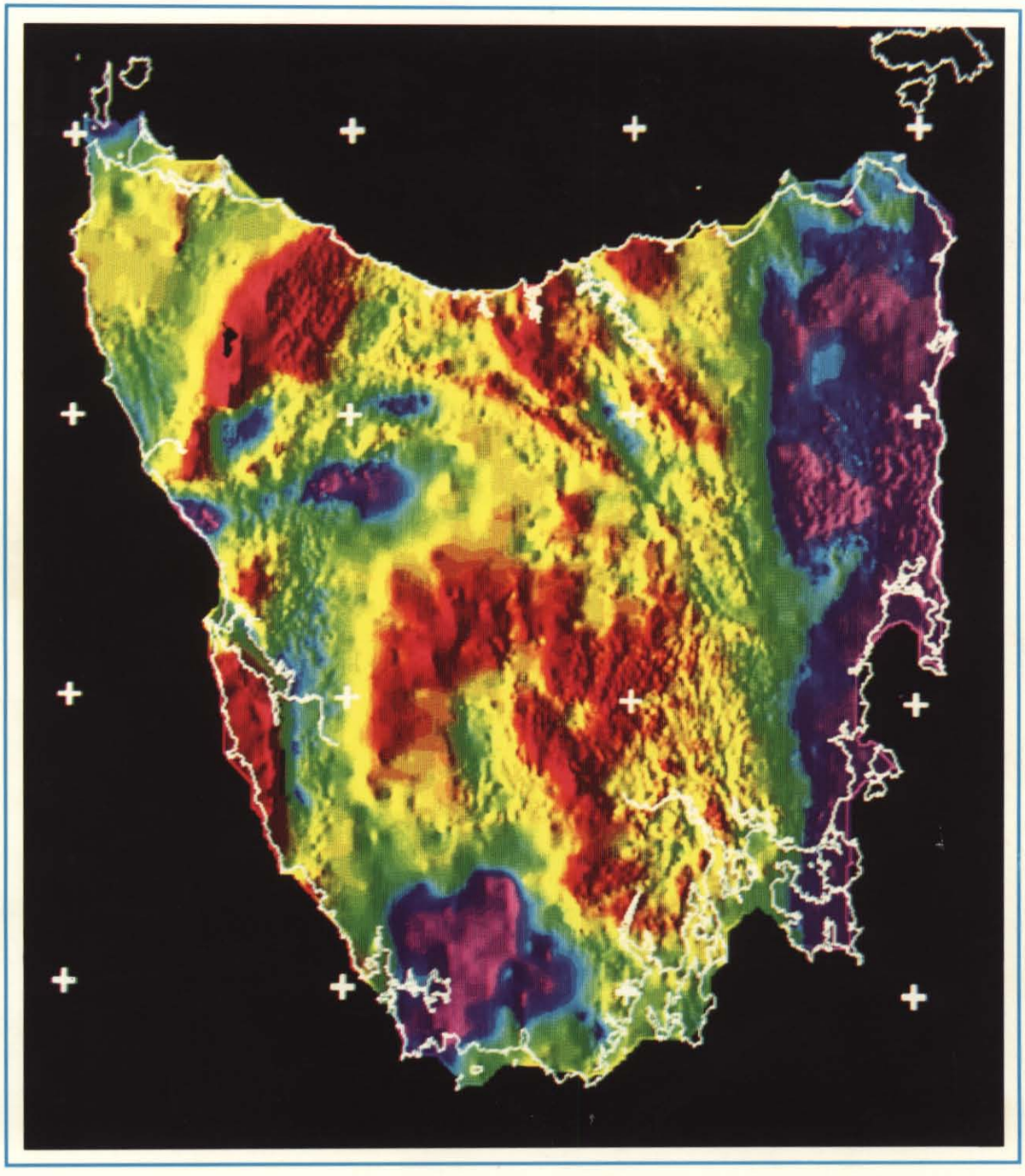
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TASMANIA



An Island of Potential

New perspectives on mineral exploration

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TASMANIA DEPARTMENT OF MINES

1992

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TASMANIA: AN ISLAND OF POTENTIAL

New perspectives on mineral exploration

Papers presented at a symposium
Sheraton Hotel, Hobart
16–17 September 1992

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2/4

FOREWORD

In September 1992, the Tasmania Department of Mines (TDM) and the Tasmanian Development Authority (TDA), in conjunction with the Tasmanian Chamber of Mines (TCM) and the Centre for Ore Deposits and Exploration Studies (CODES) at the University of Tasmania, held a two-day symposium in Hobart to discuss new developments in the understanding of Tasmanian mineral prospectivity.

The symposium was run by an organising committee comprising:

Mr Peter Baillie (TDM)
Dr David Duncan (TDM)
Dr Bruce Gemmell (CODES)
Mr Rod Hargreaves (TDM)
Professor Ross Large (CODES)
Dr Robert Richardson (TDM)
Mr Mark Smith (TDA)
Mr David Whitrow (TCM)

This Bulletin is a collection of material presented at the symposium, both as oral presentations and as poster displays. The papers cover a wide range of issues related to Tasmanian prospectivity. The inclusion of several contributions which canvas the possibility of a "thin-skinned" tectonic model for the Tasmanian Palaeozoic, together with several important contributions relating to gold mineralisation, should ensure that the volume has a long shelf life.

Because of time constraints, minimal editing was carried out, although some attempt has been made to ensure consistency through the various contributions. In most cases references cited by authors have not been rigourously checked and some errors and inconsistencies are likely. Most figures are as presented by authors. Colour plates have been used by some authors and may be found in the pocket inside the back cover of the volume.

It should be noted that a number of authors refer to "TCR" reports. These are open-file company exploration reports which are held in the Department of Mines library. Other company reports referred to should be sought from the relevant company.

ACKNOWLEDGEMENTS

Production of this Bulletin was undertaken by staff of the Department of Mines. Papers were collated and edited by Peter Baillie, Michael Dix and Robert Richardson. Final typesetting and layout was done by Michael Dix. The assistance of Rohan Sedgman, Margaret Ellis and Cheryl Kershaw in various phases of the preparation of this Bulletin is gratefully acknowledged, as is the input of John Ladaniwskyj and Anthony Hollick of the Cartographic Section, and word processor operators Claire Humphries, Ann Taylor, Lisa Doran and Jan Howie.

COVER

Residual Bouguer Anomaly map of Tasmania, based on Mantle91 model method. Bouguer density 2.67 t/ m^3.
(Image courtesy M. Roach, CODES).

3/4

CONTENTS

Exploration rock geochemistry in the Rosebery mine area, western Tasmania ... 7
Aung Pwa, W. Naschwitz, M. Hotchkis and J. C. van Moort

The Huminex system for geochemical exploration ... 17
W. E. Baker

The Environment Protection Act ... 20
R. E. Bingham

Gold in Tasmania ... 24
R. S. Bottrill, D. L. Huston, J. Taheri and Khin Zaw

Tasmania's development environment ... 47
C. Brooks

Platinum Group Elements and their host rocks in Tasmania: A summary review ... 48
A. V. Brown

Geochemical constraints on tectonic models and the importance of lithochemical data in exploration ... 56
A. J. Crawford

Tasmania Department of Mines programs — MRVP, NETGOLD and AMB ... 58
D. McP. Duncan

Current systematic regional mapping: new potentials for mineral discovery ... 70
J. L. Everard, R. H. Findlay, M. P. McClenaghan, D. B. Seymour and A. V. Brown

The Mt Read Volcanics: An explorer's perspective ... 83
F. G. Fitzgerald

Stable isotopes and geochemistry as exploration indicators ... 84
G. R. Green and J. Taheri

Hematite / barite alteration in the Owen Conglomerate at North Lyell ... 92
I. Hart

Laser ablation sulphur isotope analysis at the University of Tasmania — preliminary results from a new technique with research and exploration applications ... 93
D. L. Huston, M. Power and R. R. Large

Geology and genesis of silica flour and gold in the Corinna district, Tasmania ... 96
Khin Zaw, N. J. Turner, R. R. Large, H. Nolan and T. Mernagh

The geological and structural controls on mineralisation at the Renison tin mine ... 97
P. A. Kitto

Tasmanian exploration — the challenge and the opportunity ... 118
R. R. Large

Finding Cambrian keys: An essay in controversy, prospectivity and tectonic implications 124
D. E. Leaman

Gold exploration and the use of magnetic methods in northeast Tasmania ... 149
D. E. Leaman

Mount Read Volcanics: Host sequence to Cambrian massive sulphide deposits in western Tasmania ... 161
J. McPhie and J. B. Gemmell

4/4

Stratigraphic-facies associations and their relationship to mineralisation in the Mount Read Volcanics ... 167
J. Pemberton and K. D. Corbett

New perspectives on Tasmanian geology ... 177
C. McA. Powell

Changes in the earth sciences ... 188
S. M. Richards

Geology and geophysics of the Lisle – Golconda goldfield, northeast Tasmania. ... 189
M. J. Roach

Regional geophysics of the Alberton – Mangana goldfield, northeast Tasmania ... 199
M. J. Roach

Mineralogy and stable isotope geochemistry of the Beaconsfield, Salisbury and Lefroy goldfields ... 208
D. W. Russell and J. C. van Moort

Geology and prospectivity of the Arthur Mobile Belt. ... 227
N. J. Turner, R. S. Bottrill, A. J. Crawford and I. Villa

Australian Geological Survey Organisation (AGSO): Programs of relevance to Tasmania ... 234
N. Williams

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1/10

Exploration rock geochemistry in the Rosebery Mine area, western Tasmania

AUNG PWA[1], W. NASCHWITZ[2], M. HOTCHKIS[3] and J. C. VAN MOORT[1]

1. Geology Department, University of Tasmania; 2. Geopeko; 3. Australian Institute of Nuclear Science and Engineering

ABSTRACT

This study reports on the role of rock geochemistry in massive sulphide exploration in the Rosebery mine area. The study involved four aspects: (1) distinction between the host rock and the footwall pyroclastics; (2) geochemical zonality associated with the Rosebery deposit; (3) geochemical haloes around the Rosebery deposit; (4) geochemical evaluation of the host rock.

The difficulty in distinguishing between the host rock and footwall, which have similar lithological characteristics because of the alteration effect within the Rosebery mine area, may be removed by examining their geochemical signatures. The host rock is characterised by the enhancement of TiO_2, Al_2O_3, Fe_2O_3, MgO, K_2O, CaO, MnO, P_2O_5, Pb, Zn, Rb, Ba and Tl, and depletion of SiO_2, Na_2O, Cu and Sr. The footwall pyroclastic rocks have enrichment in SiO_2, K_2O, Cu, Rb, and possibly MgO and MnO, and depletion in TiO_2, Al_2O_3, CaO, Na_2O, P_2O_5, Sr, Ba and Tl. Distinction between the host rock and footwall pyroclastics can be made by using the relations between TiO_2, Al_2O_3 and SiO_2. Higher concentrations of MgO, CaO, MnO, P_2O_5, Ba and Tl in the host rock compared to the footwall also play a major role to distinguish it from the footwall.

The Rosebery deposit is associated with significant lateral and vertical (stratigraphic) geochemical zonalities. The lateral zonality sequence (from upper level to lower level along the dip direction) is defined as As-Ba-Sb-Pb-Zn-Cu. The stratigraphic zonality sequence may also be arranged (from top to bottom) as (As, Ba, Sb)-(Pb, Zn)-Cu.

The Rosebery deposit is associated with well-defined surface geochemical haloes (at least 3000 × 1200 m) of Ba, Mn, Fe, and F which are much larger than the mineralogical alteration zone and which also extend into hangingwall.

The dispersion haloes of K, Rb, Na, Ca, Sr, K/Na and Rb/Sr outline the footwall alteration zone and the host rock of the Rosebery deposit, and also extend into the hangingwall pyroclastics.

Ba, Tl, Ga and V together with Pb, Zn, As, Sb and Ag may be the element association to determine the mineralisation potential of the host rock.

INTRODUCTION

The Mt Read Volcanics are known to be highly prospective for massive sulphide deposits of the Mt Lyell, Rosebery/Hellyer type. Intensive exploration concentrating on the search for blind mineral deposits is being carried out following the discovery of large, hidden, Hellyer deposit in 1983. The delineation of geochemical haloes in wallrocks may enhance the success of exploration for blind deposits.

To the present there are only few exploration-oriented rock geochemical studies of massive sulphide mineralisation in the Mt Read Volcanics terrane, in western Tasmania. Among them Smith (1975), Green *et al.* (1981), Naschwitz (1985), Naschwitz and van Moort (1991) and Green (1990) described geochemistry of host rock and geochemical characteristics of wallrock alteration zone associated with the Rosebery deposit. Large and Huston (1986) and Huston and Large (1987) found that the 'zinc ratio' can distinguish the styles of mineralisation, and is of use in determination of bedrock anomalies and drill intersections at an early stage of exploration. Sheppard (in Govett, 1983) carried out a detailed study of the geochemical dispersion patterns around the Mt Lyell deposits and investigated the element and mineralogical variation related to sulphide deposits. The recent study of Smith and Huston (1992) found that there are three elemental suites associated with the different positions of massive sulphide mineralisation in the Rosebery deposit. They also mentioned the physicochemical conditions in which the elements were deposited and defined pathfinder elements such as Tl and Hg to locate blind deposits.

As the cost of massive sulphide exploration, particularly exploratory drilling, is escalating, a more selective basis for defining targets is essential. Rock geochemistry in conjunction with careful geological study may provide this.

