0234		Electrolytic Zinc Company of Australasia Limited, Lyell EZ Explorations, Mt Lyell Mining and Railway Co.	Scott, B	1958	Mineralisation in the Carbine Group, Precambrian.
61_0331	SPL381	Renison Associated Tin Mines NL	Gilfillan, J. F.	1961	Balfour tin field. Notes on a visit to Balfour on 29 and 30 April 1961.
64_0371	SPL392	Broken Hill Proprietary Company Limited	Whitehead, S.	1964	Petrological Report No. M11/64. Specimens from Balfour, Tasmania.
64_0373	SPL410	Broken Hill Proprietary Company Limited	Chesnut, W. S.	1964	Report on Balfour, Tasmania – Prospecting 1963–1964.
64_0374	SPL410	Broken Hill Proprietary Company Limited	Whitehead, S. Apthorpe, M.	1964	Petrological Report No. M 19/64. Specimens from Balfour, Tasmania.
65_0383	SPL410	Broken Hill Proprietary Company Limited	Taylor, C. P.	1965	Ground Magnetic Survey Balfour, Tasmania.
65_0388	SPL410	Broken Hill Proprietary Company Limited	Whitehead, S.	1965	Petrological Report No. M9/65. Specimens from DDB5 – Balfour, Tasmania.
65_0394	SPL410	Broken Hill Proprietary Company Limited	Chesnut, W. S.	1965	Report on Balfour, Tasmania – Prospecting 1964/1965.
65_0411	SPL410	Broken Hill Proprietary Company Limited	Kingston G. C.	1965	Geological plans, Balfour.
67_0467	SPL17	McPhar Geophysics Proprietary Limited	Bell, R. A. Hallof, P. G.	1967	Report on induced polarization and resistivity survey in the Mt Balfour area, Tasmania.
69_0577	EL16/1968	ACI Operations Proprietary Limited	Davies, H. G.	1969	EL 16/68 – Progress report December 1968–August 1969.
69_0599	EL16/1968	ACI Operations Proprietary Limited	Davies, H. G.	1968	R.9039 November–December 1968 – Corporate exploration of Tasmanian mineral resources: Progress report.
70_0634	101M/1967 58M/1968 62M/1968 63M/1968	Mineral Holdings Australia Proprietary Limited	Nye, P. B.	1970	Report on the extraction of information relating to the mineral leases of Mineral Holdings Australia in the Specimen Hill area of the Mount Balfour mineral field, north-western Tasmania.
73_0947	EL16/1968	ACI Limited	McIntyre, M. H.	1971	Mineral exploration in EL 16/68, Balfour, north-west Tasmania, 1970–1971.
73_0948	EL16/1968	ACI Minerals Proprietary Limited	McIntyre, M. H.	1973	Mineral exploration in EL 16/68, Balfour, Northwest Tasmania, 1972–73.
73_0950	EL16/1968	ACI Minerals Proprietary Limited	Davies, H. G. McIntyre, M. H.		Assorted reports, EL 16/68, Balfour area, 1971–1973.

<i>Report No</i>	<i>Tenement</i>	<i>Company</i>	<i>Author</i>	<i>Date</i>	<i>Title</i>
74_1070A	EL16/1968	ACI Minerals Proprietary Limited	Jackaman, B.	1972	The geology of The Clump prospect, Balfour, Northwest Tasmania.
74_1070B	EL16/1968	ACI Minerals Proprietary Limited	Anon	1972	Geology of the Specimen Hill area, Balfour.
74_1070C	EL16/1968	ACI Minerals Proprietary Limited	McIntyre, M. H.	1972	Summary report on regional geological mapping in EL 16/68, Balfour, Tasmania
74_1070D	EL16/1968	ACI Minerals Proprietary Limited	McIntyre, M. H.	1972	Mineral exploration in EL 16/68, Balfour, Tasmania. Summary report for field season, 1971-72.
77_1218	SPL762	Tico Mines Proprietary Limited	Langsford, N. R.	1977	Report on exploration on SPL 762, Balfour, Tasmania, January-June, 1977.
79_1382	SPL774 SPL781	CRA Exploration Proprietary Limited	Porter, T. M.	1979	The Balfour-Specimen Hill program, six monthly report to June 26, 1979.
80_1475	SPL774 SPL781	CRA Exploration Proprietary Limited	Porter, T. M.	1980	The Balfour-Specimen Hill program, six monthly report to December 26, 1979.
81_1516	EL1/1977	CRA Exploration Proprietary Limited	McKay, A. D. Flis, M. F.	1980	Results of geophysical surveys in the Balfour area (NW Tas.).
82_1730	4M/1974 59M/1968	CRA Exploration Proprietary Limited	Heithersay, P. S.	1982	ML's 59M/68 and 4M/74 - Balfour Tasmania. Report for the year ending 31 December, 1981.
82_1740		CRA Exploration Proprietary Limited	Heithersay, P. S.	1982	Mineral leases 120M/67, 121M67, 10M/73, 1M/73, 2M/76, 93M/77, 94M/77 and 95M/77, Balfour - Tasmania. Report for the year ending 31 December, 1981.
82_1741	58M/1968 63M/1968	CRA Exploration Proprietary Limited	Heithersay, P. S.	1982	ML's 63M/68 and 58M/68 Balfour, Tasmania. Report for the year ending 31 December, 1981.
82_1742	19M/1976	CRA Exploration Proprietary Limited	Heithersay, P. S.	1982	Mineral Lease 19M/76 - Balfour, Tasmania. Report for the twelve months ending 31 December, 1981.
82_1743		CRA Exploration Proprietary Limited	Heithersay, P. S.	1982	Mineral leases 20M/76, 72M/77, 103M/77, 104M/77, 8M/78, 57M/78 and SPL's 774 and 781 Balfour. Report for the twelve months ending 31 December, 1981.
82_1753	EL1/1977	Geopeko Limited	Carey, S. W.	1981	Notes to accompany the photo-interpretation of the country between the Arthur and Pieman rivers, Tasmania.
83_1932	EL1/1977 SPL774, SPL781	CRA Exploration Proprietary Limited	Langsford, N. R.	1982	Geology and mineralisation, Specimen Hill area, Balfour NW Tasmania.
83_1933	19M/1976	CRA Exploration Proprietary Limited	Dickson, T. W.	1983	Final report Mineral Lease 19M/76. LLL and B Syndicate Balfour, Tasmania.

<i>Report No</i>	<i>Tenement</i>	<i>Company</i>	<i>Author</i>	<i>Date</i>	<i>Title</i>
83_1934		CRA Exploration Proprietary Limited	Dickson, T. W.	1983	Final report Mineral Leases 20M/76, 72M/77, 103M/77, 104M/77, 8M/78, 57M/78 and SPL's 774 and 781 L
83_1935		CRA Exploration Proprietary Limited	Dickson, T. W.	1983	Final report Mineral Leases 120M/67, 121M/67, 10M/73, 1M/76, 2M/76, 93M/77, 94M/77 and 95M/77 L & L Syndicate, Balfour.
85_2349	EL1/1977	CRA Exploration Proprietary Limited	Legge, P. J.	1980	The lead zinc potential of the younger Precambrian rocks of North West Tasmania.
85_2482	EL15/1984		Laan, P.	1985	Final report on EL 15/84 at Balfour – 22nd August, 1985.
88_2900	EL21/1987	Aureole Resources Proprietary Limited	Cromer, W. C.	1988	Exploration Licence 21/87 – Balfour. Annual Report: Year 1 (20 January, 1988–19 January, 1989).
88_2900A	EL21/1987	Leaman Geophysics	Leaman, D. E.	1988	Balfour–Trowutta area, North West Tasmania. Evaluation of regional geophysics, implications specific to EL21/87.
89_2987	EL21/1987	Aureole Resources Proprietary Limited	Morrison, K. C.	1989	Exploration Licence 21/87 – Balfour, partial relinquishment report.
89_3060	EL21/1987	Aureole Resources Proprietary Limited	Hofto, V. Morrison, K. C.	1989	Exploration Licence 21/87 – Balfour, Annual Report: Year 2 (20 January, 1989–19 January, 1990).
90_3206	EL21/1987	Aureole Resources Proprietary Limited	Morrison, K. C. Hofto, V.	1990	Exploration Licence 21/87 – Balfour. Annual Report: Year 3 (20 January, 1990–19 January, 1991).
90_3207	EL53/1988	Soloriens Mining Proprietary Limited	Morrison, K. C. Hofto, V.	1990	Exploration Licence 53/88 – Mount Frankland. Annual Report : Year 2 (6 January, 1990–5 January, 1991).
91_3213	EL1/1990 EL40/1989, EL41/1989, EL42/1989, EL43/1989, EL44/1989, EL45/1989, EL46/1989, EL52/1989	Leaman Geophysics	Leaman, D. E.	1990	Geophysical-structural review, Rocky Cape Block, NW Tasmania.
91_3229	EL52/1989	Geopeko Limited	Virgoe, K. J. Mathison, I. J.	1991	EL52/89 Balfour. Report on exploration activity March 1990 to February 1991. Relinquishment report.
91_3315	EL53/1988	Soloriens Mining Proprietary Limited	Morrison, K. C.	1991	Exploration Licence 53/88, Mount Frankland. Annual Report : Year 3 (6 January 1991–5 January 1992).
91_3316	EL21/1987	Aureole NL	Morrison, K. C.	1991	Exploration Licence 21/87 – Balfour. Relinquishment and final report.
92_3403	EL53/1988	Soloriens Mining Proprietary Limited	Morrison, K. C.	1992	Exploration Licence 53/88 – Mount Frankland. Annual Report: Year 4 (6 January, 1992–5 January, 1993).
93_3511	EL18/1992	CRA Exploration Proprietary Limited	Parkinson, R. G.	1993	Mt Frankland EL 18/92 – Report on exploration for the first year of tenure 6/11/92 to 5/10/93.

<i>Report No</i>	<i>Tenement</i>	<i>Company</i>	<i>Author</i>	<i>Date</i>	<i>Title</i>
94_3644	EL18/1992	CRA Exploration Proprietary Limited	Parkinson, R. G.	1994	Mount Frankland EL 18/92. Report on exploration for the second year of tenure, 6/10/93 to 5/10/94.
94_3644A	EL18/1992	N J Turner Geological Services	Turner, N. J.	1994	Report on the stratigraphic and structural setting of rocks in EL 18/92, Balfour district, North-West Tasmania.
95_3734	EL4/1994	CRA Exploration Proprietary Limited	Menpes, S. A.	1995	Balfour EL 4/94. Report on exploration for the first year of tenure 3/6/94 to 3/5/95.
95_3734A	EL4/1994 EL18/1992	N J Turner Geological Services	Turner, N. J.	1994	Report on geological mapping and rock chip sampling around The Clump, Murrays Reward and other localities in EL18/92, Balfour district, north western Tasmania.
95_3802	EL18/1992	CRA Exploration Proprietary Limited	Menpes, S. A.	1995	Third Annual Report for the period ending 10 October 1995. EL18/92, Mt Frankland, Tasmania.
96_3912	EL4/1994	CRA Exploration Proprietary Limited	Menpes, S. A.	1996	Second Annual Report for the period ending 3 May 1996. EL 4/94 Balfour, Tasmania.
96_3912A	EL4/1994	CRA Exploration Proprietary Limited	Patterson, G. W.	1996	A review of exploration at Specimen Hill, Balfour, Tasmania.
96_3931	EL18/1992	CRA Exploration Proprietary Limited	Tear, S. J.	1996	Fourth Annual Report for the period ending 5 October 1996. EL18/92 Mt Frankland, Tasmania.
98_4115	EL4/1994	Rio Tinto Exploration Proprietary Limited	Russell, S. A. J. Tear, S. J.	1997	EL 4/94, Balfour. Third annual and final report for the period 3 May 1996 to 11 November, 1997, Tasmania, Australia.
98_4121	EL18/1992	Rio Tinto Exploration Proprietary Limited	Tear, S. J. Russell, S. A. J.	1997	EL18/92, Mt Frankland. Fifth and final Annual Report for the period from 6 October 1996 to 11 November 1997, Burnie SK55-03, Tasmania, Australia.
99_4346	EL4/1998	Pacific-Nevada Mining Proprietary Limited	Westbrook, S.	1999	EL04/98 Balfour. Report on exploration activity 10-7-98 to 10-7-99.
00_4493	EL4/1998	Pacific-Nevada Mining Proprietary Limited	Newnham, L. A.	2000	EL4/1998 – Balfour area. Partial relinquishment report.
01_4570	EL4/1998	Pacific-Nevada Limited Partnership	Newnham, L. A.	2001	EL4/1998 – Balfour area. Relinquishment report.

APPENDIX 2

Mineral deposit locations, Balfour–Temma area

<i>Refno</i>	<i>Name</i>	<i>Main commodity</i>	<i>Other</i>	<i>AMG east</i>	<i>AMG north</i>	<i>Reference</i>
26001	Mt Balfour Cu mine	Cu	Au, Ag	322 700	5 435 100	Min Map 3, TCR 82-1753, Plan
26007	Nelson Bay River	Fe, Cu	Mag	310 250	5 442 320	TCR 88-2823, 82-1721
26008	Possum Creek	Fe, Cu, Ag	Au, Pb, Mag	310 200	5 428 900	TCR 88-2823, 82-1721
26009	Strickland; Temma	Fe, Pb, Zn	Cu, Ag, Sn, W	309 450	5 433 740	TCR 88-2823, 82-1721
26010	Little Eel	Fe, Cu, Ag	Mag, W, Sn	307 400	5 432 550	TCR 88-2823, 82-1721; Britton (1997)
26011	Rebecca	Fe, Cu, Pb	Ag, Au, Mag	308 450	5 437 750	TCR 88-2823, 82-1721
26012	Couta	Cu, Ag	As, Au	305 536	5 438 347	TCR 88-2823, 82-1721
26013	Richardsons Point	Cu		305 800	5 432 400	TCR 88-2823, 82-1721
26016	No Mans Creek (4375-M)	Fe, Cu		310 000	5 431 000	TCR 82-1753 Plan
26017	North Mt Balfour	Cu		322 200	5 436 200	Min Map 3, TCR 65-394, 82-1753
26018	The Clump	Cu		321 600	5 436 900	Min Map 3, TCR65-394 69-577
26019	Un-named	Cu		321 600	5 432 200	Min Map 3, TCR 65-394
26020	Balfour Blocks	Cu		322 600	5 432 300	Min Map 3, TCR 65-394
26021	Balfour Mines Dvt.; Gully Cu	Cu		322 510	5 433 515	Min Map 3, TCR 82-1753, 94-3644; JLE
26022	Un-named	Cu		322 200	5 436 200	TCR 65-394
26023	Un-named	Cu		321 000	5 437 500	TCR 65-394
26024	Gurr & Herrings	Cu		322 800	5 433 900	TCR 65-394
26025	Balfour Cons	Cu		323 000	5 433 000	TCR 65-394
26026	Un-named	Cu		322 500	5 431 700	TCR 65-394
26027	Un-named	Cu		322 500	5 434 800	AR
26028	Un-named	Sn		322 300	5 431 700	TCR 65-394
26029	Un-named	Cu		320 750	5 435 500	AR
34001	Section 4132M; ?Tatlow's shaft	Cu, Ag	Au, As, Fe, W	324 100	5 428 900	GSB 10; TCR 94-3644
34002	Section 4238M	Cu	Au, Pb	323 500	5 428 100	GSB 10
34003	Section 4279M (Dawson R)	Fe, Mt, Py	Au	311 400	5 427 700	GSB 10
34004	Pierpont Morgan	Cu		324 900	5 427 100	TCR 65-394, Plan, Min Map 3; TCR 94-3644
34005	Grace Creek	Fe, Cu	Mag	312 000	5 427 550	TCR 88-2823, Min Map 3
34006	Specimen Hill	Sn, W		323 800	5 429 400	TCR 82-1740, 1933, 1218
34007	Tin Creek – North	Sn		322 500	5 431 700	TCR 77-1218
34008	Tin Creek – South	Sn		323 500	5 430 400	TCR 77-1218
34009	Matrix Creek	Sn		323 300	5 429 700	TCR 77-1218
34010	Emmetts Creek	Sn		324 100	5 430 400	TCR 77-1218
34011	Murrays Reward	Cu		324 500	5 429 550	TCR 65-394, Plan 83-1932
34012	Central Balfour	Cu		324 300	5 430 000	TCR 65-394, Plan 83-1932
34013	Un-named	Cu		322 100	5 430 700	TCR 82-1753 Plan
34014	Un-named	?		324 200	5 420 500	TCR 65-394

<i>Refno</i>	<i>Name</i>	<i>Main commodity</i>	<i>Other</i>	<i>AMG east</i>	<i>AMG north</i>	<i>Reference</i>
34015	Un-named	?		326 500	5 429 730	TCR 82-1753
34016	Un-named	Sn		324 900	5 426 600	TCR 82-1753, Min Map 3
34017	Un-named	Sn, Pb, Cu		323 200	5 427 800	TCR 82-1753, Min Map 3
34018	Un-named	Sn, W		322 700	5 429 500	TCR 82-1753, Min Map 3
34019	Un-named	Cu		326 300	5 424 700	TCR 82-1753, Min Map 3
34020	Waratah	Cu		325 740	5 424 350	TCR 82-1753
34021	Un-named	Cu		326 000	5 422 000	TCR 82-1753
34022	Balfour South	Cu		326 730	5 421 500	TCR 82-1753, Min Map 3, GSB 10
34023	Mt Hazleton	Cu		326 600	5 420 260	TCR 82-1753
34024	Un-named	Cu		327 200	5 420 700	TCR 82-1753
34025	Un-named	Cu		328 300	5 419 600	TCR 82-1753, Min Map 3, GSB 10
34026	Un-named	Cu		329 500	5 422 200	Min Map 3, GSB 10
34027	Un-named	Cu		333 200	5 421 900	Min Map 3, GSB 10
34028	Un-named	Cu		331 100	5 419 100	TCR 82-1753 plan
34029	Un-named	Sn		331 100	5 419 200	65-411
34030	Un-named	Cu		328 400	5 415 300	TCR 82-1753 plan
34031	Poseidon	Cu		328 500	5 414 500	TCR 82-1753, Min Map 3, GSB 10
34032	Un-named	Cu		328 100	5 413 900	TCR 82-1753
34033	Un-named	Cu		329 400	5 425 700	TCR 65-394, 65-411
34034	ML3802M	Cu		325 390	5 425 270	TCR 65-394, 65-411
34035	Premier; Old Murray Bros.	Cu	Sn	323 770	5 431 240	TCR 65-394, 65-411
34036	Un-named	Sn?		323 600	5 430 600	TCR 65-394, 65-411
34037	Harpers	Cu		324 200	5 430 600	TCR 65-394
34038	Un-named	Cu		324 200	5 430 300	TCR 65-394
34039	Tatflows (main shaft)	Sn, Zn, W, As, Cu		324 470	5 429 280	TCR 82-1932
34040	Robbies	Sn, Cu		324 335	5 428 750	TCR 83-1932
34041	Un-named	Sn		323 000	5 429 200	TCR 83-1932
34042	Un-named	Cu		324 200	5 428 800	TCR 83-1932
34043	Un-named	Sn, Zn		324 100	5 429 600	TCR 83-1932
34044	Un-named	Cu		370 740	5 435 495	
34045	Un-named	Sn, Cu?		324 600	5 423 780	
34046	Un-named	Cu		323 100	5 431 100	AR
34047	Un-named	Cu		323 200	5 430 500	AR
34048	Un-named	Cu		323 700	5 430 700	AR
34049	Mt Lyell Pr-1	Cu		325 300	5 423 400	65-411
34050	Mt Lyell Pr-2	Cu		329 600	5 420 600	65-411
34051	Mt Lyell Pr-3	Cu		330 300	5 419 600	65-411
34052	Un-named	Cu		323 700	5 428 500	TCR 77-1218
34053	Emmets Cu	Cu		323 900	5 430 900	TCR 94-3644
34054	Un-named	Cu		327 500	5 425 100	TCR 94-3645
34055	Un-named	Cu		326 600	5 420 700	RSB
34056	Un-named	Cu		320 700	5 435 500	AR
34057	Un-named	Cu		322 400	5 432 600	AR

<i>Refno</i>	<i>Name</i>	<i>Main commodity</i>	<i>Other</i>	<i>AMG east</i>	<i>AMG north</i>	<i>Reference</i>
34058	Un-named	Cu		322 400	5 434 600	AR
34059	Un-named	Cu		323 100	5 431 200	AR
34060	Un-named	Cu		323 200	5 430 500	AR
34061	Un-named	Cu		323 800	5 430 150	AR
34062	Tatlow's south shaft	Sn		324 350	5 429 150	TCR 94-3645
34063	Tatlow's trench	Sn, Zn, W, As, Cu		324 374	5 429 218	RSB
34064	Un-named	Sn, Cu		324 600	5 428 777	TCR 77-1218
34065	Un-named	Sn, W		323 600	5 429 600	TCR 77-1219
34066	Un-named	Sn		323 600	5 430 400	Plan 1888
34067	Un-named	Sn		323 500	5 429 800	Plan 843c
34068	Un-named	Sn		323 500	5 428 900	Plan 843c
34069	Un-named	Sn		323 400	5 429 100	Plan 843c
34070	Un-named	Sn		323 900	5 429 700	Plan 843c
34071	Un-named	Sn		323 800	5 426 500	Plan 843c
34072	Un-named	Sn		323 700	5 429 500	Plan 843c
34073	Un-named	Sn		323 700	5 429 700	Plan 843c
34074	Un-named	Sn		324 150	5 429 500	Plan 1888
34075	Un-named	Sn		324 100	5 429 350	Plan 843c
34076	Un-named	Sn		324 050	5 429 200	Plan 843c
34077	Un-named	Sn		324 300	5 429 600	Plan 1888
34078	Un-named	Sn		324 250	5 429 250	Plan 843c
34079	Un-named	Sn		324 450	5 429 150	Plan 843c
34080	Un-named	Sn		324 500	5 429 050	Plan 843c
34081	Un-named	Sn		323 700	5 429 150	Plan 1888
34082	Un-named	Sn		324 200	5 429 450	Plan 843c
34083	Un-named	Cu		325 300	5 422 800	GSB 10
35036	Toner #4	Cu		338 200	5 408 300	Min Map 3, TCR 84-2113
35035	Toner River #1	Cu		337 100	5 410 500	Min Map 3, TCR 84-2113
35046	Toner River #2	Cu		336 500	5 410 700	TCR 84-2113, GSB 10
35047	Toner River #3	Cu		336 000	5 409 600	TCR 84-2113, GSB 10
35048	Toner River Nth: ML 4003M	Cu		335 200	5 412 800	GSB 10
35049	Toner River Sth: ML 3598M	Cu		336 000	5 409 600	GSB 10
35050	Toner River SE: ML 3752M	Cu		338 200	5 408 300	GSB 10