This paper presents a summary of current research on exploration rock geochemistry in the Rosebery mine area., including 203 analyses of Smith (1975) (for major elements and Tl only) and Naschwitz (1985), unpublished AAS and XRF analyses of 123 drill-core samples, re-analyses of 76 surface samples (collected by Naschwitz) using PIXE/PIGME (Proton Induced X-ray Emission and Proton

AUNG PWA ; NASCHWITZ, W.; HOTCHKIS, M.; VAN MOORT, J. C. 1992. Exploration rock geochemistry in the Rosebery Mine area, western Tasmania. *Bull. geol. Surv. Tasm.* 70:7–16.

Induced Gamma ray Emission) analysis, and additional analyses of 135 drill core samples by PIXE/PIGME.

GEOLOGY AND MINERALISATION

The geology and mineralisation of the Rosebery deposit has been comprehensively described by many workers (Brathwaite, 1969, 1972; Green *et al.*, 1981; Naschwitz, 1985; Corbett and Lees, 1987; Khin Zaw *et al.*, 1988; Corbett and Solomon, 1989; Huston and Large, 1988; Large 1989; Green, 1990; Lees *et al.*, 1990, Khin Zaw, 1991) and will not be described in detail. The Rosebery deposit is the major volcanic-hosted Zn-Pb-Cu-Ag-Au deposit in the Cambrian Mt Read Volcanic belt. The mineralisation occurs within a tuffaceous shale at the contact between the footwall and the hangingwall pyroclastic rocks. The mineralisation has a stratigraphic zonation typical of volcanogenic massive sulphide deposits, characterised by pyrite-chalcopyrite rich zones at the lower portion and sphalerite-galena-pyrite rich zones at the upper portion. A barite-carbonate rich zone occurs at the top of the ore horizons.

The footwall pyroclastics consist of ignimbritic feldspar-phyric pumiceous flow tuff which has been altered to quartz-sericite-chlorite schist. The host-rock shale with disseminated pyrite is commonly siliceous, sericitic and chloritic, and is normally overlain by pyritic black slate. The hangingwall rocks are sericitic quartz-feldspar-phyric epiclastics which are lithologically different in detail from the footwall pyroclastics (Corbett and Lees, 1987; Lees *et al.*, 1990). The Mt Black Volcanics, mainly composed of weakly sericitised and chloritised dacitic to andesitic lavas, generally overlie the hangingwall pyroclastics. The Central Volcanic Complex (CVC) containing the above-mentioned rock units in the Rosebery mine area is faulted against the Dundas Group of volcanics and sediments to the west by the Rosebery Fault.

DISTINCTION BETWEEN THE HOST ROCK AND FOOTWALL PYROCLASTICS

The host-rock tuffaceous shale of the Rosebery mine area has been altered to quartz-sericite-chlorite schist with similar lithological characteristics to the footwall pyroclastics. This makes it difficult to distinguish between these two units within the mine area (Green *et al.*, 1981; Lees *et al.*, 1990), particularly in underground exploration and exploratory drilling.

It has been known that the alteration zone associated with the Rosebery deposit is characterised by enrichment in Si, K, Rb, Mn, Fe, Mg, S and H_2O and depletion in Al, Na, Ti, Ca, Sr, Zr, Y and Nb (Green *et al.*, 1981; Naschwitz, 1985; Naschwitz and van Moort, 1991).

We have made an attempt to distinguish host rock from footwall pyroclastics using original geochemical data (203 samples) Smith (1975) and Naschwitz (1985). They focused on the geochemical characteristics of the footwall alteration and distribution of trace elements in host rock and ores, and did not attempt to differentiate in general between the host rock and footwall rock.

The study has revealed that the variation and relation of major, minor and trace elements are undoubtedly useful to characterise the above rock units and to discriminate between them (Aung Pwa, 1990).

The host rock is defined by the enhancement of TiO_2, Al_2O_3, Fe_2O_3, MgO, K_2O, CaO, MnO, P_2O_5, Pb, Zn, Rb, Ba and Tl and depletion of SiO_2, Na_2O, Cu and Sr.

The footwall pyroclastics are characterised by enrichment in SiO_2, K_2O, Cu, Rb, and possibly MgO and MnO, and depletion in TiO_2, Al_2O_3, CaO, Na_2O, P_2O_5, Sr, Ba and Tl.

Distinction between the host rock and footwall pyroclastics can be made by using the relations between TiO_2, Al_2O_3 and SiO_2 (fig. 1). Enhancement of TiO_2 and Al_2O_3 and depletion of SiO_2 in the host rock and reverse variation in the footwall is the characteristic geochemical signature. Discriminant analysis also suggests that the use of TiO_2, Al_2O_3 and SiO_2 as variables is one of the best criteria, giving 94.5% classification success when defining the host rock and footwall pyroclastics. Other elements, such as MgO, CaO, MnO, P_2O_5, Ba and Tl, which show enrichment in the host rock, also play a major role in distinguishing the host rock from the footwall.

The current study suggests that the variation of and relation between TiO_2, Al_2O_3, Nb/Y and Zr/TiO_2 are also extremely useful in defining footwall and host rock.

GEOCHEMICAL ZONALITY ASSOCIATED WITH THE ROSEBERY DEPOSIT

Volcanogenic massive sulphide deposits are commonly characterised by mineralogical alteration zones which are associated with significant rock geochemical haloes, It has been known that these geochemical haloes, extending hundreds to thousands of metres away from ore zones, are much larger than observable mineralogical alteration zones (Goodfellow, 1975; Wahl, 1978; Aung Pwa, 1978; Pirie and Nichol, 1981; Govett and Aung Pwa, 1981; Govett, 1983; Lahtinen, 1989) and also form large exploration targets. The delineation of geochemical haloes, characterised by geochemical zonality in geologically prospective ground, makes it possible to detect deeply buried deposits.

The geochemical zonality is commonly associated with hydrothermal and volcanogenic massive sulphide mineralisation (Beus and Grigorian, 1977; Boyle, 1979; White, 1981; Lahtinen, 1989). A significant geochemical zonality from upper level to lower level along dip direction (Ag-Pb-Zn-Cu-(Ni, Co)) has been found to be associated with Bawdwin massive sulphide deposit, Burma (Aung Pwa, 1981). Lahtinen (1989) also mentioned that geochemical zonality can be applied in massive sulphide exploration in the Pukkiharju Zn-Cu prospect, Central Finland.

The Rosebery deposit is characterised by lateral and stratigraphic mineral zoning of the lens system (Brathwaite, 1969, 1972; Green *et al.*, 1981; Naschwitz, 1985; Huston and Large, 1988; Khin Zaw *et al.*, 1988; Green and Iliff, 1989; Khin Zaw, 1991). Shallow-level, post-tectonic granitic intrusion of Devonian age (Lees *et al.*, 1990) has been interpreted from the gravity data in the Rosebery mine area (Large, 1986). Solomon *et al.* (1987) also pointed out that Devonian hydrothermal activity resulted in chemical remobilisation in the Rosebery massive sulphide deposit. Such a process may produce lateral geochemical zonation due to the mobility of elements in the hydrothermal environment. Mobile elements are generally enriched in the upper or outer margins of mineralised systems or the upper level of geothermal systems (White, 1981; Watts and Hassemer, 1989).

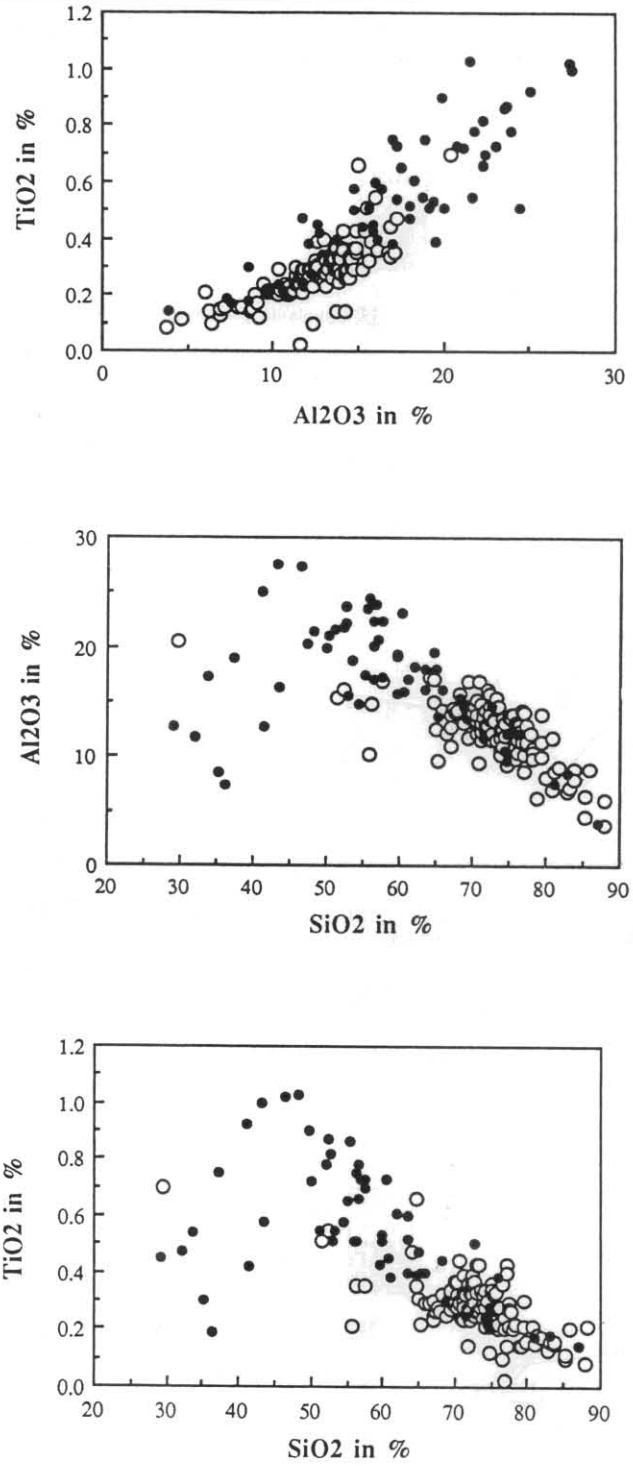


Figure 1

Relation between SiO_2, Al_2O_3 and TiO_2 in the host rock and footwall pyroclastics (based on XRF data by Smith, 1975, and Naschwitz. 1985.

● host rock, ○ footwall

Aung Pwa (1991) studied the variation of Cu, Pb, Zn, Ag, Sb, As and Ba in 123 host rock samples of drill core (with 10 to 20 m sample spacing) from the 270 mS and 300 mN sections to determine the zonality of elements associated with the Rosebery deposit. Ba and Sb were determined by XRF method and other elements were analysed by AAS by Australian Assay Laboratories Group. All drill core samples in this study were taken from host rock with major ore zones. No footwall and hangingwall samples were available.

Smith and Huston (1992) showed that there is a zonal feature of element association:

(1) elements concentrated in the upper portions of the orebody and in the adjacent wall rocks (Pb, Zn, Au, Cd, and Sb);

(2) elements concentrated in the lower portions of the orebody and adjacent wall rocks (Cu, Bi, As, and Fe), and;

(3) elements dispersed well outside zones of strong mineralisation (Tl and Hg). This is probably a stratigraphic zonality feature.

Our study has revealed that the Rosebery massive sulphide deposit is associated with significant lateral (along dip direction of the host rock) and vertical (stratigraphic) geochemical zonality.

Ba, As, Sb, Ag, and possibly Pb, are enriched in the upper portion of and stratigraphically above the ore zones and are considerably depleted in the lower portion of and stratigraphically below the ore zones. In contrast, Cu is enriched in the lower portion of and stratigraphically below the ore zones. Zinc enveloping the ore zone does not show significant variation with depth. The variation of As, Ba, Sb and Cu in the host rock from the 270 mS section is shown in Figures 2–5. Based on the results from both sections (using the coefficient of contrast of Beus and Grigorian, 1977) the lateral geochemical zonality sequence (from upper level to lower level along the dip direction of the host rock) has been arranged as As-Ba-Sb-Pb-Zn-Cu (Aung Pwa, 1990). Silver cannot be included in the arrangement, as the Ag values in the host rock of the lower portion of the section are lower than one ppm (which is the detection limit). However silver, generally similar to As, Ba and Sb, shows remarkable enrichment in the upper portion of the ore zone. Such a lateral geochemical zonality feature may reflect the remobilisation of elements during Devonian hydrothermal activity. The vertical (stratigraphic) zonality sequence may also be similar to the lateral zonality but it is not possible to arrange the sequence as was done for lateral zonality. The general sequence of stratigraphic zonality may be defined (from top to bottom) as (As, Ba, Sb) - (Pb, Zn) - Cu, which is generally similar to the mineralogical zonality. The stratigraphic zonality feature may reflect original depositional condition.

Further investigation to determine the whole picture of geochemical zonality by multi-element analysis should be made.

GEOCHEMICAL HALOES AROUND THE ROSEBERY DEPOSIT

The following are preliminary results of a current project studying distribution of multi-elements in the rocks on the surface of the Rosebery area. The rock samples collected by Naschwitz were re-analysed, after having been leached by hot HNO_3, using PIXE/PIGME analysis. (More detailed sampling and analysis are in progress to examine the present results and to evaluate the geochemical anomalies). This study involved Ca, K, Fe, Na, Al, Mn, Ti, S, Rb, Sr, Zr, Y,

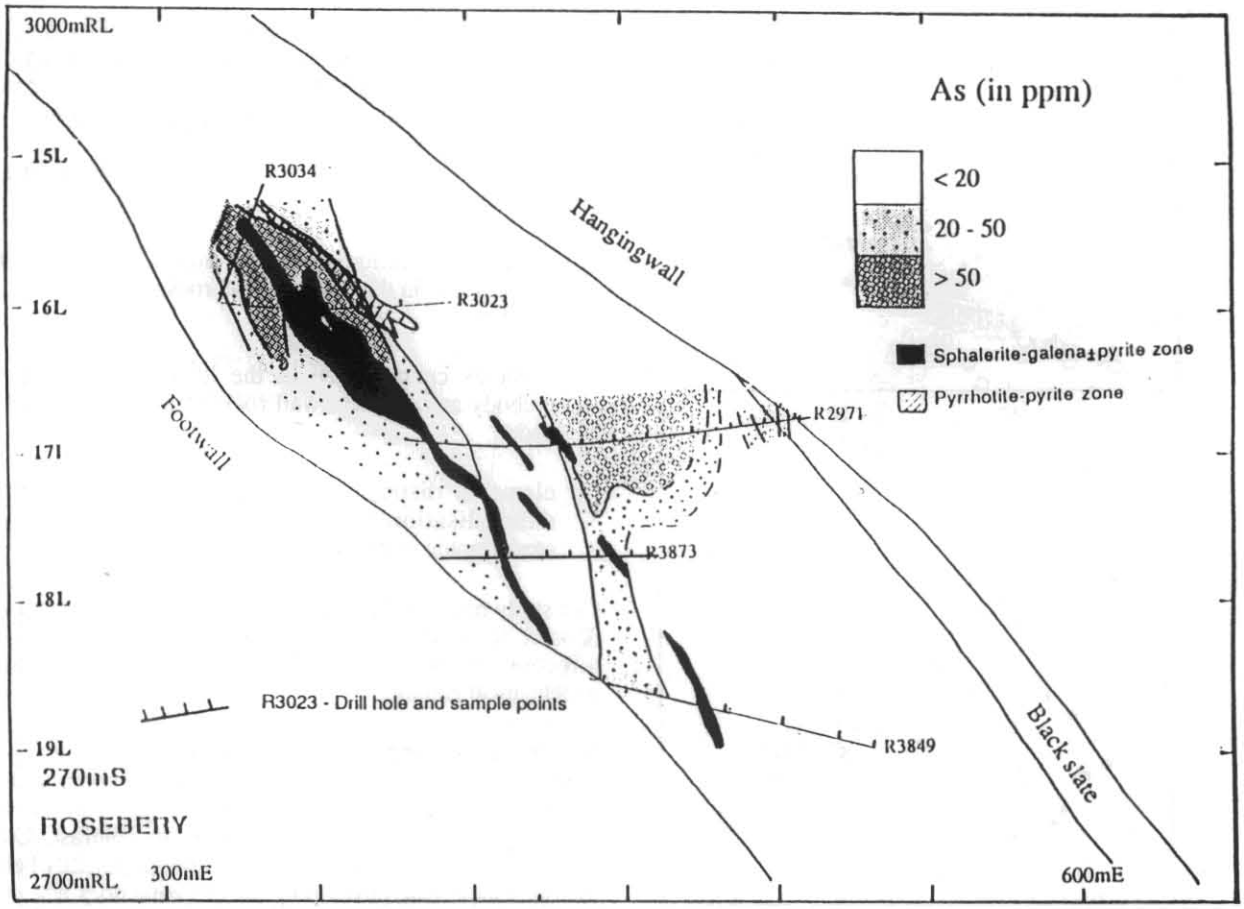


Figure 2. Variation of As in the host rocks from 270 mS section, Rosebery deposit. (Ore zones modified after Khin Zaw *et al.*, 1988).

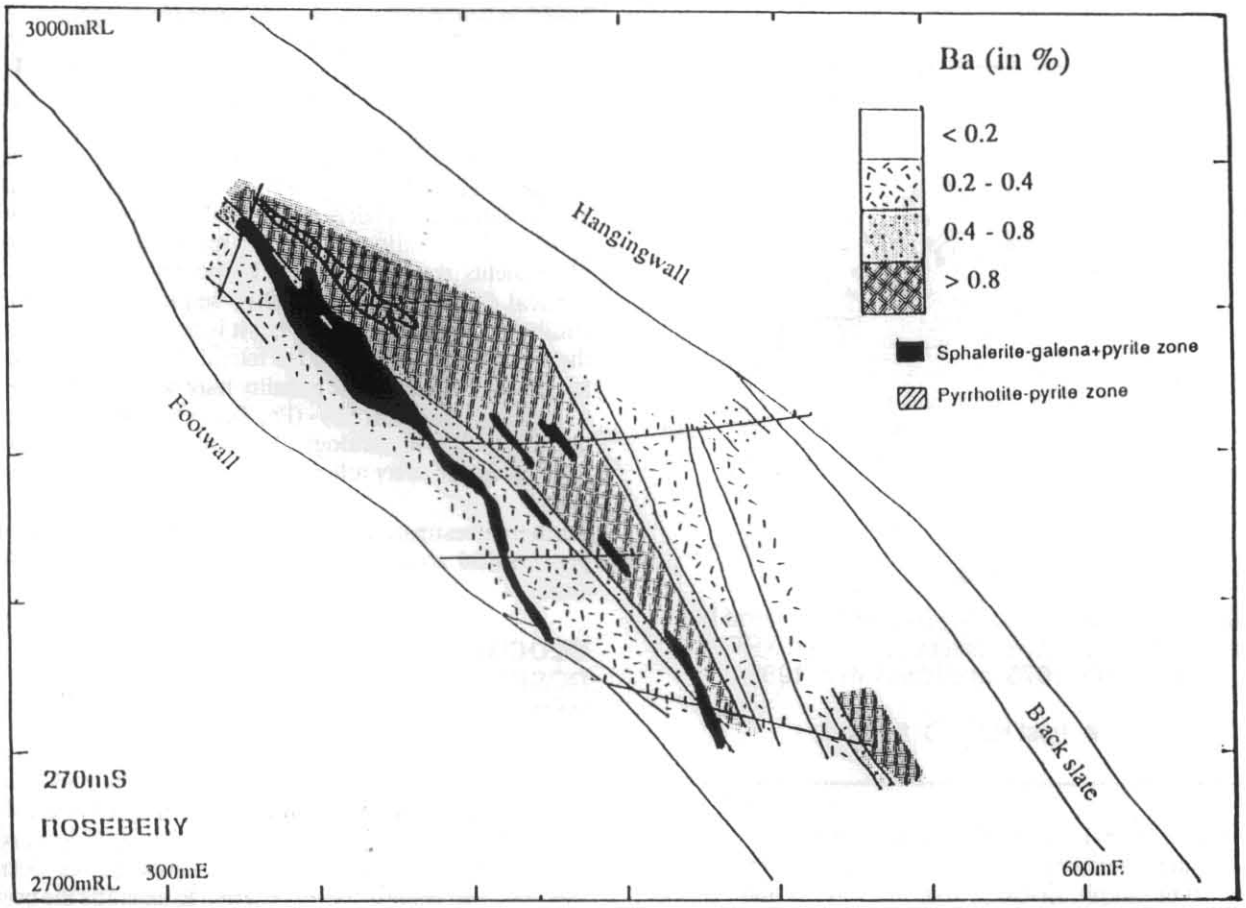


Figure 3. Variation of Ba in the host rocks from 270 mS section, Rosebery deposit.

5 cm

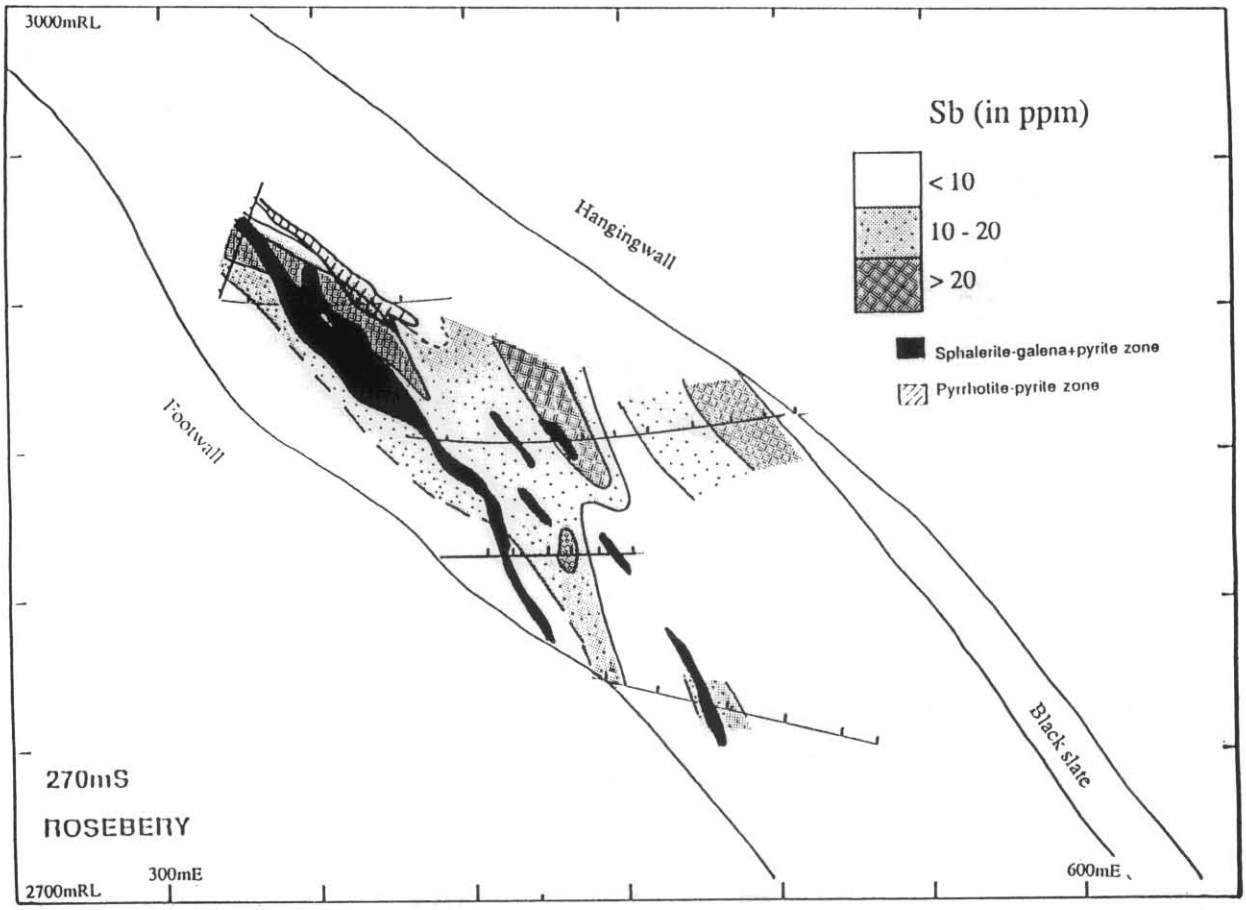


Figure 4. Variation of Sb in the host rocks from 270 mS section, Rosebery deposit.

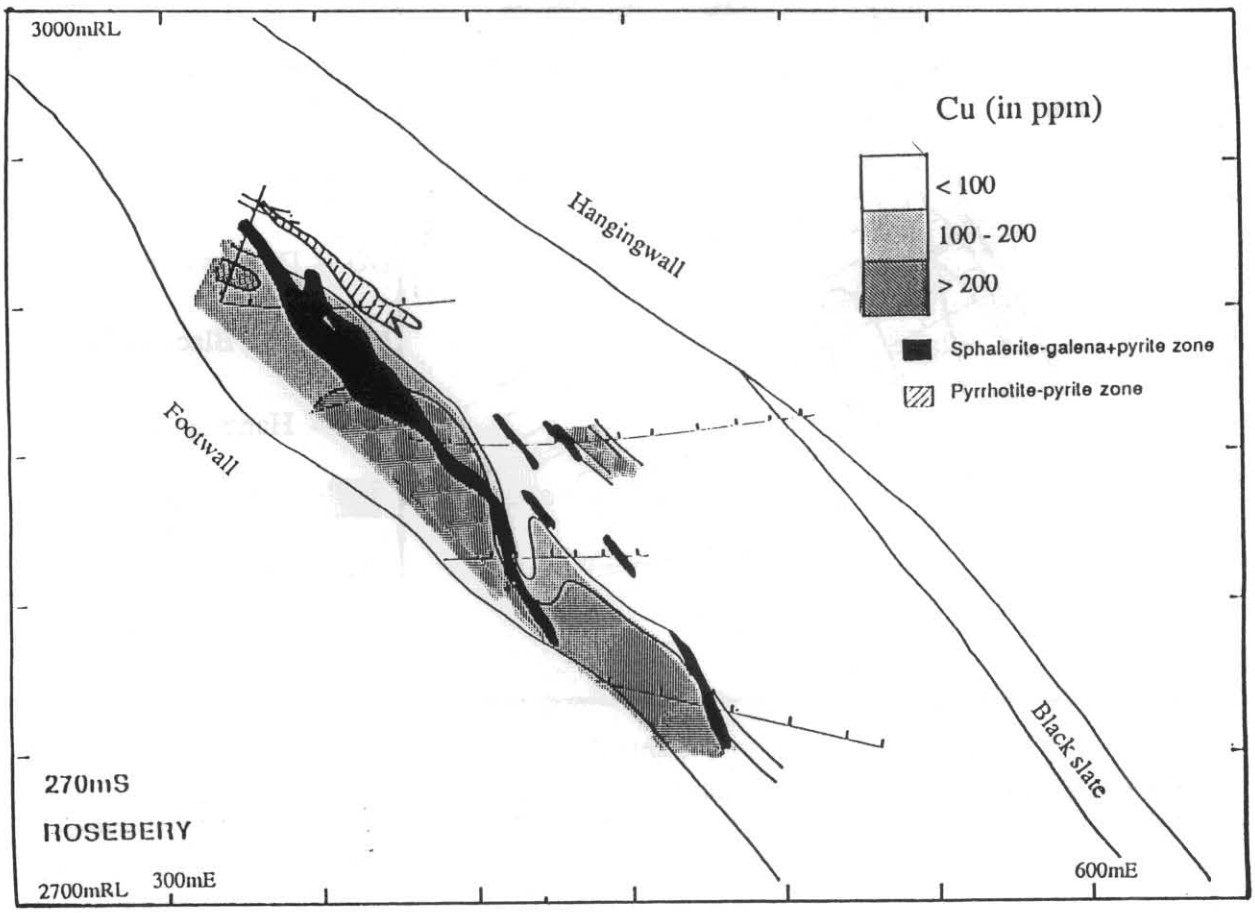


Figure 5. Variation of Cu in the host rocks from 270 mS section, Rosebery deposit.