APPENDIX 3

Sample locations, Balfour-Temma area

Reg No.	Name	Minerals	Modifiers	AMG (mE)	AMG (mN)	Locality	Collector	Year	Field No.	Treatment	Comments
C108201	ore	qtz, py, cpy		324490	5429590	Murrays Reward	rsb	1999	MR1		
C108202	ore	qtz, cpy		324490	5429590	Murrays Reward	rsb	1999	MR2	PTS, DPS, IS	
C108203	ore	cpy, cv, qtz		324490	5429590	Murrays Reward	rsb	1999	MR3	CA	
C108204	ore	qtz, py, cv		324490	5429590	Murrays Reward	rsb	1999	MR4	PTS, CA	
C108205	ore	cv?, qtz, cpy		324490	5429590	Murrays Reward	rsb	1999	MR5	DPS, CA, IS	
C108206	ore	qtz	Cu	324490	5429590	Murrays Reward	rsb	1999	MR6	CA	
C108207	ore	qtz, py	fgd, diss	324490	5429590	Murrays Reward	rsb	1999	MR7		
C108208	ore	cc		324490	5429590	Murrays Reward	rsb	1999	MR8	PTS, CA	Quartz cemented by chalcocite and malachite
C108209	vein	qtz		324490	5429590	Murrays Reward	rsb	1999	MR8, 9	PTS CA	Leached barren?
C108210	ore		Cu, rich	324490	5429590	Murrays Reward	rsb	1999	MR10	PTS, CA	
C108211	ore		Cu, rich	324490	5429590	Murrays Reward	rsb	1999	MR11	CA	Azurite
C108212	ore		Cu, rich	324490	5429590	Murrays Reward	rsb	1999	MR12	CA	
C108213	ore	cc	brx	324490	5429590	Murrays Reward	rsb	1999	MR13		Breccia with quartz clasts in py
C108214	ore	qtz, py, cpy	bndd	324490	5429590	Murrays Reward	rsb	1999	MR14	CA	Quartz with bands of py and cpy
C108215	ore	cpy, qtz	breccia	324490	5429590	Murrays Reward	rsb	1999	MR15	PTS	
C108216	ore	cv, py, qtz		324490	5429590	Murrays Reward	rsb	1999	MR16	CA	Chalcocite
C108217	ore	py, cc	mass	324490	5429590	Murrays Reward	rsb	1999	MR17		Malachite
C108218	qtz	cpy		324490	5429590	Murrays Reward	rsb	1999	MR18		
C108219	vein	wf, cst, qtz		323900	5429500	Specimen Hill	rsb	1999	SpH3	DPS, CA	
C108220	vein	cst, mus, qtz		323900	5429500	Specimen Hill	rsb	1999	SpH4	PTS CA	
C108221	vein	wf, qtz		323900	5429500	Specimen Hill	rsb	1999	SpH5	CA	
C108222	vein	cst, qtz		323900	5429500	Specimen Hill	rsb	1999	SpH6	PTS, DPS, CA, IS	
C108223	vein	cst, qtz		323900	5429500	Specimen Hill	rsb	1999	SpH7	PTS, DPS	
C108224	sandstone	tur	altd	323900	5429500	Specimen Hill	rsb	1999	SpH8		
C108225	ore	sulfide-rich breccia		324374	5429218	Tatlows	rsb	1999	Tat1	PTS, DPS, CA	
C108226	ore	qtz, wf	sulfide	324374	5429218	Tatlows	rsb	1999	Tat2	PTS, DPS, IS	
C108227	slate	chloritic		324374	5429218	Tatlows	rsb	1999	Tat3	PTS, EMP	
C108228	slate		dark grey?	324374	5429218	Tatlows	rsb	1999	Tat4	CA	
C108229	ore	qtz	sx	324374	5429218	Tatlows	rsb	1999	Tat5	PTS, IS, CA	
C108230	ore	py	mass	324374	5429218	Tatlows	rsb	1999	Tat6	PTS CA	
C108231	ore	qtz	sx	324374	5429218	Tatlows	rsb	1999	Tat7	CA	
C108232	ore	semi-massive sulfides		324374	5429218	Tatlows	rsb	1999	Tat8	PTS CA	
C108233	ore	massive sulfides		324374	5429218	Tatlows	rsb	1999	Tat9		
C108234	ore	Cu		324306	5429822	Central Balfour	rsb	1999	BC1	PTS, IS, CA	Cu ore
C108235	vein	qtz	mass	324306	5429822	Central Balfour	rsb	1999	BC2		
C108236	slate	chl	sulfides	324306	5429822	Central Balfour	rsb	1999	BC3	PTS	

Reg No.	Name	Minerals	Modifiers	AMG (mE)	AMG (mN)	Locality	Collector	Year	Field No.	Treatment	Comments
C108237	ore	Cu		326730	5421495	South Balfour	rsb	1999	SB3	PTS	
C108238	ore	Cu		326730	5421495	South Balfour	rsb	1999	SB4	DPS, IS	
C108239	ore	qtz	bndd	326730	5421495	South Balfour	rsb	1999	SB5	PTS, IS, CA	
C108240	qtz	py, cpy		325738	5424156	Waratah Prospect	rsb	1999	Warat 1	PTS, DPS, CA, IS	
C108241	qtz	py		325385	5425270	Galena Prospect	rsb	1999	Balf 1	CA	
C108242	qtz	py, chl		323770	5431240	Premier	rsb	1999	Prem 1	PTS, EMP, DPS, IS	
C108243	ore	cpy, py		323770	5431240	Premier	rsb	1999	Prem 2	CA, IS	
C108244	slate		brx, sili	322790	5432340	Balfour Blocks	rsb	1999	BB1	CA	
C108245	qtz	crystals, vugg		322790	5432340	Balfour Blocks	rsb	1999	BB2	DPS, IS	Open space
C108246	vein	qtz, py		322790	5432340	Balfour Blocks	rsb	1999	BB3	CA, IS	Qtz-py cut by fibrous quartz
C108247	ore	cpy		322790	5432340	Balfour Blocks	rsb	1999	BB4	PTS, DPS, CA, IS	
C108248	slate	chl, py		322790	5432340	Balfour Blocks	rsb	1999	BB5	PTS, EMP, CA, IS	
C108249	slate	chl, cpy	veinlets	322790	5432340	Balfour Blocks	rsb	1999	BB6	PTS, EMP, IS	
C108250	breccia	cpy, py	clasts	322790	5432340	Balfour Blocks	rsb	1999	BB7		
C108251	ore	cpy, qtz		322790	5432340	Balfour Blocks	rsb	1999	BB8		
C108252	ore	cpy, qtz		322790	5432340	Balfour Blocks	rsb	1999	BB9	CA	
C108253	ore		wthd, Cu?	322790	5432340	Balfour Blocks	rsb	1999	BB10	IS, CA	Weathered ore with native Cu
C108254	ore	qtz, cpy, py	bndd	305536	5438347	Couta Mine	rsb	1999	Cout 8	DPS, CA, IS	
C108255	slate			305536	5438347	Couta Mine	rsb	1999	Cout9		
C108256	ore	cpy, qtz		305536	5438347	Couta Mine	rsb	1999	Couta 10	PTS, IS, CA	
C108257	slate	chl	black	321594	5436885	Clump	rsb	1999	Clump 1	PTS, EMP, CA	
C108258	breccia	qtz	slate	321594	5436885	Clump	rsb	1999	Clump 2	DPS, CA, IS	
C108259	breccia		sulfides	321594	5436885	Clump	rsb	1999	Clump 3	PTS, IS, CA	Non siliceous
C108260	ore			321594	5436885	Clump	rsb	1999	Clump 4	DPS, IS, CA	
C108261	slate	py	brx	321594	5436885	Clump	JT	1999	Clump 5	PTS, IS, CA	
C108262	slate	black, green		324490	5429590	Murrays Reward	JT	1999	MR 19	PTS	
C108263	ore	py, cpy	bndd	324490	5429590	Murrays Reward	JT	1999	MR 20	CA	
C108264	?	chl		324490	5429590	Murrays Reward	JT	1999	MR 21	PTS	Chlorite alteration
C108265	ore			324490	5429590	Murrays Reward	JT	1999	MR 22	PTS, DPS	Ore samples
C108266	breccia	qtz, cpy, py	slate	324490	5429590	Murrays Reward	JT	1999	MR 23		
C108267	basalt		altd	324490	5429590	Kannunah Bridge	JT	1999	Kbridge1	PTS, EMP, CA	
C108268	siltstone	chl		324490	5429590	Murrays Reward	JT	2000	BC9-10.3	PTS	
C108269	siltstone	dol, chl, qtz		324490	5429590	Murrays Reward	JT	2000	BC9-62.3	PTS	
C108270	ore	dol, qtz	sulfides	324490	5429590	Murrays Reward	JT	2000	BC9-62.6	PTS	
C108271	ore	dol, qtz		324490	5429590	Murrays Reward	JT	2000	BC9-63.4	QP	
C108272	ore	dol, cpy, qtz		324490	5429590	Murrays Reward	JT	2000	BC9-71.0	QP	
C108273	ore	cpy, qtz		324490	5429590	Murrays Reward	JT	2000	BC9-73.0	QP	
C108274	ore	qtz	sulfides	324490	5429590	Murrays Reward	JT	2000	BC9-82	PTS, QP	
C108275	ore	qtz, minor sulfides		324490	5429590	Murrays Reward	JT	2000	BC9-86.4	QP	
C108276	ore	dol, qtz	sulfides	324490	5429590	Murrays Reward	JT	2000	BC9-153.5	PTS	
C108277	siltstone	py, diss	lami, grey	324490	5429590	Murrays Reward	JT	2000	BC9-167.8	PTS	
C108278	ore	dol, qtz		324490	5429590	Murrays Reward	JT	2000	BC9-221.1	QP	

Reg No.	Name	Minerals	Modifiers	AMG (mE)	AMG (mN)	Locality	Collector	Year	Field No.	Treatment	Comments
C108279	ore	qtz		324490	5429590	Murrays Reward	JT	2000	BC9-224.8	QP	Barren
C108280	ore	dol, qtz		324490	5429590	Murrays Reward	JT	2000	BC11-121.3	QP	
C108281	ore	dol, qtz		324490	5429590	Murrays Reward	JT	2000	BC11-127.7	QP	
C108282	ore	dol, qtz		324490	5429590	Murrays Reward	JT	2000	BC11-153.0	QP	
C108284	ore	dol, qtz	sulfides	324490	5429590	Murrays Reward	JT	2000	BC11-159.3	QP	
C108285	vein	py, cpy, apy		323900	5429500	Specimen Hill	JT	2000	BC8-31.20	IS	
C108286	vein	wf, qtz, py		323900	5429500	Specimen Hill	JT	2000	BC8-43.4	IS	
C108287	vein	py, apy, wf	qtz	323900	5429500	Specimen Hill	JT	2000	BC8-56.6		
C108288	vein	py, wf, apy	massive	323900	5429500	Specimen Hill	JT	2000	BC8-79.2		
C108289	vein	sl, cpy, apy	qtz	323900	5429500	Specimen Hill	JT	2000	BC8-87.3	IS	
C108290	vein	qtz	sulfides	323900	5429500	Specimen Hill	JT	2000	BC4-99.9		
C108291	vein			323900	5429500	Specimen Hill	JT	2000	BC8-107.0		
C108292	vein	qtz, wf, cst	cpy	323900	5429500	Specimen Hill	JT	2000	BC8-128.2		
C108293	vein	apy, py, wf	cst	323900	5429500	Specimen Hill	JT	2000	BC8-144.1		
C108294	vein			323900	5429500	Specimen Hill	JT	2000	BC8-203.70		
C108295	vein	dark grey sltst		323900	5429500	Specimen Hill	JT	2000	BC8-240.0		Contact between massive sulph.
C108296	vein	Bi		323900	5429500	Specimen Hill	JT	2000	BC8-251.7		Sulphide-rich vein with high Bi
C108297	vein	qtz	sulfides	323900	5429500	Specimen Hill	JT	2000	BC2-64.3		
C108298	vein	wf		323900	5429500	Specimen Hill	JT	2000	BC2-69.0		Sulphide vein with wolf. crystals
C108299	vein	qtz, wf, apy		323900	5429500	Specimen Hill	JT	2000	BC2-141.6		
C108300	siltstone	sulfides	brecciated	323900	5429500	Specimen Hill	JT	2000	BC2-152.4		
C108401	vein	qtz	siltst	305536	5438347	Couta Mine	rsb	1999	cout-1	QP	Minor Cu?
C108402	vein	qtz		305536	5438347	Couta Mine	rsb	1999	cout-2	QP, CA	Major quartz lode, 0.6-1 m wide, in siltst
C108403	vein	qtz	Cu	305536	5438347	Couta Mine	rsb	1999	cout-3	CA	Quartz vein, minor Cu stains
C108404	ore		sx, Cu	305536	5438347	Couta Mine	rsb	1999	cout-4		Main lode, sulfide-rich
C108405	vein	qtz	sx	305536	5438347	Couta Mine	rsb	1999	cout-5	QP	Small quartz-sulfide vein
C108406	vein	qtz	sx	305536	5438347	Couta Mine	rsb	1999	cout-6	QP, CA	Quartz sulfide vein (10 cm)
C108407	vein	qtz		305536	5438347	Couta Mine	rsb	1999	cout-7	DPS, QP, CA	Barren quartz
C108408	vein	qtz, chl	whit, vugg	308636	5437019	Temma Farm Q	rsb	1999	temma farm-1	PTS, DPS, QP, CA	20 cm
C108409	ore		sx	326730	5421495	South Balfour adit	rsb	1999	sb-1	CA, PTS, EMP, IS	
C108410	ore		sx	326730	5421495	South Balfour adit	rsb	1999	sb-2	QP, CA	
C108411	qtz		vein	326600	540160	Mt Hazleton prospect	rsb	1999	mthaz-1		1 m wide
C108412	qtz		xls	323900	5429500	Specimen Hill	rsb	1999	sb-2	QP	
C108413	qtz	cpy, py	vein	323900	5429500	Specimen Hill	rsb	1999	mthaz-1		
C108414	ore	stp, gn		309360	5433630	Strickland	rsb	1999	str-1	PTS, EMP, CA	Lead rich sample
C108415	ore	qtz	sulfide	309360	5433630	Strickland	rsb	1999	str-2	DPS, QP, IS	
C108416	ore	mt, stp	sulfide	309360	5433630	Strickland	rsb	1999	str-3	PTS, IS, CA	
C108417	ore	py, wthd	siliceous	309360	5433630	Strickland	rsb	1999	str-4		
C108418	slate	chl		309360	5433630	Strickland	rsb	1999	str-5	PTS CA	
C108419	ore	py, qtz		309470	5433850	Strickland	rsb	1999	str-6	CA	
C108420	ore	mt	massive	309470	5433850	Strickland	rsb	1999	str-7	IS	

Reg No.	Name	Minerals	Modifiers	AMG (mE)	AMG (mN)	Locality	Collector	Year	Field No.	Treatment	Comments
C108425	basalt	Cu, Camb	Spinks Ck	330600	5446400	Kannunah Bridge	rsb	1999	pts		
C108426	chert			340500	5442090	Sumac Road Q	rsb	1999			
C108427	slate	py		341000	5438500	Mt Bertha Road Q	rsb	1999			
C108428	sulfates			341000	5438500	Mt Bertha Road Q	rsb	1999		xrd	
C108429	siltstone		spotted	337570	5437260	Sumac Road	rsb	1999		PTS	
C108430	lamprophyre		wthd	321150	5436150	Balfour-Heemskirk Rd	rsb	1999		PTS	
C108431	siltstone		pblast	320760	5437640	Balfour Road junction	rsb	1999		PTS, EMP	
C108432	gabbro			325670	5439830	Blackwater Road	rsb	1999		PTS	
C108433	chert		Cu	339840	5440770	near Blackwater Road	rsb	1999		PTS	
C108434	vein	qtz, cst		323900	5429500	Specimen Hill	rsb	1999			
C108435	vein	qtz, wf		323900	5429500	Specimen Hill	rsb	1999			
C108436	siltstone	chl, py	veins	321050	5437390	n-most Balfour wkgs	rsb	2000		PTS	
C108437	siltstone		pblst	321200	5437190	North of Clump	rsb	2000		PTS	
C108438	ore	py, cpy, qtz	cgd	321800	5437000	Clump	rsb	2000		IS	
C108439	breccia	cpy, ser	slate	321800	5437000	Clump	rsb	2000		PTS	
C108440	slate		spot, carb	321500	5436900	North of Clump	rsb	2000		PTS	
C108441	siltstone		carb	321500	5436900	North of Clump	rsb	2000		PTS	
C108442	siltstone			321500	5436900	North of Clump	rsb	2000			
C108443	quartz		milky	321500	5436900	North of Clump	rsb	2000			
C108444	slate		spot, carb	320760	5437640	Temma Road	rsb	2000			
C108445	slate		vein, carb	320760	5437640	Temma Road	rsb	2000			
C108446	ironstone	mt, hem	wthd	310320	5442180	Nelson Bay River	rsb	2000		PTS	
C108447	ironstone	mt, qtz		310250	5442320	Nelson Bay River	rsb	2000		PTS	Grunerite?
C108448	amphibolite	act, qtz		310250	5442320	Nelson Bay River	rsb	2000		PTS	Vein? sid?
C108449	schist?	chl?	sili, bndd	310250	5442320	Nelson Bay River	rsb	2000		PTS	
C108450	ironstone	mt, qtz, sid	wthd	310200	5428900	Possum Creek	rsb	2000		PTS	
C108451	ore	mt, py, qtz	Cu	310200	5428900	Possum Creek	rsb	2000		PTS	
C108452	siltstone	chl		310200	5428900	Possum Creek	rsb	2000		PTS	
C108453	ore	mt		310200	5428900	Possum Creek	rsb	2000			
C108454	ore	mt, am, sid		310200	5428900	Possum Creek	rsb	2000		PTS, EMP	
C108455	slate		spot, black	322100	5436450	North Mt Balfour	rsb	2000			
C108461	breccia	qtz, py, cpy		337070	5410350	Toner River Prospect	rsb	2000		PTS	?pmp
C108463	ore	Cu	wthd	337070	5410350	Toner River Prospect	rsb	2000			
C108464	vein	qtz	molds	324335	5429005	Robbies	rsb	2000			
C108465	vein	qtz, py		324335	5429005	Robbies	rsb	2000			
C108466	siltstone?	cst	diss	324335	5429005	Robbies	rsb	2000			
C108467	ore	qtz	sx	324374	5429218	Tatlows	rsb	2000			
C108468	ore	qtz, cst, apy	cpy	324600	5423777	South of Robbies	rsb	2000		PTS	
C108469	ore	cc		324490	5429590	Murrays Reward	rsb	2000			
C108470	siltstone	py		306800	5430900	Temma	rsb	2000		PTS	
C108471	siltstone	qtz, chl	vein	338344	5411423	Mt Bolton	rsb	2001		PTS	
C108472	ore		sx, Cu	337070	5410350	Toner River Prospect	rsb	2001			

Reg No.	Name	Minerals	Modifiers	AMG (mE)	AMG (mN)	Locality	Collector	Year	Field No.	Treatment	Comments
C108473	slate	sx, Cu	bndd	326730	5421495	South Balfour adit	rsb	2001		PTS	
C108474	breccia	cpy		326730	5421495	South Balfour adit	rsb	2001			
C108475	vein	qtz, py		326730	5421495	South Balfour adit	rsb	2001			
C108476	vein	qtz, cpy		326730	5421495	South Balfour adit	rsb	2001			
C108477	vein	qtz, cpy, py		322790	5432340	Balfour Blocks	rsb	2001			(py in cpy)
C108478	vein	qtz, chl, py		322790	5432340	Balfour Blocks	rsb	2001		PTS	
C108479	siltstone	py		340700	5462900						
C108480	vein	qtz	molds	324490	5429590	Murrays Reward	rsb	2001			
C108481	ore	qtz, cpy, py	Cu	324490	5429590	Murrays Reward	rsb	2001			
C108482	nodules	py		324490	5429590	Murrays Reward	rsb	2001			In siltstone
C108483	vein	qtz	fold	324490	5429590	Murrays Reward	rsb	2001			
C108484	ore	cpy, bn	breccia	324490	5429590	Murrays Reward	rsb	2001			
C108485	siltstone	tur		323880	5429390	Specimen Hill	rsb	2001		PTS	
C108486	siltstone	tur	breccia	323790	5429360	Specimen Hill	rsb	2001		PTS	
C108487	ore	qtz, chl, cpy	py	322510	5433515	Balfour Mine Dvt	rsb	2001		PTS	
C108488	ore	qtz, chl, cpy	py	321594	5436885	Clump - outcrop	rsb	2001		PTS	
C108489	ore	qtz, chl	py	321438	5436898	shaft NE of Clump	rsb	2001		PTS	
C108490	brochantite			324490	5429590	Murrays Reward	rsb	2001		xrd	Secondary
C108491	azurite			324490	5429590	Murrays Reward	rsb	2001		xrd	Malachite
R007204	quartz		barren				AR	2001		DPS, IS	

<i>abbreviation</i>	<i>name</i>	<i>abbreviation</i>	<i>name</i>	<i>abbreviation</i>	<i>name</i>
act	actinolite	EMP	microprobe	QP	Quick Plate
altd	altered	eqgr	equigranular	qtz	quartz
am	amphibole	fgd	fine grained	ser	sericitic
apy	arsenopyrite	fgnd	fine grained	shear	sheared
blac	black	FI	fluid inclusion	Si	siliceous/silica-saturated
bn	bornite	fold	folded	sid	siderite
bndd	banded	fsp	feldspar	sifd	silicified
brec	brecciated	gn	galena	silt	silty
brow	brown	grt	garnet	sist	siltstone
brx	breccia	hbd	hornblende	sl	sphalerite
CA	chemical analysis	hem	hematite	spot	spotted
carb	carbonaceous	IS	isotopic analysis	stp	stilpnomelane
cc	chalcocite	Lami	laminated	sx	sulphide
cgd	coarse grained	lim	limonite	TS	thin section
chl	chlorite	mgd	medium grained	tur	tourmaline
CO3	carbonate	mt	magnetite	vein	veined
cpy	chalcopyrite	mus	muscovite	vugg	vuggy
cst	cassiterite	pblst	porphyroblastic	whit	white
cv	covellite	po	pyrrhotite	wf	wolframite
diss	disseminated	porph	porphyry/tic	WR	whole rock analysis
dol	dolomite	PT	polished thin section	wthd	weathered
DPS	doubly polished section	py	pyrite	XR	xrd

APPENDIX 4

Brief descriptions of the Balfour–Temma deposits

Introduction

This is a brief summary of the mineralised sites visited and observations made in 2000–2001 for this project. All maps and sections are very approximate and illustrative only. All maps are oriented north to the top, except for Figure 13.

Balfour Cu deposits

Road cutting, Temma–Balfour Road (320 760 mE; 5 437 640 mN)

A relatively fresh road cutting exposing steeply dipping siltstone. No known workings nearby, but the Balfour lode structure is probably represented by minor quartz veining with limonite after pyrite and/or carbonates? Host slate/siltstone is black, carbonaceous and spotted with at least two types of altered porphyroblast, including garnets (Bottrill, 2004a). Samples C108444–445, C108431.

Un-named (northernmost) workings (321 050 mE, 5 437 390 mN)

One small trench and two pits were located, one in a creek bed with no dumps (fig. 11). Not fully accessible by 4WD (short walk but overgrown).

The only mineralisation visible was quartz-free pyrite veinlets (5 mm wide) in grey-black siltstone (C108436); vein structure: 310°/60°W.

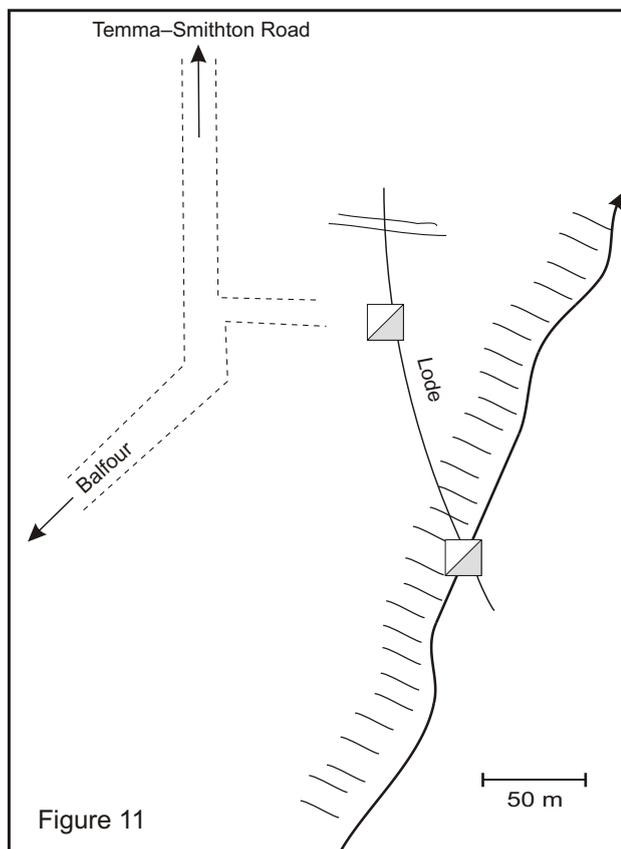


Figure 11

The Clump Prospect (321 800 mE, 5 437 000 mN)