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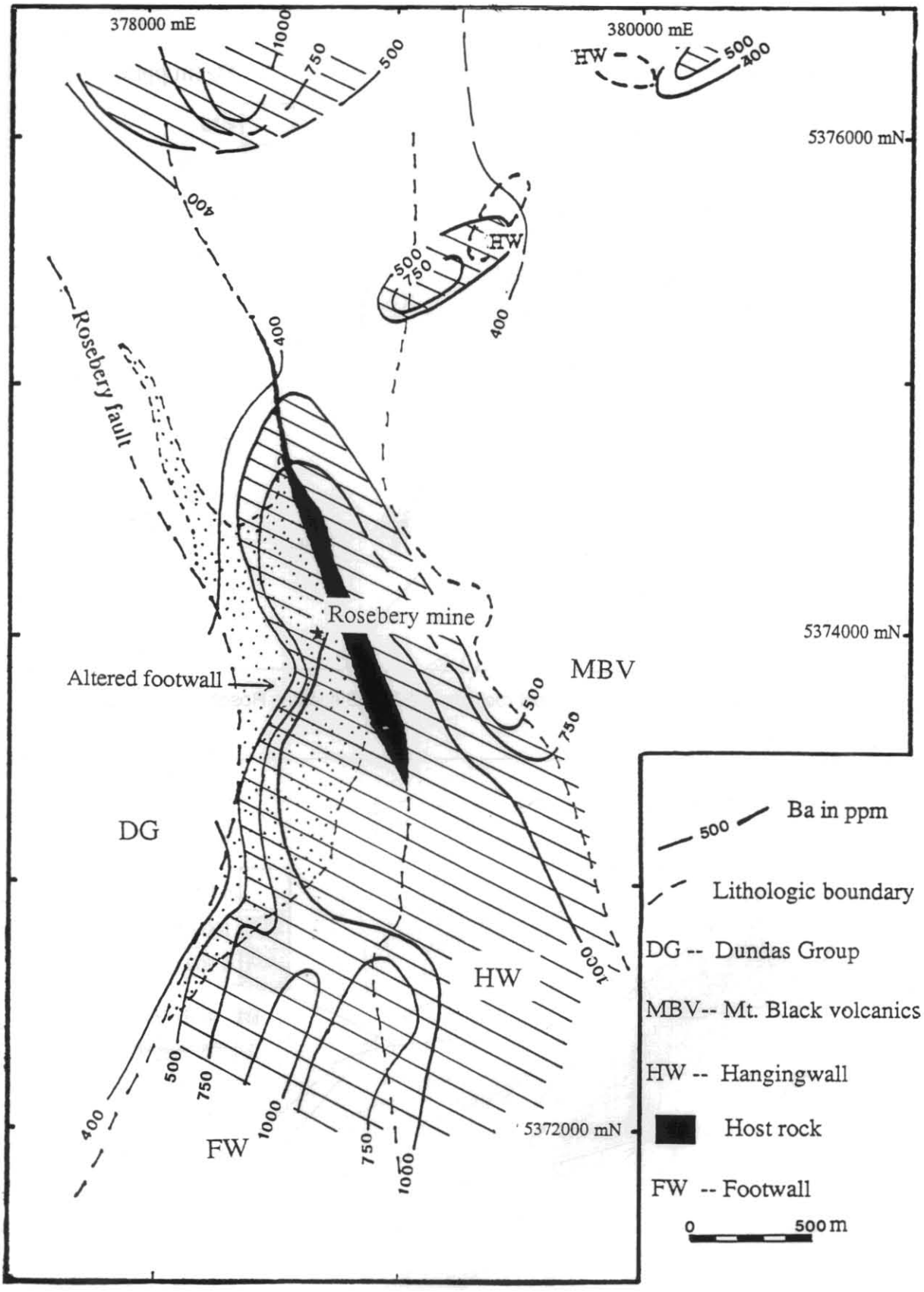


Figure 6

Distribution of Ba in the rocks of the Rosebery mine area. Data based on re-analaysis by PIXE of the surface rock samples originally collected by Naschwitz (1985). (Geology modified after Lees, 1986).

5 cm

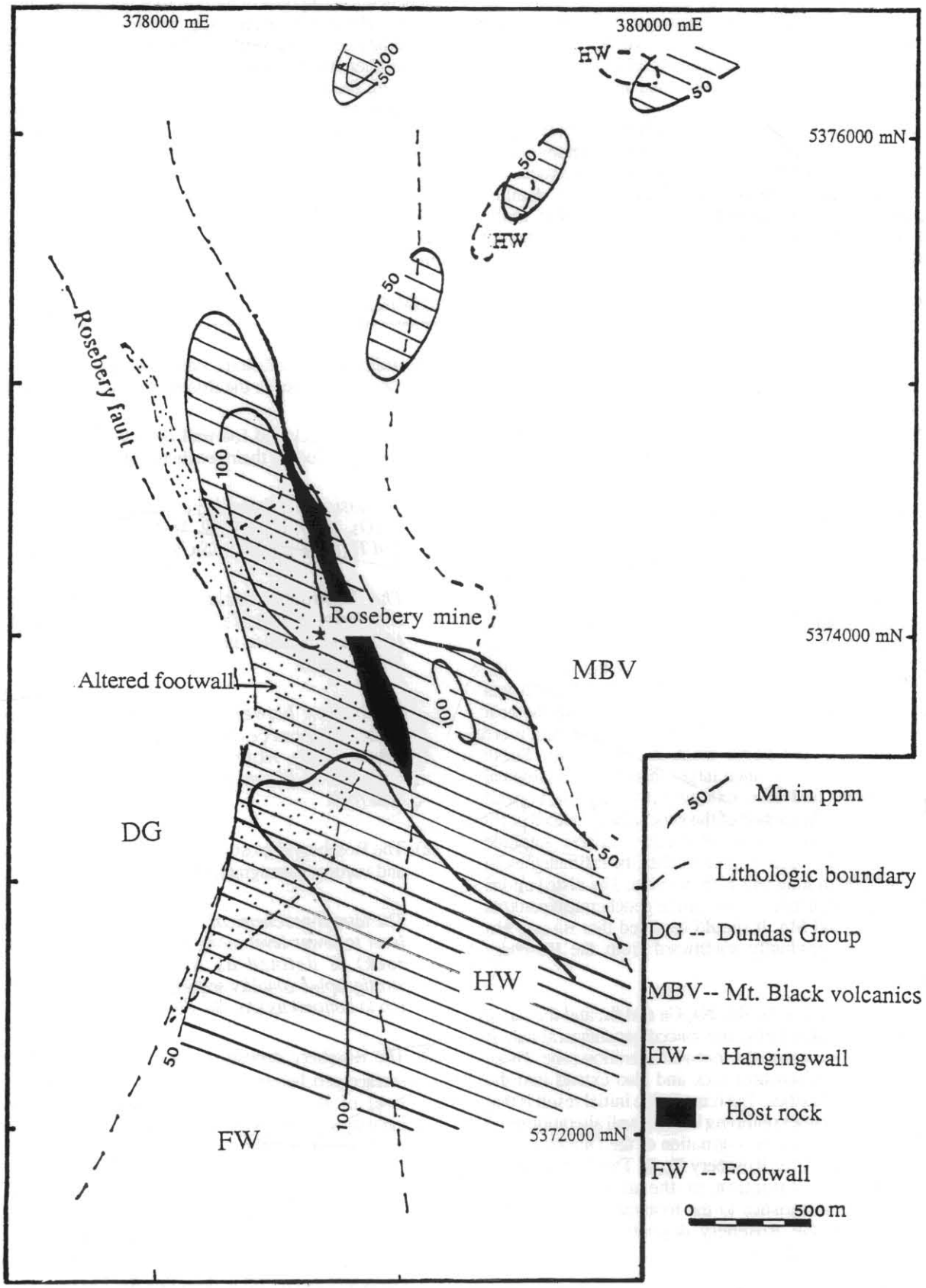


Figure 7

Distribution of Mn in the rocks of the Rosebery mine area. Data based on re-analaysis by PIXE of the surface rock samples originally collected by Naschwitz (1985). (Geology modified after Lees, 1986).

5 cm

Ba, Ni, Co, Pb, Zn, Cu, Ag, *F, V, Cl, Ga, As, Mo, Cd, Cr, Li, Tl, Ge, Sn, W, U* and *Th* (the elements italicised are new elements which Naschwitz did not determine) to determine their spatial distribution around the Rosebery deposit and to define further prospective ground in the area.

The data smoothing technique used by Naschwitz (1985) has the advantage that it presents a statistically valid image of the wallrock alteration pattern. However even the process of smoothing within a small area eliminates the detailed signature of the element distribution. The present study, using hand-contouring, gives more detailed patterns of element distribution and broader geochemical haloes.

The well-defined and large N-S trending geochemical haloes of Ba, Mn, Fe and F outline the mineralised host rock (Rosebery deposit) and footwall alteration zone. Figures 6 and 7 show the areal distribution of Ba and Mn in the rocks of the Rosebery mine area. Well-defined zones of Ba and Mn greater than 500 ppm and 50 ppm respectively outline the host rock of the Rosebery deposit and footwall alteration zone. Although hangingwall samples are not available from the east of the central part of the host rock it is, on the basis of the geochemical data in the east of the southern and northern parts, evident that a Ba halo greater than 400 ppm extends more than 500 m and 700 m into the hangingwall and footwall pyroclastics respectively from the Rosebery ore zones. A halo of Mn greater than 50 ppm also extends more than 500 m each into the hangingwall and footwall pyroclastics. Both haloes (500 ppm Ba and 50 ppm Mn) extend laterally more than 2000 m to the south from the ore zone, but only limited extention, generally the same as the alteration zone, is noted to the north. Although sufficient data are not available at present in the northern part of the host rock, the Ba halo (greater than 400 ppm) may extend more than 1000 m to the north from the ore zone. These geochemical haloes are much larger than the mineralogical alteration zone and also extend into the hangingwall pyroclastics. The dimension of the geochemical haloes of Ba and Mn associated with the Rosebery massive sulphide deposit can, on the basis of present data, be estimated to be more than 3000 m long and 1200 m wide. The distributions of Fe and F also generally show similar geochemical patterns to those of Ba and Mn. It should be noted that Ba and Mn values increase gradually southward from the Rosebery deposit.

Other elements such as K, Rb, Na, Ca and Sr, and the ratios K/Na and Rb/Sr, also form pronounced geochemical haloes which are coincident with the footwall alteration zone. These outline the mineralised host rock and also extend into the hangingwall pyroclastics. The remarkable initial result is that the geochemical haloes outlining the footwall alteration zone extend into the White Spur Formation of the Dundas Group immediately west of the Rosebery Fault. This indicates that the White Spur Formation in the area has similar geochemical characteristics to the footwall alteration zone associated with the Rosebery deposit. More detailed examination is in progress.

GEOCHEMICAL EVALUATION OF HOST ROCK

In surface exploration and exploratory drilling, it is important to evaluate the mineralisation potential of the host rock when it has neither indication of alteration nor trace of mineralisation. One part of the current research, based on the PIXE/PIGME analysis of the host rocks from the drill holes in different parts of the Rosebery mine area, has been to determine whether it is possible to distinguish between the geochemical response of the host rock associated with or near mineralisation, and that without or away from mineralisation. The results so far obtained are encouraging, but further study is still needed. Ba, Tl, Ga and V, together with Pb, Zn, As, Sb, Ag, may be the potential association of elements required to evaluate the mineralisation potential of the host rock in the Rosebery mine area. Smith and Huston (1992) have also demonstrated that Tl, which gives an extensive geochemical halo, may be used in detecting blind deposits, especially on a regional scale in the Rosebery area. The present study reveals that Tl may also be effectively used as a pathfinder element of massive sulphide mineralisation in mine-scale exploration.

CONCLUSIONS

The following conclusions, based on the exploration rock geochemical studies in the Rosebery area, can be made:

(1) The host rock and footwall pyroclastics can be clearly distinguished by their geochemical characteristics.

The host rock is defined by enhancement of TiO_2, Al_2O_3, Fe_2O_3, MgO, K_2O, CaO, MnO, P_2O_5, Pb, Zn, Rb, Ba and Tl and depletion of SiO_2, Na_2O, Cu and Sr.

The footwall pyroclastics are characterised by enrichment in SiO_2, K_2O, Cu, Rb, and possibly MgO and MnO, and depletion in TiO_2, Al_2O_3, CaO, Na_2O, P_2O_5, Sr, Ba and Tl.

Distinction between the host rock and footwall pyroclastics can be clearly made by using the relations between TiO_2, Al_2O_3 and SiO_2. Enrichment in MnO, P_2O_5, Ba, Tl, Pb and Zn can also be used in defining the host rock.

(2) The Rosebery deposit is associated with distinct lateral and vertical (stratigraphic) geochemical zonalities.

The lateral geochemical zonality sequence (from upper level to lower level along the dip direction of the host rock) is defined as As-Ba-Sb-Pb-Zn-Cu. The stratigraphic zonality sequence can be arranged (from top to bottom) as (As, Ba, Sb) - (Pb, Zn) - Cu.

(3) The Rosebery deposit is associated with well-defined surface geochemical haloes (at least 3000 × 1200 m in size) of Ba, Mn, Fe and F, which extend into the hangingwall and footwall pyroclastics. The haloes are much larger than the mineralogical alteration zone.

(4) The dispersion haloes of K, Rb, Na, Ca, Sr, K/Na and Rb/Sr outline the footwall alteration zone and the host rock of the Rosebery deposit, and also extend into the hangingwall pyroclastics. These element and element ratios are also useful in detecting the footwall alteration zone related to massive sulphide deposit.

(5) The area within the enrichment zones of Ba and Mn greater than 500 ppm and 50 ppm respectively between the Rosebery deposit and the Rosebery Lodes is of prime interest to focus further detailed exploration. However more detailed study to evaluate these surface geochemical anomalies, to determine the possible source, is necessary and hence is in progress.

(6) Evaluation of the host rock to determine the mineralisation potential can be made by using the geochemical variation of Ba, Tl, Ga and V together with Pb, Zn, As, Sb and Ag in the host rock being examined.

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1/3

The Huminex system for geochemical exploration

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INTRODUCTION

Where leaching processes are highly active in the development of soil profiles, as is the case in western Tasmania, the "B" horizon tends to be strongly depleted of heavy metals. This problem has long been recognised by mineral explorers and their solution to it has been to make use of the "C" horizon, which is less affected by leaching processes, for soil geochemical exploration.

Studies in the Department of Mines found the humic substances to be extremely aggressive in the degradation of economic minerals (Baker, 1986), and it follows that these substances are the most likely cause of the excessive leaching recorded for western Tasmania soils. If this interpretation is correct then metals removed by weathering of bedrock will move through the soil profile as complexes with the humic substances. It is thus possible that investigations of the humic substances–metal associations are capable of indicating the substrate distribution of metals of economic interest.

Conventional "A" horizon sampling and analysis has generally been rejected because of erratic response to substrate mineralisation. This is thought to be due to the analytical method, which involves total extraction of samples containing variable proportions of inorganic and organic components. If some means could be found of making use of "A" horizon sampling, the resulting method would fulfill the need for mineral explorers to conduct their investigations with little impact on the environment. To test the idea of a new system of "A" horizon soil geochemical exploration several field areas were selected for study.

FIELD STUDIES

An area southwest of Waratah was selected as the main trial site for the "A" horizon sampling. Previous studies of the area indicated a Dighem anomaly and "C" horizon geochemical anomalies (Collins, 1985). No mineralisation has been recorded in the area, which is underlain by Cambrian volcanic rocks. These rocks host a small Pb-Zn orebody at the old Magnet Mine, four kilometres to the north.

The "A" horizon sampling was carried out at 20 m intervals on a traverse spacing of 100 m, and a 2-man party collected 320 samples in five days. The humic substances were extracted from these samples and the associated metals determined. The contoured results for Pb are shown in Figure 1 and those for Ag, As, Au, Cu, Pb and Zn along Traverse 100 S are given in Figure 2.

The results clearly indicate that analysis of humic substances from the "A" horizon has detected the anomalies previously discovered only by augering to the "C" horizon. Subsequent drilling along Traverse 100 S to test the "high" of the "A" horizon results located vein style mineralisation at a depth of 90 m. A zone 25 m in width was found to contain veins varying in width from 0.1 to 1.0 m, with values of up to 23% Zn, 19% Pb, 460 g/t Ag and 5 g/t Au.

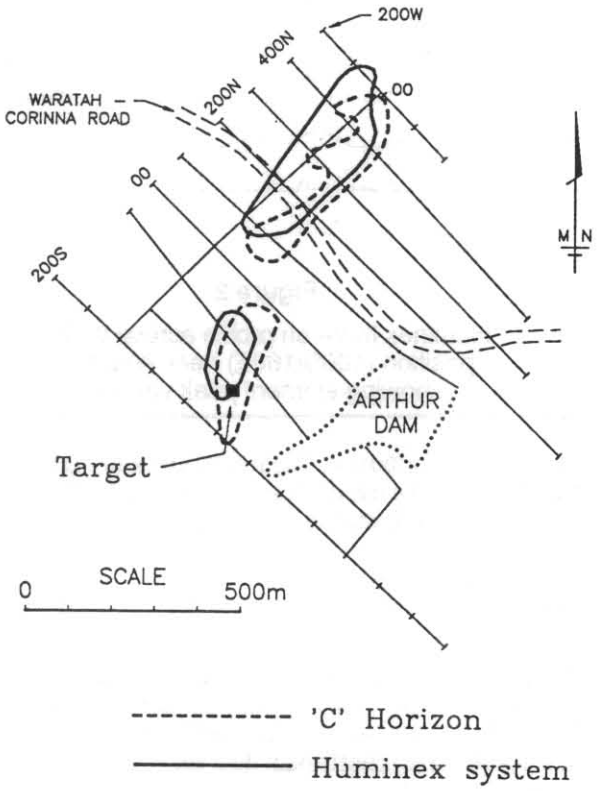


Figure 1

Comparison of "C" Horizon and Huminex anomaly definition near Waratah.

Less intensive studies were undertaken near Zeehan, north of the Henty gold prospect, and near Narrawa. The Zeehan study was undertaken at the site of the old Oceana Mine, and samples were collected along existing traverses 3 700 N and 3 300 N. This area was extensively disturbed by large-scale dozer blade sampling and was the site of former mining. The Oceana samples were analysed for Cu, Pb and Zn; the traverse results are given in Figure 3. Once again it can be seen that the results given by the humic substances reflect those from previous "C" horizon sampling. It is also of interest that contamination, which is often a problem around old mine sites, is not in evidence for the humic samples.

Samples were taken from north of the Henty gold prospect and near Narrawa to test the ability of the humic samples to

BAKER, W. E. 1992. The Huminex system for geochemical exploration. *Bull. geol. Surv. Tasm.* 70:17–19.

5 cm

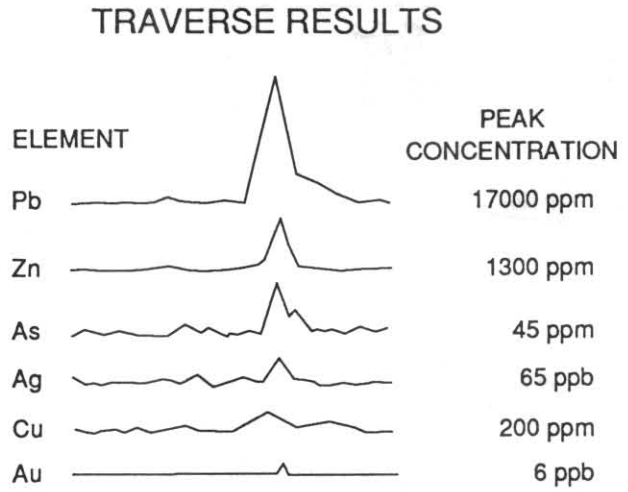


Figure 2

Huminex traverse profile across target position (100S/160E) near Waratah showing element peak values.

indicate Au distribution. The results given in Figures 4 and 5 indicate that the use of these samples yields results which reflect gold distribution in the substrate.

CONCLUSIONS

To date all test applications of the use of soil humic substances in soil exploration geochemistry have been successful in detecting anomalous metal distributions. Studies have been undertaken in drier regions of Tasmania and these have confirmed that the method is widely applicable.

This new procedure for use of "A" horizon samples has been patented by the Department of Mines as the Huminex System of exploration geochemistry, and its application to soils is now commercially available. It offers low sampling costs, clear anomaly definition, and can be undertaken with no impact on the environment. Research into other applications of the method is continuing, and it is anticipated that it will be applicable to the organics present in drainage waters where the rainfall is such that mobile soil humic substances are leached from the soils.

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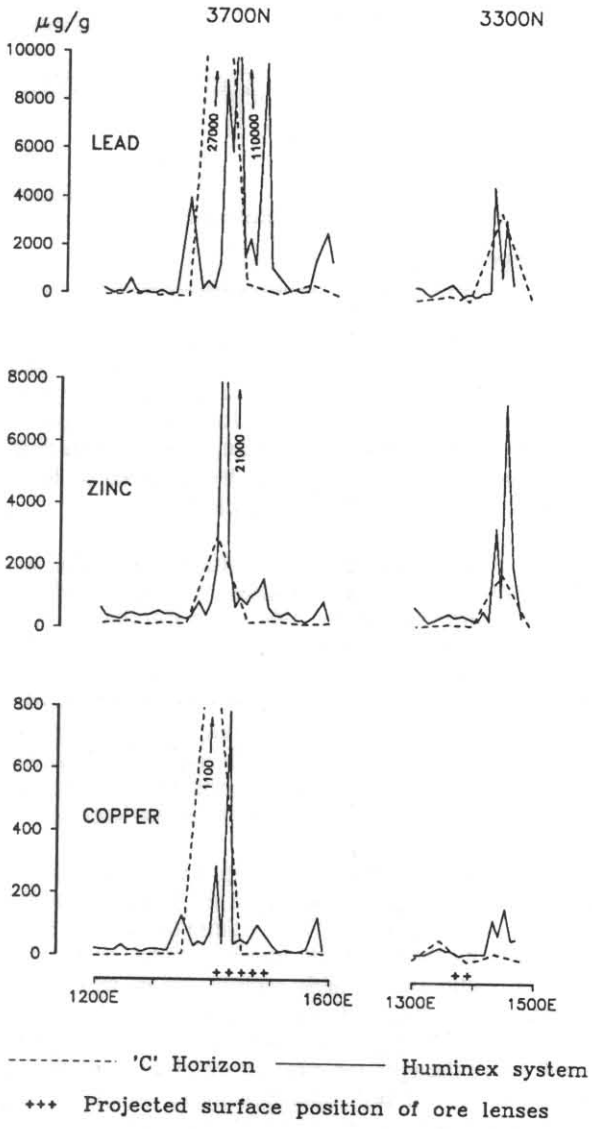


Figure 3

Comparison of "C" Horizon and Huminex results in the vicinity of the Oceana Mine, Zeehan.

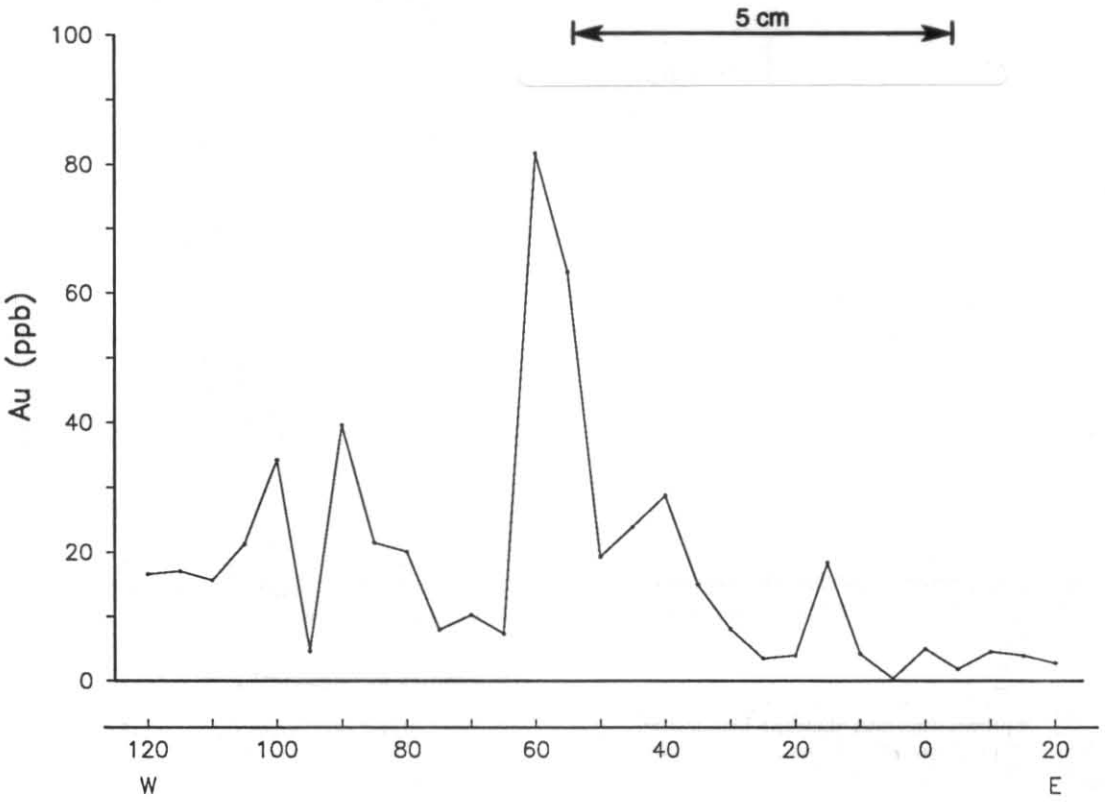


Figure 4

Huminex traverse profile (65N) across Henty Fault Zone north of Henty gold prospect