Two shafts and a large adit with sizeable dumps were located (fig. 12); these are easily accessible by 4WD. Large dumps occur at the main adit (overgrown and almost inaccessible) with abundant rich lode samples, but rather weathered, showing coarse patches of pyrite, chalcopyrite and slate in massive quartz (C108438–439). Large dumps also lie near the main shaft (321 600 mE, 5 436 885 mN), but contain little rich mineralisation (C108257–261). The dumps contain some black shale-quartz-sulphide breccias. The lode actually crops out in a small gully north of this shaft, exhibiting a vertical, north-striking vein containing quartz-pyrite, chalcopyrite and chlorite (C108488). Another shallow shaft lies to the north (321 438 mE, 5 436 898 mN), with a small dump and some

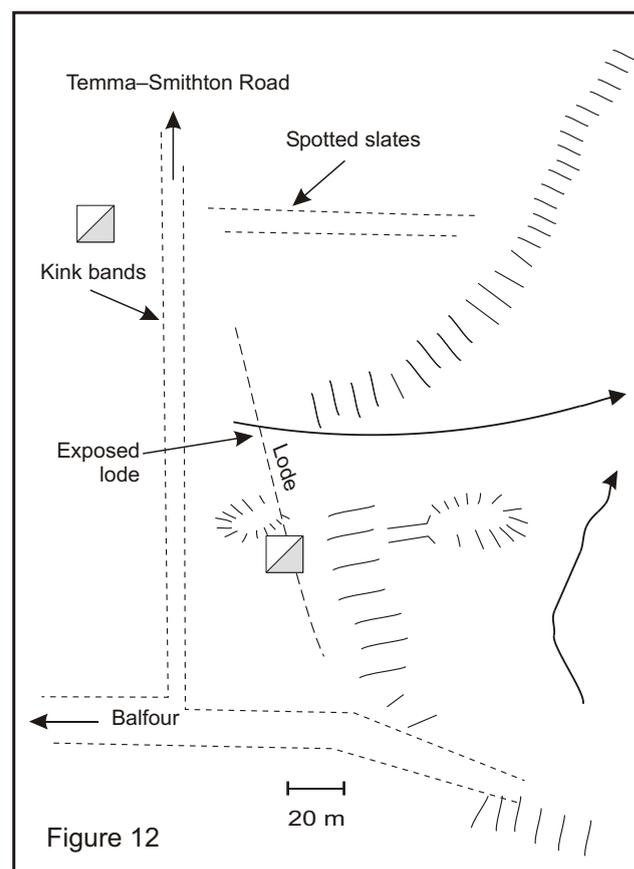


Figure 12

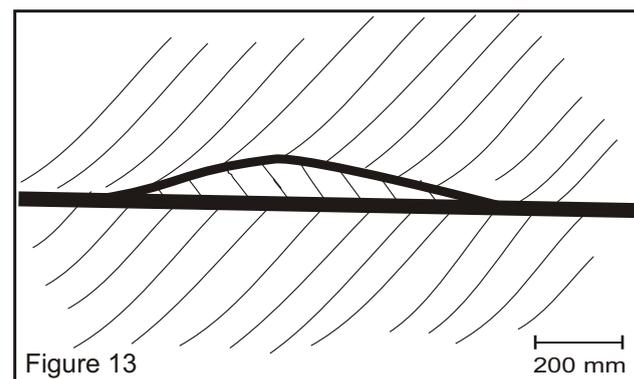


Figure 13

mineralisation (C108489). Mine plans are located in TCR 69-577, 73-947 and 73-950 (see Appendix 1)

Nearby bulldozed tracks and shallow trenches give good exposures of country rock. Good outcrops of host slate and siltstone occur on the tracks near the prospect, showing quartz veins on kink bands (fig. 13).

Un-named workings south of The Clump (North Mt Balfour?) (322 200 mE, 5 436 200 mN)

One old, deep trench was located with a small dump containing white quartz. Several large recent bulldozer cuts on the hill to the east (322 100 mE, 5 436 450 mN) expose black siltstone bedrock with spotting but no mineralisation (C108455). Accessible by 4WD with difficulty. Good outcrops of host slate and siltstone, showing structural relationships.

Balfour Mines Development (322 510 mE, 5 433 515 mN)

One inaccessible adit with a small dump was located with difficulty; also some trenches and bulldozer cuts. Other workings were reported but not located, with the area (including most tracks) all highly overgrown and almost inaccessible (fig. 14).

The dump has some lode samples, rather weathered, showing coarse patches of pyrite and chalcopyrite in quartz + chloritic slate.

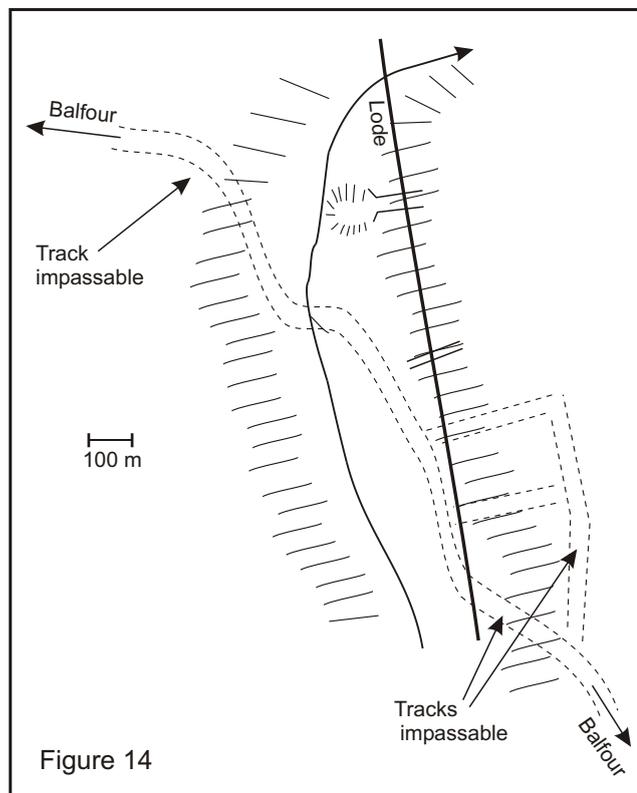


Figure 14

Balfour Blocks

Two shafts with sizeable dumps (322 790 mE, 5 432 340 mN) and a short adit (322 790 mE, 5 432 400 mN); all are easily accessible by 4WD on a good track (fig. 15).

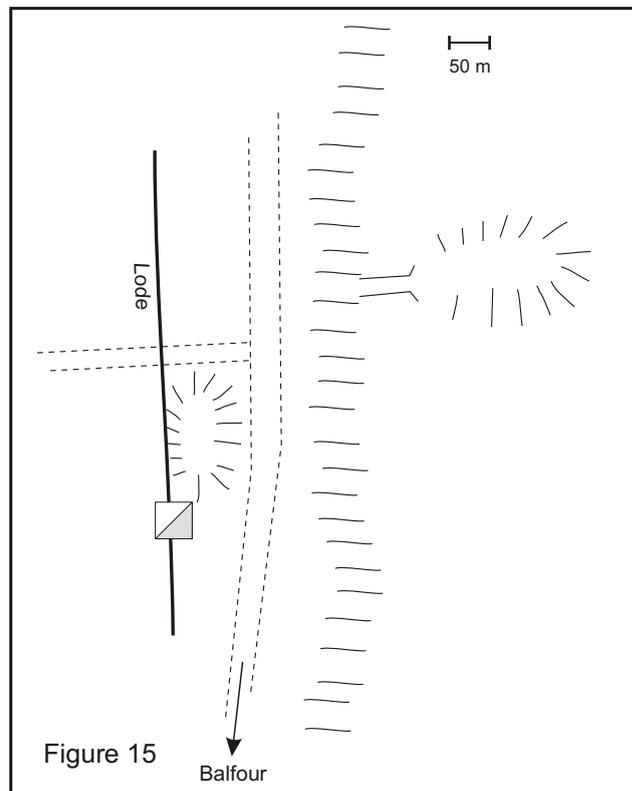


Figure 15

Little fresh outcrop occurs but the large dumps have areas of abundant lode samples, mostly highly weathered, showing:

- coarse but leached patches of pyrite and chalcopyrite in quartz;
- chalcopyrite veins in quartz;
- pyrite clasts and crystals in massive chalcopyrite;
- quartz-slate breccias with disseminated pyrite and chalcopyrite;
- minor vuggy quartz containing chalcopyrite;
- coarse rhombic cavities left by leached carbonates (dolomite?);
- several styles and generations of quartz, including late fibre veins;
- slaty wall rocks also contain disseminated pyrite and chalcopyrite; and
- quartz veins and chlorite (disseminated and in veins).

Samples C108244-253, C108477.

Also present is an adit (accessible, but only intersecting weak lode structure: thin quartz-chlorite-pyrite zones; samples: C108478). Mine plans are located in TCR67-467 and 69-577 (see Appendix 1).

Premier (323 770 mE, 5 431 250 mN)

One shaft and small dump, easily accessible by 4WD on good track. The dumps show weakly pyritic quartz samples (samples 108242, 108243).

There is little fresh outcrop. A lens of massive quartz (~12 3 m) sits in chloritic slate with small quartz-pyrite veins and quartz breccias.

Central Mt Balfour (342 306 mE, 5 429 822 mN)

This deposit appears to be basically an extension of the Murrays Reward lode (see below) and is easily accessible from the main Balfour Road. One roadside shaft (exuding water and precipitating native copper, dangerous to vehicular and foot traffic) lies at the foot of the ridge and several adits worked the lode above this level. A large adit near the shaft is accessible, but contains little visible sulfide lode and was collapsed in the stope, but contains abundant copper sulfates.

There are sizeable dumps containing weathered quartz-pyrite-chalcopyrite ore similar to Murrays Reward, chloritic slate with disseminated and vein pyrite, and massive quartz with patches of pyrite in black slate (samples: C108234–236).

Mine plans are located in TCR65-411 (see Appendix 1).

Murrays Reward (324 490 mE, 5 429 590 mN)

This is the largest working in the field and exhibits one medium-sized open cut (~100 40 m?), one shaft and at least two adits and some large dumps (fig. 16). All are easily accessible from the main Balfour Road, near the Balfour township. The adits (on the eastern side of the ridge) are partly accessible, but lode structures are mostly stoped out or collapsed in the stopes.

Mine plans are located in TCR65-411 and 69-577 (see Appendix 1).

The dumps show:

- coarse grained but leached patches of pyrite and chalcopyrite in quartz;
- laminated lode with bands of quartz, pyrite, chalcopyrite and slate;

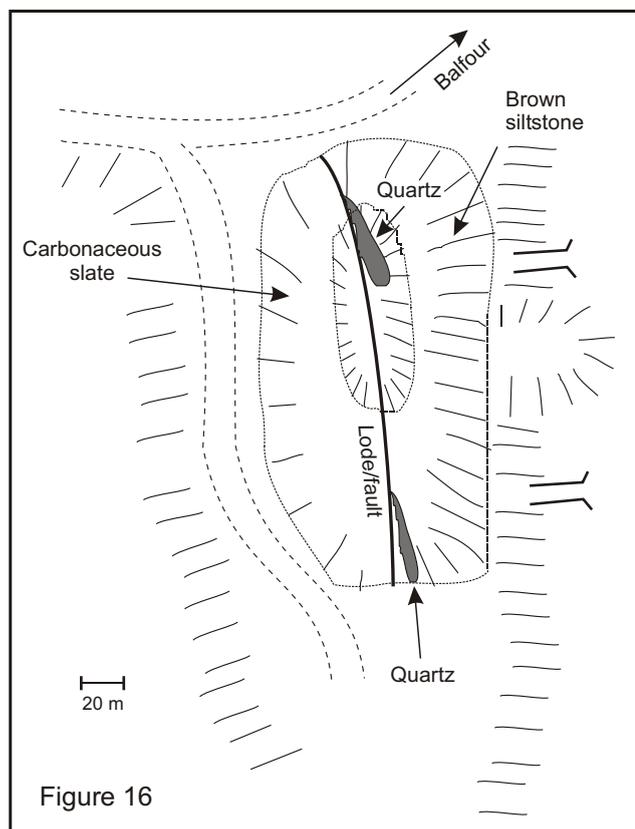


Figure 16

- pyrite and quartz clasts in massive chalcopyrite (now largely altered to chalcocite, covellite and malachite);
- breccia with quartz, pyrite and slate in chalcopyrite;
- quartz with rhombic clasts after a carbonate, and possibly some remnant pink carbonate?

Sulphide lode, barren quartz veins and country rocks are all well exposed in the open cut (fig. 16) (samples C108201–218; 262–266; 469; 480–484; 490–491).

Patchy, weathered sulfide ore occurs along a vertical fault zone trending ~180°. Supergene enrichment is prevalent and most chalcopyrite is largely altered to covellite, digenite and some secondary Cu minerals, including brochantite, malachite, azurite, posnjakite and woodwardite.

The country rock on the eastern side of the fault is a limonitic siltstone with some pyrite nodules (<40 mm), dipping ~80°W. On the western side are black, carbonaceous slate and siltstone with some small-scale folding; they are almost horizontal near the fault but dipping to about 70°W ~10 m away (fig. 17).

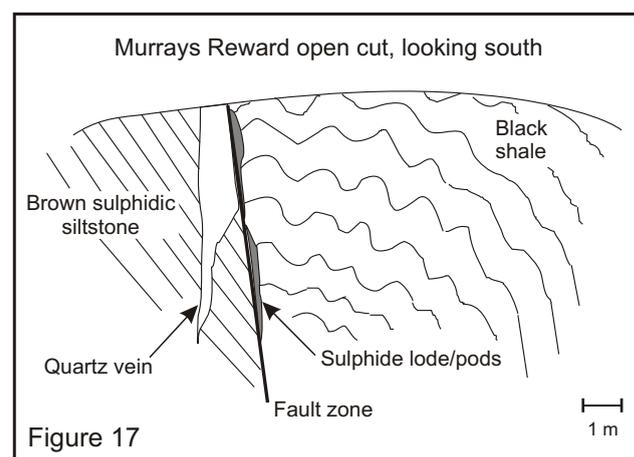


Figure 17

Several styles and generations of quartz vein occur (all barren). Most are on the eastern side of the fault, and are irregular, discontinuous, folded and cut by faulting.

The core from several diamond-drill holes is preserved in the MRT core store (samples C108268–284).

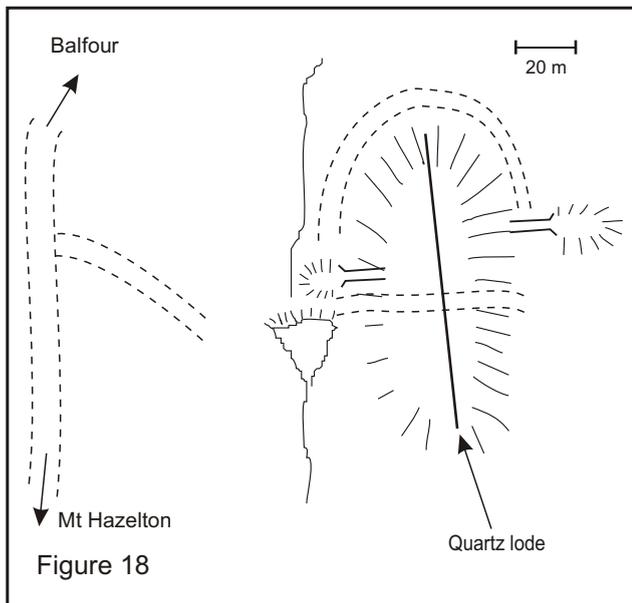
Patchy, weathered sulfide ore occurs along a vertical fault zone trending ~180°.

'Galena Prospect' (325 385 mE, 5 425 270 mN)

One shaft and short adit (inaccessible) with a small dump, ~300 m from the main road. The dump contains some poor lode samples, black slate with quartz-pyrite veins (sample C108241).

Waratah Prospect (325 738 mE, 5 424 156 mN)

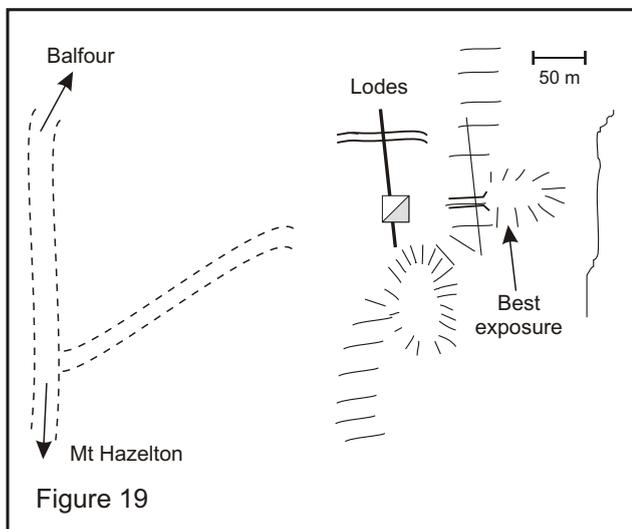
A prominent ridge again represents the lode, which is easily accessible by 4WD from the old Balfour track. Two adits (inaccessible) have small dumps. A large, recent bulldozer cut across the lode is present (fig. 18).



Lode samples show mostly barren quartz pyrite and trace chalcopyrite in laminated 'pyjama' siltstone (sample C108240).

South Balfour (326 567 mE, 5 421 274 mN)

The workings on this deposit lie ~300 m west of the main track to Mt Hazelton, this track following a prominent ridge. The workings, which are accessible by 4WD with difficulty, consist of one shaft and two(?) adits (one accessible, intersecting lode structures) plus trenches, with sizable dumps (fig. 19).



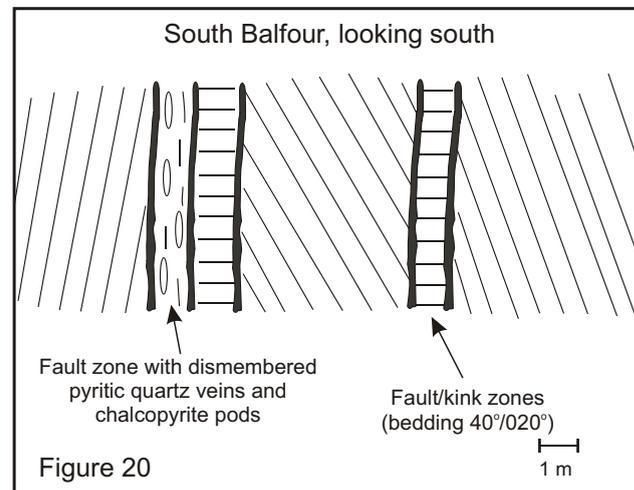
Large dumps contain abundant lode material (samples C108237-239), mostly weathered, showing:

- coarse but leached patches of pyrite (some as crystals to ~25 mm) in quartz;
- banded quartz-pyrite lode;
- chalcopyrite veins in green slate; and
- chalcopyrite veins in quartz.

Ward (1911) reported dolomite and magnetite, but these were not evident to us.

Near the mouth of the adit can be seen a relatively fresh outcrop of a vertical quartz-sulphide lode striking $010^{\circ}/70^{\circ}W$, in the sheared axial plane of a small anticline in grey chloritic siltstone. Pyrite and slate clasts and some white apatite needles occur in the irregular quartz veins. Chalcopyrite occurs mostly on the edges of the quartz vein (fig. 20).

There are several styles and generations of quartz (samples: C108473-476).



Mt Hazelton workings (326 600 mE, 5 420 700 mN)

Two adits underlie the track to Mt Hazelton; these are accessible, but failed to intersecting lode structures, only unmineralised, leached quartzite. Some geologically similar small pits occur on the north face of Mt Hazelton (at 326 600 mE, 5 420 600 mN).

Toner River

Accessible with difficulty from the Heemskirk Road, near Mt Bolton (~5 401 100 mN). Workings are largely overgrown but located were one shaft, one short adit/trench (accessible, intersecting unweathered lode structure; 337 070 mE, 5 410 350 mN), one inaccessible adit (336 970 mE, 5 410 370 mN) and sizeable dumps. Other workings occur in the area but are badly overgrown and not easily accessible (fig. 21).

Outcrop is good in much of the area. Dumps have abundant lode samples, showing coarse but leached patches of pyrite and chalcopyrite in quartz (samples C108460-463).

The trench/adit shows chloritised, silicified slate, quartz veins with minor pyrite and chalcopyrite, and pyrite lenses in a silicified shear zone striking $130^{\circ}/90^{\circ}$ (fig. 22). Host rocks strike N-S and dip $30-80^{\circ}E$, except adjacent to the fault. Abundant massive quartz blows occur ~200 m to the northwest (>0.4 m wide, over ~20 m long).

Several styles and generations of quartz occur.

Dolerite dykes were reported in the area, closely associated with, and parallelling the lodes, but they were not seen by us. There are reportedly some extensive lodes and several workings in the area, but dense bush impeded exploration.

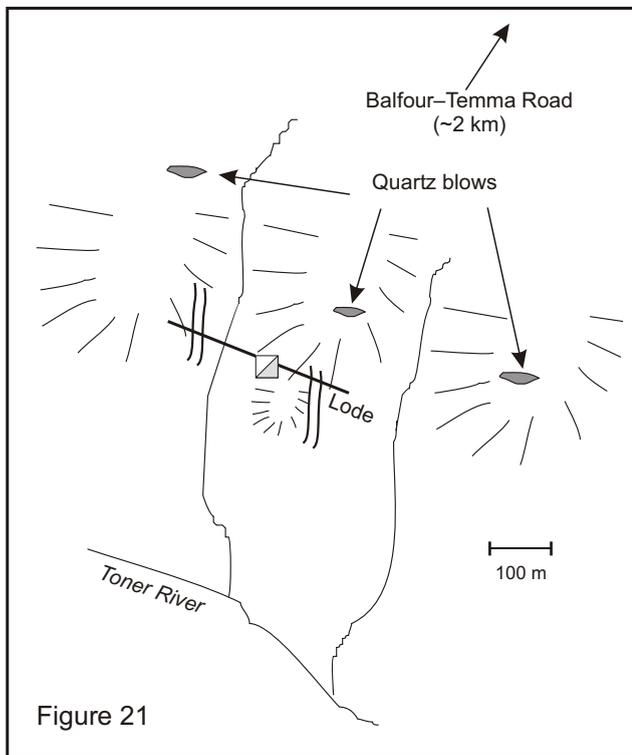


Figure 21

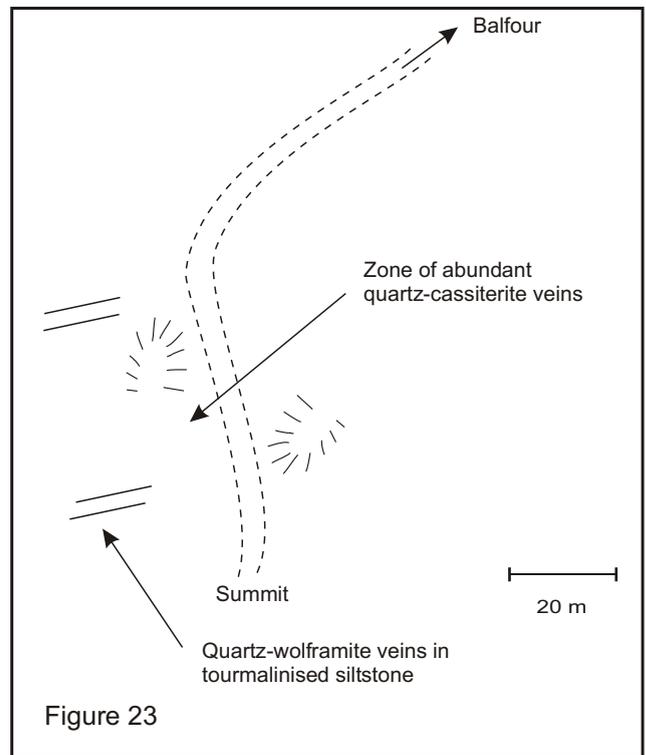


Figure 23

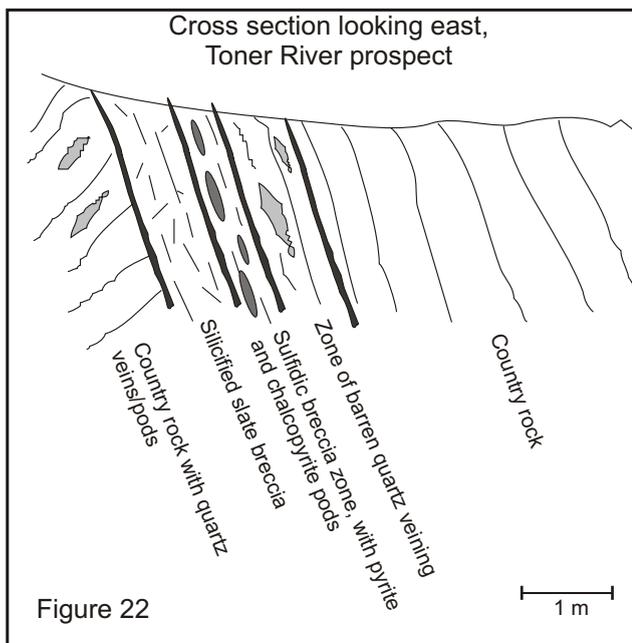


Figure 22

Balfour Sn/W deposits

Specimen Hill (323 800 mE, 5 429 400 mN)

Easily accessible by 4WD from Balfour Road. There is a large sluiced area on the top and flanks of the hill and several trenches and small diggings occur. An old adit near the road collapsed and is inaccessible (323 600 mE, 5 429 600 mN) (fig. 23).