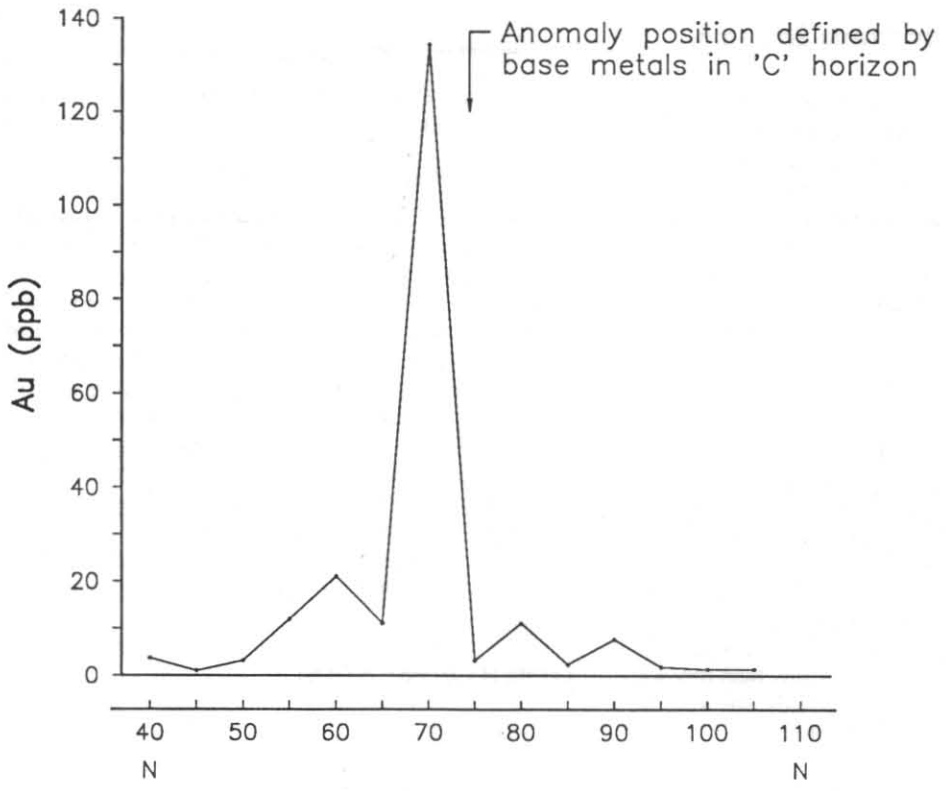


Figure 5

Huminex traverse profile (5810E) across Narrawa anomaly.

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1/4

The Environment Protection Act

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INTRODUCTION

The *Environment Protection Act 1973* is one small part of the mosaic of regulatory controls affecting mineral exploration and the mining industry in Tasmania. Perhaps the most important thing about the Act is the way in which it relates to all the other pieces of the mosaic, and consequently this paper will range a little further than the limited title may suggest.

Nonetheless, I propose to start with the *Environment Protection Act 1973*, and to consider in particular the way in which it operates at present, and its relationship with both existing and proposed mining legislation. I will also outline some of the major deficiencies and benefits of the existing legislative scheme.

The Tasmanian Government is presently undertaking a review of all its environment and planning legislation, and in the second part of this paper I will focus on what might be, rather than what is. Central to this discussion is the role of environment protection legislation in the greater scheme of things, and the extent to which good environmental outcomes can be achieved by means other than "command and control".

CURRENT LEGISLATION

THE ENVIRONMENT PROTECTION ACT 1973

Tasmania's current environment protection legislation dates from the early 1970s, and it bears the hallmarks of the approach to environmental protection issues at that time. It needs to be said first off that Tasmania achieved in 1973 a consolidated and integrated piece of environment protection legislation. A number of other Australian States have only recently achieved, or are still intending to achieve, the same degree of consolidation. The Tasmanian legislation, and the administrative structures which it establishes, amount to a consolidated environmental protection authority, with extensive licensing and regulatory powers.

The Act spans air, water and noise pollution, and waste management, and establishes two principal methods of regulatory control. These are features that are well suited, from a pollution control perspective, to managing existing operations[1]. The first control system is a series of offences, supported by a regime of penalties. The Act makes it an offence to cause or permit the emission of a pollutant from fixed or moving sources, unless it complies with standards prescribed for these purposes. The regulations then provide permissible levels of point source standards for various pollutants being emitted to air, water and noise.

The Act also provides a system of Ministerial exemptions for operations which do not meet the prescribed standards. These are coupled with a fee system — introduced in the 1990/91 Budget — which is designed to encourage the preparation of performance improvement plans[2].

The second method of control is a system of licensing particular types of operations, known as scheduled premises. The Act contains a prohibition on operating unlicensed scheduled premises, and defines those premises by reference to a listing of activities set out in a schedule to the Act. Again, there is a system of licence fees, and a means of appeal in relation to the imposition of licence conditions, exercisable both by an applicant, and by a limited range of third party objectors.

From a mining and mineral exploration perspective, the list of scheduled premises includes:

- primary metallurgical works;
- ferrous and nonferrous metal works;
- electroplating works;
- crushing and grinding works;
- premix bitumen plants;
- mines producing or processing more than 100 t of raw material per year;
- quarries used for the extraction of more than 100 t of raw material per year;
- lime, gravel, sand, loam, soil or clay pits producing or processing more than 100 tonnes of raw material per year;
- oil refineries[3].

The Act is essentially a pollution control Act which deals with point source emission standards, and which is silent about objectives such as the minimisation of waste. Also, it is silent about diffuse sources of pollution, and there is little consideration of the assimilative capacity of the environment under the required standards. When coupled with a lack of baseline data against which improvements or decreases in ambient environmental quality can be measured, these features demonstrate the major deficiency of the legislation. Other weaknesses include a lack of any statutory basis for environmental impact assessment, a reliance upon criminal sanctions for enforcement, and the lack of a mechanism to develop and implement statements of environmental policy which can respond to new or emerging environmental issues[4].

OTHER LEGISLATION

As noted above, no single Tasmanian Act provides comprehensive and coherent planning and environmental protection requirements for exploration and development of mineral resources. The *Environment Protection Act 1973* is

BINGHAM, R. 1992. The Environment Protection Act. *Bull. geol. Surv. Tasm.* 70:20–23.

* Views expressed in this paper are personal ones.

supported by planning controls under the *Local Government Act 1962*, and by the *Mining Act 1929*. Other land management legislation (such as the *Forestry Act 1922, the Crown Lands Act 1976* and the *National Parks and Wildlife Act 1970*) also deal with the protection of the environment. In some cases these can restrict or exclude exploration or mining in reserved or other areas.

THE CONTEXT OF ENVIRONMENT PROTECTION LEGISLATION

The world has changed significantly since 1973, and attitudes to environment protection have changed accordingly. Most significantly, there is now a genuine awareness within industry that it has a major environmental responsibility, and it is thinking constructively about its role in this respect. Similarly, Governments have realised that there is more to life than regulation, and environmental outcomes can be achieved more effectively in ways other than legislatively requiring them.

INDUSTRY ENVIRONMENTAL RESPONSIBILITY

In my view, there are three significant factors at work. Firstly, a new environment protection regime in Tasmania must recognise the level of industry awareness of environmental issues. Two recent examples demonstrate the extent to which the game has changed.

In supporting the approach of "best-practice environmental management", the Australian Manufacturing Council has proposed a new paradigm to achieve environmental results. This focuses on sensitive environmental regulation which encourages resource efficiency, and optimisation of pollution management. In turn this requires the application of environmental technologies, and the use of market demands for environmental products as a force for change. These new directions are coupled with openness and co-operation from regulators, unions and the community.

In the words of the Council:

> "The growing complexity of the regulations required, the high costs of enforcement for Government with constrained budgets, and the increasing competitive pressures on firms forced both Governments and firms to search for new ways to resolve these competing pressures"[5].

Similarly, the Business Council of Australia has recently flagged a similar approach[6]. The Council seeks to incorporate the goal of sustainable development within all industry operations, and nominates a number of principles whereby this might be achieved. These include:

- recognising environmental management as among the highest corporate priorities;
- assessing environmental performance against appropriate standards and seeking continuous performance improvement;
- communicating with Government, employees, shareholders, the general public, local communities, the media and environmental groups in regard to environmental policies, programs, practices and performance;
- developing employee commitment to the protection of the environment;
- integrating environmental impact considerations into all aspects of products and processes;
- developing, reviewing and practising appropriate emergency contingency plans;
- encouraging sound environmental management by contractors and suppliers;
- enhancing technology and skills co-operation with contractors and suppliers;
- the assessment and management of environmental risk.

Again, similar perspectives of sensitive regulation, openness and public accountability are inherent in this approach.

I believe it is significant that two peak industry bodies have recently published documents along these lines. They are by no means alone, and recent documents provided by the Australia Mining Industry Council have reflected a similar concern to improve environmental performance. Plainly, new environmental regulation must recognise this shift.

A further relevant factor is the recognition by Government, industry and the community generally of the need for consistency of objectives. There is also increasing agreement about what those objectives should entail. Foremost amongst these is sustainable development.

The World Commission on Environment and Development (the Bruntland Commission) in 1987 defined a concept of sustainable development as "development which meets the needs of the present without comprising the ability of future generations to meet their own needs".

The Business Council of Australia interprets sustainable development as providing a means of integrating environmental and economic goals to produce outcomes that are both environmentally acceptable and cost effective in an economic sense. Business and industry, being the chief sources of wealth creation in the community, have a major role to play in achieving these integrated goals.

SMALLER GOVERNMENT

Coupled with increased industry awareness has been a realisation by Government that regulation is a small part of the picture. In many ways market-based measures can more effectively and cheaply achieve environmental outcomes. In today's climate of declining public sector resources, cheaper and better ways of achieving improved environmental performance are being demanded. There is a need to recognise that regulatory "command and control" models are but one means by which environmental results can be achieved.

The 1992/93 Federal Budget, for example, included new taxation incentives for spending on the environment. New rebates have been provided for the costs of preventing, combating or rectifying pollution of the environment, and for the costs of treating, cleaning up, removing or storing waste. These supplement existing Commonwealth tax deductions for expenditure on environmental impact studies, environmental audits, environmental management plans, and costs associated with environmental monitoring. Whilst the opportunities at a State level are more limited because of

the more limited revenue base, and the nature of State revenue sources, they nonetheless need to be fully explored.

INTER-GOVERNMENT RELATIONS

The third factor which has led to a change in the context of environmental regulation is changes in inter-Government relations. Two developments in particular are significant. The first is the establishment by the Commonwealth Government of a Commonwealth Environment Protection Agency, to operate within the sphere of Commonwealth jurisdiction. The second is the signing by Commonwealth, State and Territory Governments, with the endorsement of Local Government, of the Inter-Government Agreement on the Environment[7], and the commitment to the establishment of a National Environment Protection Authority.

Under the terms of the Agreement, Governments have agreed to establish a new Ministerial Council to be known as the National Environment Protection Authority, with responsibility for the preparation of new national standards in a range of areas. These are:

- ambient air quality;
- ambient marine, estuarine, and freshwater quality;
- noise related to protecting amenity where variations in measures would have an adverse effect on national markets for goods and services;
- general guidelines for the assessment of site contamination;
- the environmental impacts associated with hazardous wastes;
- motor vehicle emissions;
- the reuse and recycling of used materials.

The Agreement includes a recognition by Governments of the need for a national approach in relation to these issues. However, the process of preparing these national standards is an open and public one, and the Authority is required to have regard to regional differences in the preparation of those standards[8].

The Agreement also deals with a range of environment protection and land use issues impacting on the mining and mineral exploration industry. These include:

- a more streamlined approach to the conduct of environmental impact assessment processes throughout Australia, including joint assessments and the accreditation of each others procedures;
- development of a national approach to the collection and exchange of environmental data;
- agreement by the Commonwealth and States and Territories to rationalise and streamline resource assessment, land-use decisions and approvals processes in order to overcome duplication of processes and ensure that responsibilities of all levels of Government are met through a single "accredited" process;
- co-operative regional assessment of heritage values with the Australian Heritage Commission; and
- co-operative arrangements for the identification and nomination of World Heritage Areas, which should see an end to disputed nominations.

From a State Government perspective, it seems that there are two principal benefits of the Agreement. The first of these is — recognising the almost unlimited extent of Commonwealth constitutional power, and existing and potential Commonwealth legislation in this area — that the Agreement represents a means of preserving State influence in relation to land use and environment issues. By means of the process of "accreditation", the possibility of State information gathering processes being utilised for the purposes of Commonwealth decision making — with consequent benefits of removal of duplication and decision making on comparable information — has been established.

The second benefit of the Agreement, from a State Government perspective, is the opportunity which it provides for rationalisation of approval processes for major projects. A common approach to environmental impact assessment, coupled with the potential for the accreditation of a single Government process, and hence an integrated assessment of project proposals, has benefits for proponents both in terms of consistency in decision making, and for Governments in terms of effective utilisation of resources.

PROPOSALS FOR REFORM

As noted at the beginning of this paper, the Tasmanian Government is committed to reviewing environment and planning legislation. The Government has signalled an intention to adopt the objective of sustainable development and economic growth[9]. It has also recognised the benefits of an integrated approach to resource management, both in terms of achieving environmental outcomes and in terms of efficiency of Government processes. In its application to the development approval process, this integration potentially delivers significant benefits.

The Government has indicated an intention to release, at the end of September 1992, detailed proposals for land-use planning and approvals reforms. The package of Bills will be the subject of public comment, prior to introduction to Parliament later this year.

Those Bills will be supported by new environment protection legislation, intended for public release early in 1993. The major thrust of that legislation will entail:

- an emphasis on clean production technology and ambient standards, in support of point source pollution control;
- a recognition of the need to be consistent with national approaches, but in a way which recognises the particular concerns of the Tasmanian community;
- an emphasis on integration of resource management tools, and a minimisation of unnecessary regulation;
- a range of enforcement measures, which do not rely simply on "command and control".

Having flagged the intention to move towards new environment standards, the Government recognises the need for industry to be able to plan for these changes. In a speech to the Parliament during the Address in Reply debate, on 28 April 1992, the Minister for Environment and Planning, the Hon. John Cleary MHA, outlined the Government's approach to this question.

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"On the issue of Ministerial exemptions the Government remains committed to the elimination of Ministerial exemptions by 30 June 1994. Only in very exceptional circumstances will any consideration be given to extending the deadline for particular cases. Even then such extensions would be very limited and would apply only if it can be unequivocally shown that they would result in a more appropriate environmental outcome taking into account the requirements of the law and community expectations. It is also important to note that legislation setting out the new environmental standards in Tasmania will be introduced before 1994. Industry and Local Government have sought guidance as to the likely standards under this legislation to enable long-term planning to continue. In order to provide certainty on the future direction for regulations and standards to all those likely to be affected, the transitional arrangements contained in a discussion paper issued in December 1991 will apply.

The new objectives will closely reflect the intended thrust of new legislation. It will be based on the principles of clean production, best available technology, and waste minimisation. Measurement of the achievements of the objectives will be by standards which may combine point source and ambient requirements. The arrangements require the Director of Environmental Management to nominate interim environmental quality objectives for each operation if requested by the holder of an exemption. This will enable current exemption holders to plan for the new legislation, and provide the opportunity to focus on environmental outcomes, not only emissions.

High environmental standards have become important to the future of Tasmania, especially in the marketing of tourism and the State's high quality food products. This reputation cannot be jeopardised, and neither I nor this Government will condone lax environmental standards. However, I hope that industry and Local Government will not see strict environmental standards as a burden forced on them but as an opportunity to meet market demands, to generate economic activity, and to create jobs"[10].

CONCLUSIONS

The principal message to emerge is that the times are changing. The Tasmanian Government has recognised the extent of industry commitment to environmental improvement, and will be designing its legislation accordingly. In the current climate, the environment is everyone's responsibility. As that responsibility is recognised, the regulatory strategies which are employed to achieve our goals should be modified.

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1/23

Gold in Tasmania

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ABSTRACT

Lode gold deposits are widespread in western and northern Tasmania, and principally occur in the pre-Carboniferous rocks of the Dundas Trough and Lachlan Fold Belt. The northeastern area is particularly important, with numerous gold-quartz veins in the turbidite bearing Mathinna Beds, of Ordovician to Devonian age, in the Lachlan Fold Belt. Some of these deposits are spatially and genetically related to granitoid intrusions, while others have probably been derived from metamorphic fluids. Gold is also a very important by-product of most of the volcanic-hosted massive and disseminated base metal deposits in western Tasmania, which are the only significant gold producers in Tasmania at present. Other interesting styles of gold mineralisation in Tasmania include the stratabound gold in the Arthur Mobile Belt and that related to Cretaceous alkaline intrusives in the Cygnet area. Alluvial gold is also widespread in Tasmania, with about 360 deposits recorded, some relatively large and rich.

INTRODUCTION

This paper is predominantly a brief literature review of gold deposits in Tasmania, firstly describing the geology of the major goldfields in the State, and then the deposits producing gold as a by-product. The different styles of mineralisation will be summarised and discussed, with suggestions for future exploration.

Gold-bearing deposits are relatively common in Tasmania (fig. 1), with over 1260 recorded on the MIRLOCH database of Tasmanian mineral deposits, approximately half of these occurring as quartz veins in the Mathinna Beds of northeastern Tasmania. Alluvial gold and various other mineralisation styles are also present. The gold production for the state is shown in Table 1, but records for smaller, early workings are poor, as a large proportion of the gold was taken directly to the mint in Victoria by the miners. Where not otherwise acknowledged, the production data were collated from various departmental records. Production from gold mines has been sporadic from 1852 to the present, with most production between about 1870 and 1920. Production records and data in McOnie (1983), Bottrill (1991), and Large *et al.* (1990) indicate a total gold production in Tasmania of about 199 t, comprising about 143 t from base metal deposits, 43 t from vein-style deposits and 13 t from alluvial deposits. At present nearly all gold production comes from the base metal mines in western Tasmania.

Acknowledgement

D. McP. Duncan instigated and reviewed this paper.

PRINCIPAL GOLDFIELDS

Northeastern Goldfields

General geology

The Mathinna Beds are turbidite sequences of Ordovician–Early Devonian age, generally classified with the Lachlan Fold Belt and closely related to sequences in Victoria and New South Wales (Powell *et al.*, in press; Powell and Baillie, in press). Powell and Baillie (in press) note two stages of deformation in the Mathinna Beds: upright to overturned folding in the Early Devonian, and recumbent folds and thrusting in the Middle Devonian. Structural and stratigraphic studies are hampered by commonly poor outcrop and the lack of marker beds and drilling. The rocks are intruded and locally contact metamorphosed by granitic to dioritic rocks of the Scottsdale and Blue Tier batholiths, of probable upper Devonian to lower Carboniferous age. The folding and syntectonic metamorphism (to lower greenschist facies) in the Mathinna Beds are considered to predate the intrusion of granitoids (McClenaghan *et al.*, 1982). Gold mineralisation is associated with the aureoles in the Lisle–Golconda district and other areas (see below), but little or no indication of hornfelsing is present in many goldfields.

The sediments consist of sandstone (litharenite and sublitharenite), quartzite, siltstone and pelites (phyllite, shale or slate), with local hornfelsing close to granitoid bodies (McClenaghan *et al.*, 1982; Powell *et al.*, in press). The mineralogy of sequences away from granitoids is simple, usually just quartz and muscovite, with lesser chlorite, albite, graphite and heavy minerals. Poikiloblastic siderite blebs are present in some mineralised areas.

Gold veins commonly occur in one major belt and several minor belts, usually with a NNW, or less commonly, a NE trend (fig.3), throughout the northeast of Tasmania, including the Beaconsfield district (parallel to the Tamar Fracture zone). These gold-mineralised zones may be related to thrust faulting, as proposed for similar situations in Victoria and New South Wales (R. A. Glen, unpublished data). Powell and Baillie (in press) consider that, despite differences in structural detail, these sequences closely resemble those of the Melbourne Trough, so the gold mineralisation in both areas could be expected to be related.

Mangana–Mathinna–Alberton–Warrentinna–Forester–Lyndhurst

The first payable gold discovery in Tasmania was in alluvial material in Tower Rivulet, near Mangana, in 1852. The "gold

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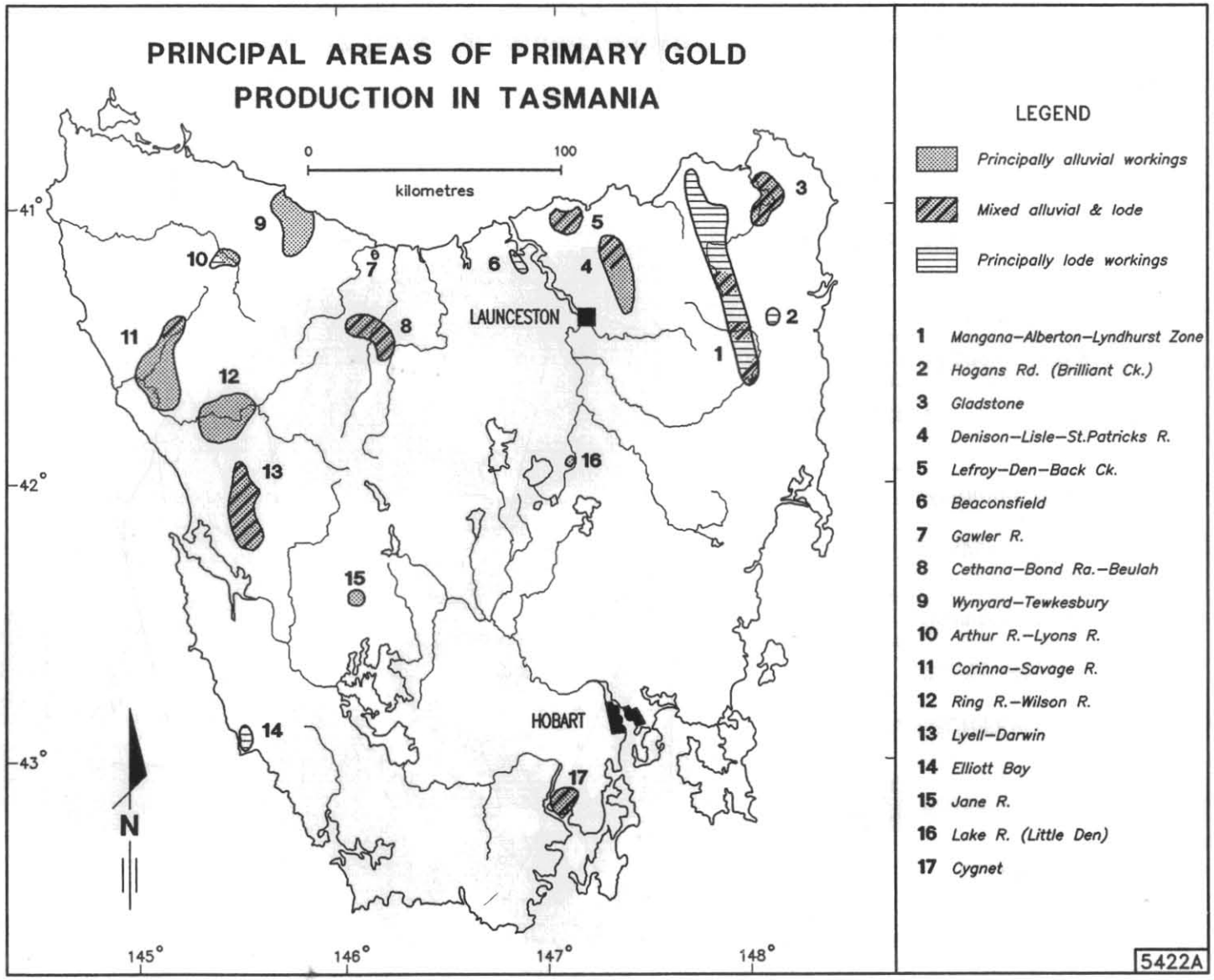


Figure 1

The distribution of major goldfields in Tasmania

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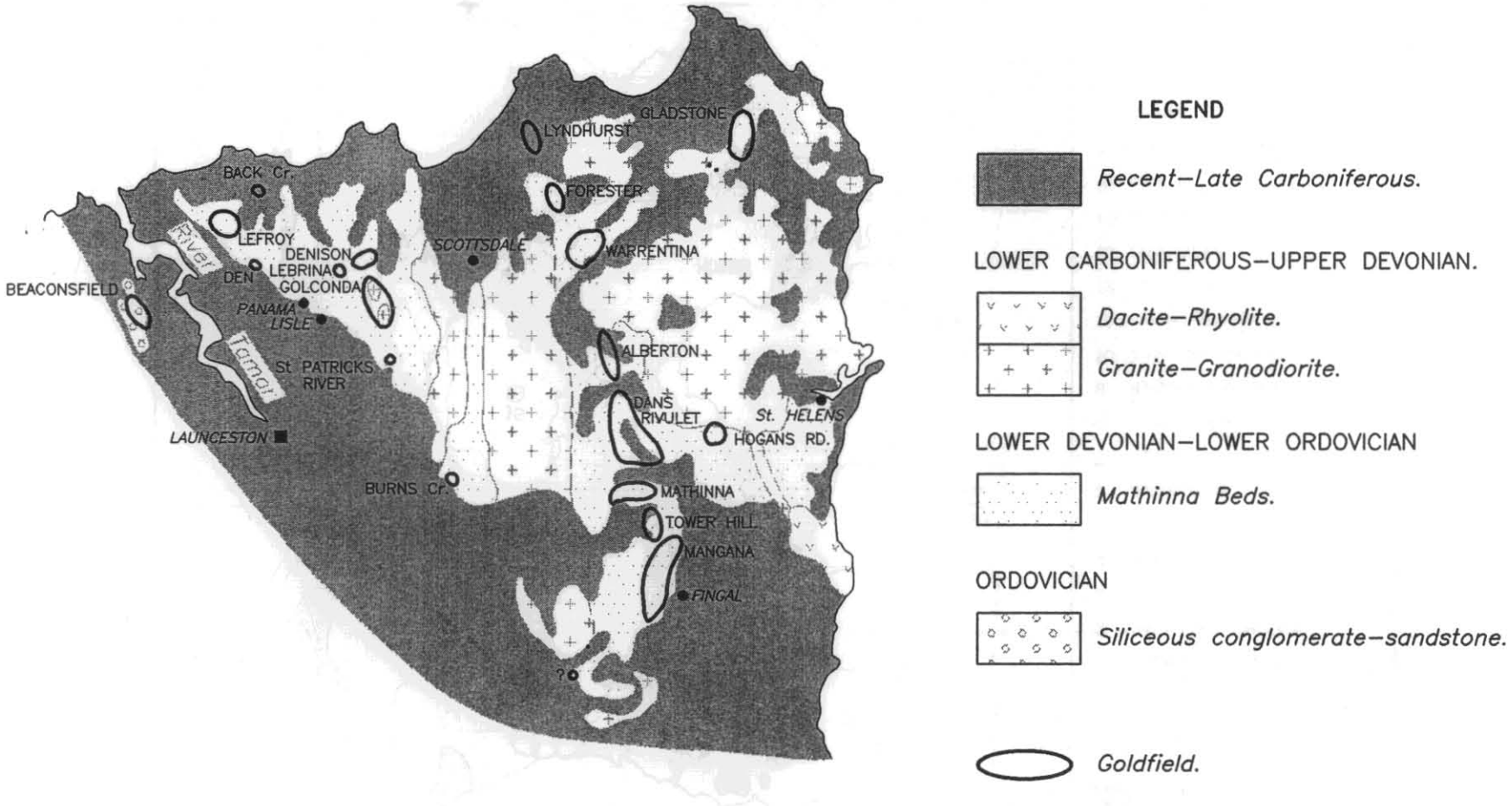