Some of the major workings on the north face (323 790 mE, 5 429 360 mN) show numerous small quartz veins (<200 mm wide), commonly vuggy, with coarse crystals of quartz and cassiterite. There are common coarse muscovite selvages and occasional coarse wolframite patches and casts after carbonate and/or sulphide minerals.

Host rocks are mostly sandstone and siliceous siltstone, tourmalinised in part, and cut by quartz stockworks and veins (samples C108219–224, 412–413, 434–435, 485–486).

Possible quartz porphyries and andesites have been reported from here, but were not seen by us. Detailed plans are located in TCR83-1932, 1935 (see Appendix 1).

The core from several diamond-drill holes is held in the MRT core store (samples C108285–300).

Tatlows (324 374 mE, 5 429 218 mN)

This mine is easily accessible by 4WD from Balfour Road. There are several shafts (with no dumps) and a deep water-filled trench (fig. 24). The trench is located on a thin north-striking, vertical quartz-pyrite vein that opens out to a coarse-grained massive sulfide pod, with arsenopyrite, wolframite, pyrite and chalcopyrite in chloritised slate (all in dump samples). Ward (1909) reported garnet, magnetite and gold, none of which were seen by us (samples C108225–233, 467). Large amounts of white quartz float, with minor muscovite and cassiterite, occur in the vicinity. Detailed plans are located in TCR83-1932 (see Appendix 1).

Robbies (343 335 mE, 5 429 005 mN)

A short distance to the south along an overgrown track are some small diggings in a quartz lode, not easily accessible by 4WD (detailed plans are located in TCR83-1932).

The lode is similar to Specimen Hill, with massive quartz + cassiterite with trace pyrite, in siltstone and slate. Some quartz is vuggy, with molds after carbonate? It may be a continuation of Tatlows lode. Some cassiterite is disseminated in sandstone (samples

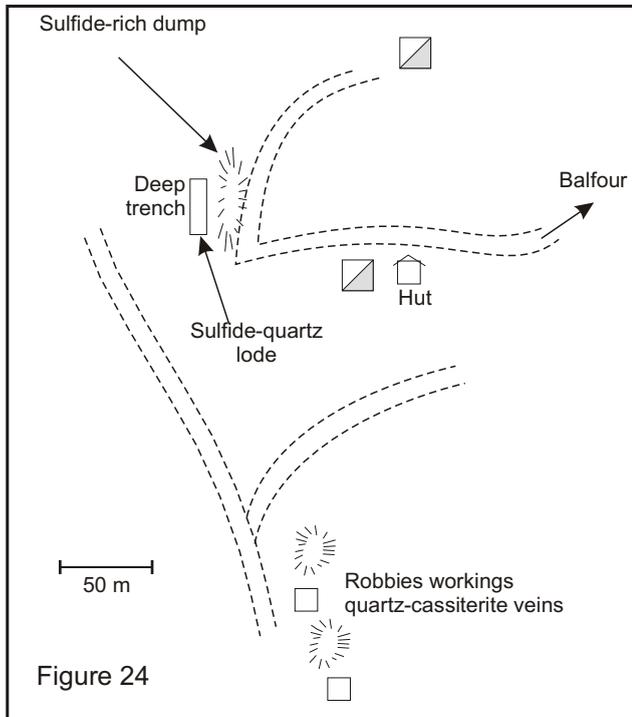


Figure 24

C108464–466). Ward (1911) reported galena and gold, none of which were seen by us.

Sluiced flat south of Robbies
(324 600 mE, 5 423 777 mN)

Easily accessible from the old south Balfour track. Workings are shallow pits and sluiced areas, exposing small, erratic quartz veins with cassiterite, pyrite and chalcopyrite, in siltstone (sample C108468).

Temma district

Couta mine (305 536 mE, 5 438 050 mN)

This mine (fig. 25) is located via private property at Couta Rocks on the coast. The lode itself is exposed on the shore. A filled shaft and small dump is located 300 m to the north at 305 536 mE, 5 438 347 mN.

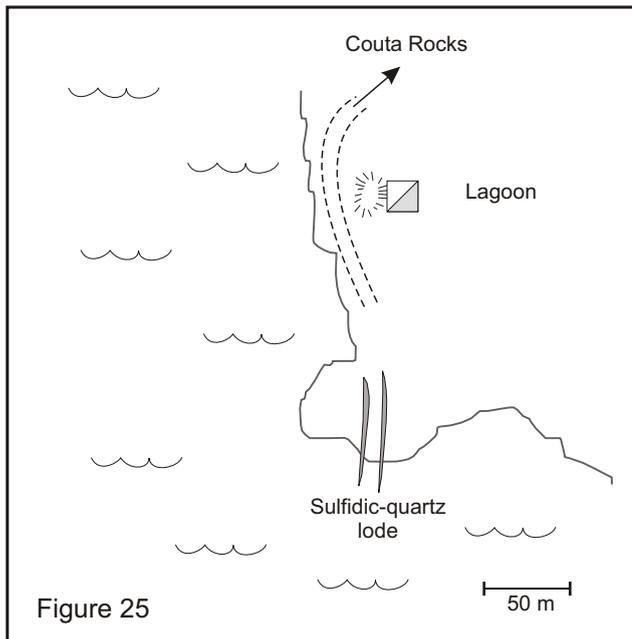


Figure 25

The lode has a number of massive quartz veins to about one metre thick in slate, siltstone and quartzite, and is continuous over more than 50 metres. Some multiple veins are separated by slate bands. Some quartz is barren and vuggy, or milky; some is limonitic or sulphide-rich (in bands <500 mm wide). The lode strikes 025°/80°W and is axial planar to a minor fold. Some chalcopyrite occurs in host slate.

(Samples C108401–407, 254–256).

Nelson River Prospect (310 320 mE, 5 442 320 mN)

Poorly accessible by 4WD to an old, collapsed bridge. Lode outcrops (magnetite-hematite, banded, massive, weathered and brecciated, C108466–467) occur on a ridge running into Nelson Bay River, but largely highly overgrown (fig. 26). Some small pits occur on the river banks, but are very obscure. Lode is exposed in the river bed and banks (310 250 mE, 5 442 320 mN) in chloritic siltstone (C108448–449), dipping 70°NW. Plans are located in TCR88-2823 (see Appendix 1).

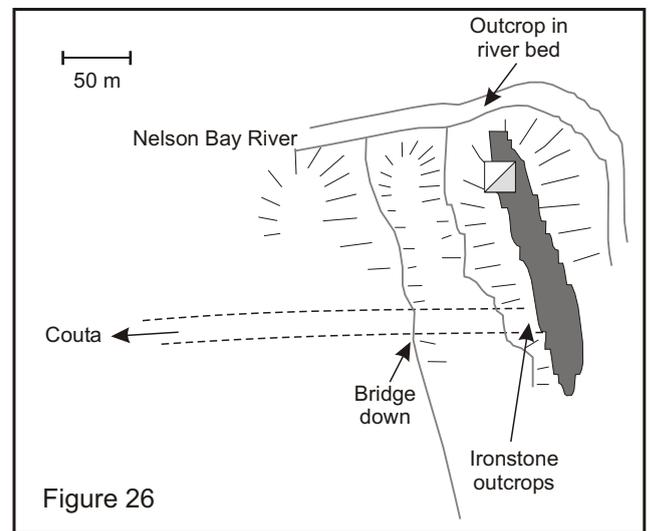


Figure 26

Temma farm (306 800 mE, 5 430 900 mN)

Barren quartz veins (180°, vertical) occur in siltstone in a small quarry on Temma farm. This location is easily accessible (samples C108470, 408).

Rebecca Prospect (~308 450 mE, 5 437 750 mN)

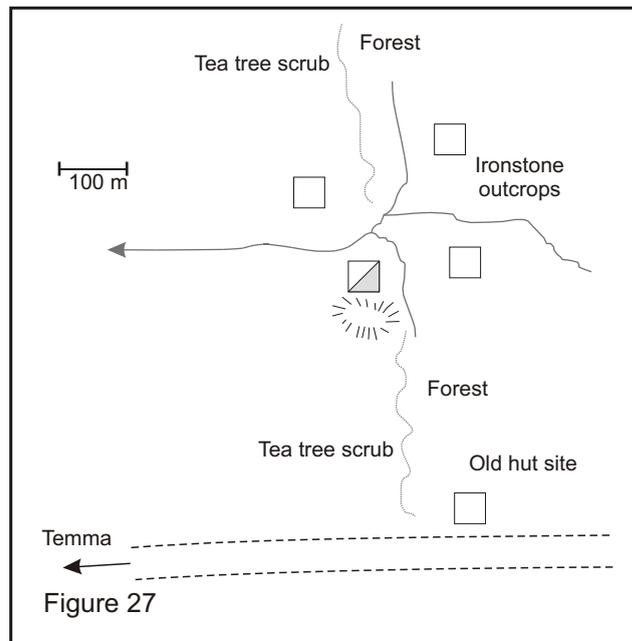
Accessible with difficulty via Temma farm. Magnetite lode reputedly outcrops but the area is highly overgrown and rather inaccessible.

Possum Creek Prospect
(310 200 mE, 5 428 900 mN)

Accessible from the old Balfour–Temma tramway formation. One shaft and trench show lode, which includes massive magnetite-carbonate, magnetite-quartz-pyrite, and magnetite-amphibole in a chloritic siltstone (samples C108450–454). Plans are located in TCR84-2151 (see Appendix 1).

Strickland mine

Accessible with difficulty via Temma farm. Lode outcrops poorly, and the area is highly overgrown. Several small pits and trenches (e.g. 309 450 mE, 5 433 740 mN) and one moderate-sized shaft and dump (309 357 mE, 5 443 646 mN; fig. 27), with samples of magnetite-hematite, pyrite-quartz, quartz-galena and galena-stilpnomelane lode (samples C108414-420). Detailed plans are located in TCR84-2151 (see Appendix 1).



APPENDIX 5

Fluid inclusion data, Balfour–Temma area

<i>Reg. Name</i>	<i>Location</i>	<i>Th</i> °C	<i>ThL</i>	<i>ThV</i>	<i>Tmf</i> °C	<i>Tmi</i> °C	<i>Comment</i>
108258	The Clump	246	L				
		247	L				
		186	L				
		188	L				
		188	L				
		175	L				
		187	L				
		169	L				
		210	L				
		169	L				
		210	L				
		212	L				
		208	L				
		259	L				
		260	L				
		261	L				
		259	L				
		258	L				
		259	L				
		262	L				
		259	L				
		259	L				
		258	L				
		262	L				
		261	L				
		261	L				
		247	L				
		281	L				
		252	L				
		255	L				
255	L						
300	L						
108258	The Clump	266	L				
		265	L		-6.0		
		287	L				
		270	L			-5.8	
		308	L			-6.0	
		330	L				
		314	L			-5.5	
		272	L				
		281	L				
		279	L				
		270	L				
		268	L				
		269	L				
		265	L				
		310	L				
		308	L				
314	L			2 to 4?	Possible existence of CO ₂		
272	L						
287	L						
Thc							
108238	Balfour South	206	L				
		163	L				
		193	L				
		187	L				
		212	L				
		192	L				
206	L						

<i>Reg. Name</i>	<i>Location</i>	<i>Th °C</i>	<i>ThL</i>	<i>ThV</i>	<i>Tmf °C</i>	<i>Tmi °C</i>	<i>Comment</i>
108238	Balfour South	214	L				Two with no changes in bubble sizes upon heating up to 300°C
		215	L				
		188	L				
		214	L				
		198	L				
		240	L				
		196	L				
		184	L				
		186	L				
108409	Balfour South	171	L				
		162	L				
		160	L				
		159	L				
		165	L				
		157	L				
		161	L				
		211	L				
		210	L				
		208	L				
		201	L				
		199	L				
		201	L				
		206	L				
		184	L				
		184	L				
		182	L				
178	L						
173	L						
171	L						
108222	Specimen Hill		L				two at T>490°C only show small increase in bubble sizes
		381	L				
		352	L				
		339	L				
		150	L				
		175	L				
		231	L				
		248	L				
		214	L				
		245	L				
		253	L				
		261	L				
		207	L				
		218	L				
		244	L				
		189	L				
		205	L				
		249	L				
		238	L				
		352	L				
303	L						
292	L						
330	L						
289	L						
210	L						
218	L						
215	L						
216	L						
292	L						
370	L						
128	L						
120	L						
382	L						

<i>Reg. Name</i>	<i>Location</i>	<i>Th °C</i>	<i>ThL</i>	<i>ThV</i>	<i>Tmf °C</i>	<i>Tmi °C</i>	<i>Comment</i>	
108298	Specimen Hill	340	L					
		341	L					
		325	L					
		319			V			
		319	L					
		286	L					
		294	L					
		285	L					A few with no changes upon freezing
		301	L					
		322	L					
		340	L					
		270	L					
		302	L					
		300	L					
		362	L					
308	L							
108286	Specimen Hill	363		V				
		386		V				
		309	L			5.5	1	
		353	L					
		320	L					
		326	L			6.0		
		315	L			7.1	-38	
		390	L					
		390			V			
		401	L					
		367	L					
		405	L					
		365	L					
		322	L					
		382	L					
		341	L					
		351	L					
452			V					
339	L							
341	L							
			L					
			L					
			L					
108415A	Strickland	310	L		-9.5			
		280	L					
		295	L			-10.4		
		280	L			-9.1		
		290	L					
		290	L					
		272	L			-10.3		
		275	L					
		270	L			-10.9		
301	L			-10.5				
108254B	Couta mine	349	L					
		295	L					
		251	L			-27	No change upon freezing for small ones with high v/l ratios	
		310	L					
		300	L					
108407	Couta mine	305	L					
		306	L		-10.5			
		304	L					
		280	L			-12		
		286	L					
		292	L			-11.3		
		324	L					
		318	L					
		290	L					
		385	L					
		398	L					

<i>Reg. Name</i>	<i>Location</i>	<i>Th °C</i>	<i>ThL</i>	<i>ThV</i>	<i>Tmf °C</i>	<i>Tmi °C</i>	<i>Comment</i>
		420	L				
		Th Co					
108408	Temma Farm	224	L		-9		
		160	L		-11.2		
		164	L				
		162	L		-11		
		165	L		-10		
		162	L				
		163	L		-9		
		162	L				
		163	L		-10.5		
108202	Murrays mine	199	L				
		195	L				
		198	L				
		209	L				
		160	L				
		198	L				
		191	L				
		192	L				
		209	L				
		214	L				
	Murrays Reward	258	L				
		260	L				
		167	L				
		210	L				
		218	L				
		225	L				
		231	L				
		226	L				
		258	L				
		226	L				
		Th Co	L				
4782	Alistair's sample	217	L				
		247	L				
		210	L				
		208	L				
		208	L				
		255	L				
		256	L		-3.1		
		276	L				
		271	L				
		264	L				
		249	L		-2.9		
		256	L				
		268	L		-1		
		254	L				
108240	Waratah	202	L				
		178	L				
		212	L				
		178	L				
		227	L				
		228	L				
		223	L				
		201	L				
		201	L				
		196	L				
		198	L				
		189	L				
		190	L				
		202	L				
		220	L				
		202	L				
		195	L				
		Th Co					

<i>Reg. Name</i>	<i>Location</i>	<i>Th °C</i>	<i>ThL</i>	<i>ThV</i>	<i>Tmf °C</i>	<i>Tmi °C</i>	<i>Comment</i>
108242	Premier	210	L		-10	-31	
		198	L		-10		
		208	L				
		225	L			-5	
		201	L				
		228	L			-4.5	-28
108245	Balfour Block	420	CP				
		423	CP				
		305	L				
		307	L			-5.2	
		361	L				
		330	L				
		322	L			-7	
		355	L				
		332	L			-6.5	
		284	L				
		386	L				
		293	L				
		276	L				
		246	L				
268	L						

V = Vapour
L = Liquid

Th = Homogenisation temperature
Tmi = Initial melting point

Tmf = Final melting point
CP = Critical Point

Th °C = Homogenisation temperature
Th_V = Homogenisation temperature (vapour)
Tmi °C = Initial melting temperature

Th_L = Homogenisation temperature (liquid)
Tmf °C = Final melting point temperature

APPENDIX 6

Geochemistry of hydrothermally-altered rocks, Balfour–Temma area

TasRok No.	Field No.	Location	Lab No.	Au (ppm)	Ag (ppm)	As (ppm)	Bi (ppm)	Ga (ppm)	Zn (ppm)	Cu (ppm)	Ni (ppm)	Co (ppm)	Sn (ppm)	W (ppm)	Pb (ppm)
108402	cout-2	Couta	990892	-0.05	-1	165	<5	7	19	91	11	5	<5	<10	91
108403	cout-3	Couta	990891	-0.05	5	165	<5	7	19	82	13	4	<5	<10	152
108406	cout-6	Couta	990893	-0.05	3	170	<5	6	20	820	15	10	<5	<10	13
108407	cout-7	Couta	990894	-0.05	-1	<20	<5	8	19	29	9	5	<5	<10	<5
108408	Temma Farm-1		990895	0.05	15	600	<5	7	26	2100	9	5	<5	<10	35
108409A	sb-1	South Balfour	990896	0.07	8	<20	<5	<5	<5	7600	15	5	13	<10	7
108409B	sb-1	South Balfour	990898	2	-0.05	59	<5	7	19	970	73	26	<5	<10	30
108409C	sb-1	South Balfour	990899	0.2	6	190	<5	5	<5	96500	148	155	13	<10	12
108410	sb-2	South Balfour	990900	-0.05	-1	<20	<5	6	19	170	13	<5	<5	<10	<5
108414B	str-1	Strickland	990901	0.05	115	<20	126	530	29	350	6	14	<5	<10	92000
108414C	Str-1	Strickland	990897	0.08	35	<20	24	115	66	7800	10	<5	<5	<10	16800
108416B	str-3	Strickland	990904	0.2	6	<20	<5	18	36	1300	<5	15	<5	<10	1600
108418	str-5	Strickland	990902	-0.05	1	<20	<5	22	105	17	29	21	<5	<10	93
108419	str-6	Strickland	990903	1.9	2	1350	<5	7	23	210	25	63	<5	<10	31
108203	MR3	Murrays Reward	990906	0.1	2y	360	73	8	<5	31000	38	96	25	<10	43
108204	MR4	Murrays Reward	990907	0.4	6	290	49	7	<5	70000	56	53	34	<10	150
108205	MR5	Murrays Reward	990944	-0.05	7	<20	<5	11	14	7000	11	<8	9	<10	44
108206	MR6	Murrays Reward	990908	0.1	110	170	<5	6	<5	51000	78	62	12	<10	24
108208	MR8	Murrays Reward	990909	0.05	24	<20	<5	<5	<5	140000	10	<8	<9	<10	10
108209A	MR8	Murrays Reward	990910	0.05	1	<20	<5	7	21	320	11	<8	<9	<10	<10
108209B	MR9	Murrays Reward	990911	0.05	22	<20	<5	7	20	1350	19	<8	<9	<10	27
108210	MR10	Murrays Reward	990912	0.1	17	<20	15	<5	<5	125000	20	9	49	<10	<10
108211	MR11	Murrays Reward	990913	0.09	21	115	61	5	<5	120000	15	<8	25	<10	62
108212	MR12	Murrays Reward	990914	0.09	24	<20	<5	<5	<5	155000	43	19	27	<10	15
108214	MR14	Murrays Reward	990939	1	22	160	6	5	18	58000	46	44	70	<10	47
108216	MR16	Murrays Reward	990915	0.2	36	37	13	5	<5	95000	125	14	63	<10	11
108219	SpH3	Specimen Hill	990916	-	-	<20	<5	6	18	165	9	<8	4700	23	63
108220	SpH4	Specimen Hill	990917	-	-	43	<5	12	20	60	11	<8	11500	63	135
108221	SpH5	Specimen Hill	990918	-0.05	-1	100	<5	<5	30	34	19	<8	145	15800	<10
108222	SpH6	Specimen Hill	990919	-0.05	-1	43	<5	21	33	52	5	<8	28	25	<10
108225	Tat1	Tatlovs prospect	990920	-0.05	19	6000	250	<5	2700	4900	<5	<8	1050	44	210
108228	Tat4	Tatlovs prospect	990921	-0.05	3	1100	10	27	69	400	9	<8	145	55	44
108229	Tat5	Tatlovs prospect	990922	-0.05	42	62000	800	<5	3400	130000	7	11	1500	53	410
108230	Tat6	Tatlovs prospect	990923	-0.05	10	7900	37	7	1650	3000	<5	<8	510	<10	120
108231	Tat7	Tatlovs prospect	990924	-0.05	-0.05	2900	28	6	49	330	12	<8	33	185	32
108232	Tat8	Tatlovs prospect	990925	-0.05	32	72000	240	<5	460	9400	11	78	400	9200	125
108234	BC1	Balfour Central	990926	0.2	4	370	<5	8	<5	30000	21	13	<9	75	<10
108239	SB5	Balfour South	990927	0.1	2	160	11	7	19	340	25	23	<9	12	10
108240	Warat 1	Waratah	990928	-0.05	-1	31	<5	6	19	33	12	<8	<9	<10	<10
108241	Balf 1	325385E 5425270N	990929	-0.05	-1	<20	<5	7	19	7	14	23	<9	<10	<10
108243	Prem 2	Premier prospect	990930	-0.05	-1	91	<5	6	23	47	22	43	<9	32	<10
108244	BB1	Balfour Blocks	990931	-0.05	-1	37	<5	12	51	610	9	14	<9	<10	<10
108246	BB3	Balfour Blocks	990932	-0.05	3	31	<5	7	16	2400	17	<8	<9	<10	72
108247	BB4	Balfour Blocks	990933	0.5	6	78	<5	<5	<5	64000	35	<8	<9	<10	<10
108248	BB5	Balfour Blocks	990945	-0.05	1	<20	<5	17	125	2600	7	<8	<9	<10	<10
108252	BB9	Balfour Block	990943	-0.05	1	<20	<5	8	24	190	8	<8	<9	<10	<10
108253	BB10	Balfour Block	990934	0.3	7	59	<5	5	<5	46000	12	<8	<9	<10	<10
108254	Cout 8	Couta	990942	-0.05	2	<20	<5	7	25	4800	10	<8	<9	<10	<10
108257	Clump 1	Clump	990935	-0.05	1	<20	<5	21	31	145	14	<8	<9	<10	<10
108258	Clump 2	Clump	990936	-0.05	1	<20	<5	7	22	430	8	<8	<9	<10	<10
108259	Clump 3	Clump	990937	-0.05	2	670	<5	11	44	4800	7	41	<9	<10	<10
108260	Clump 4	Clump	990938	-0.05	2	125	<5	13	17	21000	12	16	<9	<10	<10
108263	MR 20	Murrays Reward	990940	0.4	22	450	710	<5	<5	56000	61	27	30	<10	250
108267	Kbridge1	Murrays Reward	990941	-0.05	2	<20	<5	20	100	250	72	33	<9	<10	<10