Figure 2. The geology and major goldfields of northeastern Tasmania

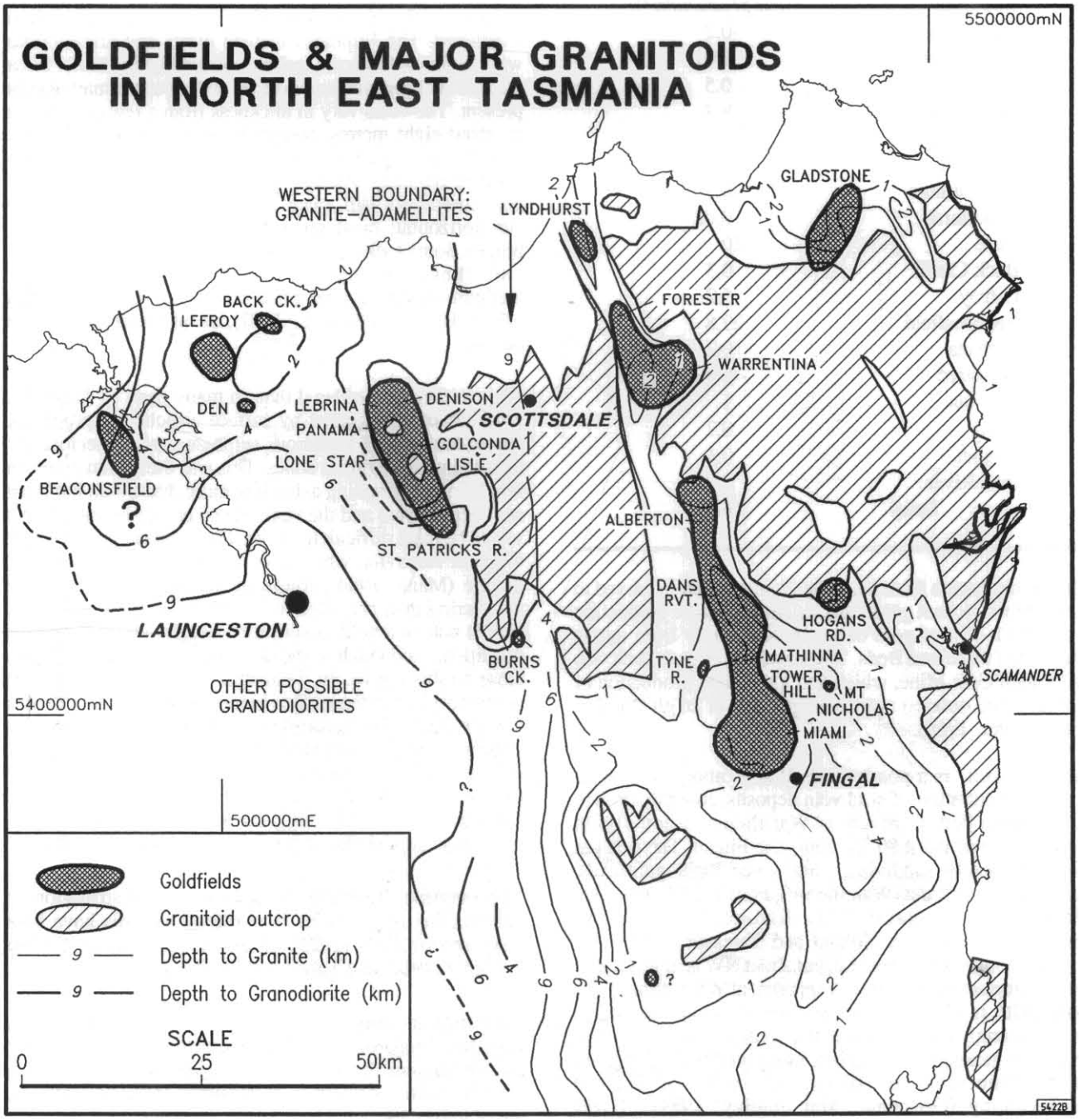


Figure 3

The distribution of the major goldfields in northeastern Tasmania, showing relationships to granitoids, after Leaman and Richardson (1992).

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Table 1

Estimated gold production for various goldfields in Tasmania (from Department of Mines records and various reports). Gold as a by-product is excluded.

Goldfield	*Gold production (t)*
Gladstone	0.2
Scamander	0.01
Mangana	0.5
Mathinna	8.8
Dans Rivulet	0.1
Alberton	0.7
Warrentinna	0.1
Lyndhurst	0.02
Lisle	10
Back Creek	0.3
Lefroy	5.2
Beaconsfield	27.8
Cethana	0.2
Wynyard	0.3
Corinna	1
Lyell	0.7
Cygnet	0.1
Jane River	0.01
Total	**56.0**

belt" running north from here (fig. 2) subsequently proved to be one of the richest goldfields in Tasmania, the production of about 11–12 t of gold being predominantly from quartz veins in the Mathinna Beds. The largest mine in the belt was the Golden Gate Mine, which had a recorded production of 7.9 t (253,865 ounces) at an average grade of 26 g/t (Noldart and Threader, 1965).

The "gold belt" is a poorly-defined zone about 2 km wide with a concentration of gold vein deposits, running through the Mathinna Beds from around Waterhouse, near the north coast, south for about 80 km almost to Fingal. The belt has been historically subdivided into seven main goldfields, namely the Lyndhurst (Waterhouse), Forester, Warrentinna, Alberton (Mt Victoria), Dans Rivulet, Mathinna and Mangana fields (fig. 2; Noldart and Threader, 1965). The strike is about NNW in general, but about NW near Mangana, and an intersecting NE trend is apparent at Warrentinna. The "gold belt" is characterised by close folding, axial plane shears, strongly cleaved slates and abundant quartz veining (of several generations). The belt, along with the bedding and major structures, are disrupted by post-granitoid mega-kinking (Goscombe and Findlay, 1989). It was probably a continuous structure, but is intruded in places by granitoid intrusions, is buried in others by later sedimentary deposits, from the Permian to Recent in age, and is intruded or partly obscured by Jurassic dolerite dykes and sills. M. Roach (this volume, p.201) considers the sediments to be 2.6 km thick below the "gold belt", and no indication of hornfelsing is present in most of the belt.

VEIN STYLE AND RELATED DEPOSITS

The belt is locally highly mineralised, with at least 300 significant known gold deposits within or in close proximity to the area (fig. 2; the MIRLOCH database of mineral deposits). Gold occurs in quartz-rich veins and breccias, samples of which can be very gold-rich (up to 1354 g/t: Twelvetrees, 1907), but are typically erratic in size and grade. Typically the grade of the deposits averaged about 1 oz/ton (31 g/t) but the Great Fingal Mine, for example, averaged nearly 200 g/t.

The quartz in the veins is usually white and glassy, but where auriferous is commonly dense and milky to blue-grey in colour, with minor sulphides, or iron oxides where weathered. The sulphides include pyrite and arsenopyrite, with lesser chalcopyrite, galena and sphalerite. Minor mica, chlorite and carbonates (ankerite and siderite) may also be present. The veins vary in thickness from a few centimetres to about eight metres, and up to about two kilometres in length (Finucane, 1935). They are commonly bedding-parallel, striking NNE, or conjugate to this (fig. 4), and commonly dip steeply. Some veins, however, are sub-horizontal; most are extensional, in fold limbs and hinges. Some lodes are breccia zones (eg. Golden Entrance), and these breccias are cemented by cherty to medium-grained quartz. Such re-faulted veins are highly mineralised (Twelvetrees, 1907), as at Beaconsfield (see below).

Blake (1939*b*) considered that, in many parts of Tasmania, gold has been upgraded by surface enrichment processes, during leaching of auriferous sulphides and reprecipitation of gold into ferruginous zones. This was the reason given for few workings reaching a depth of more than 30 m, but it has not been proven, and the veins are so erratic in grade that it would be quite difficult to prove. The situation is different in Western Australia, where gold is enriched in gossans and laterite (Mann, 1984), following much longer periods of weathering than prevailed in Tasmania. Zeegers and Leduc (1991) note that gold mobilisation usually requires extreme conditions, and much of the dissolved gold is reprecipitated close to the source. In Tasmania, sulphides are common relatively close to the surface in most goldfields. In the New Golden Gate Mine, the original workings were abandoned at shallow depth, as with most of the early mines in the area, but were later re-opened and reached a final depth of about 600 m, still with average grades of 26 g/t (Noldart and Threader, 1965). This suggests a high potential for gold reserves at depth below other mines and "barren" veins.

The possible structural controls on the distribution of gold-bearing quartz veins in northeast asmania have been discussed by Hills (1923), Blake (1933), Hughes (1952), Threader (1967) and Taheri and Findlay (1992).

According to Hills (1923), the gold mineralisation in the Alberton–Ringarooma area is controlled by a fold related to a NNW-dipping thrust fault. He considered that all the lodes were concentrated on the crest and limbs of this anticline and are of two types:

Type 1: The lodes that concentrated near the crest of the anticline and were formed due to tensional fissuring. They are generally limited, both in length and depth, but may contain 'good gold values'.

Type 2: The lodes which have been formed by faulting due to a regional 'compressive force'. These are of greater significance, as they may be continuous at greater depth.

Blake (1933) discussed the possible lithological effect on the distribution of the ore bodies and could not find any structural features which might control the distribution of the lodes.

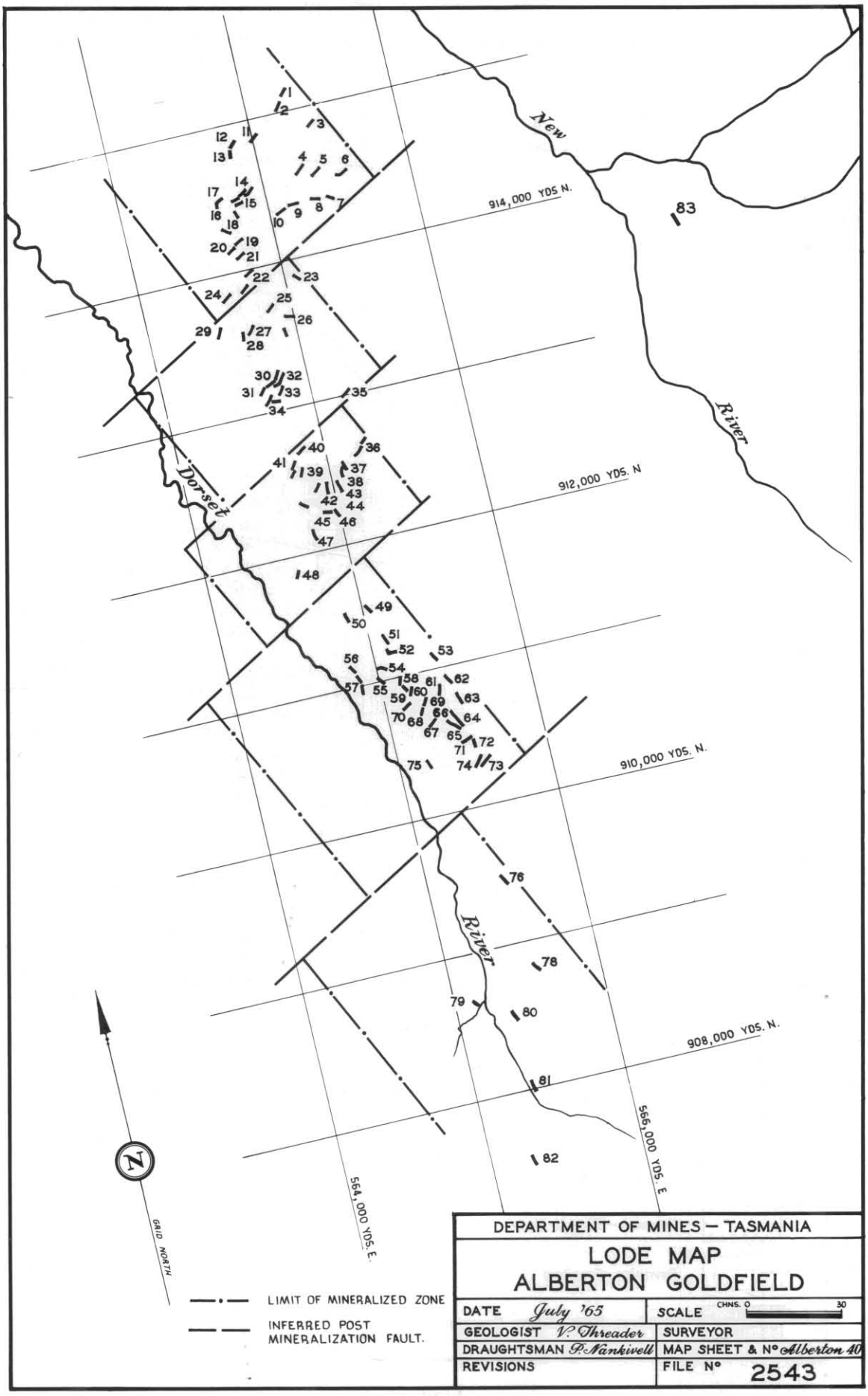


Figure 4

The distribution and strike of veins in the Alberton goldfield, after Threader (1967).

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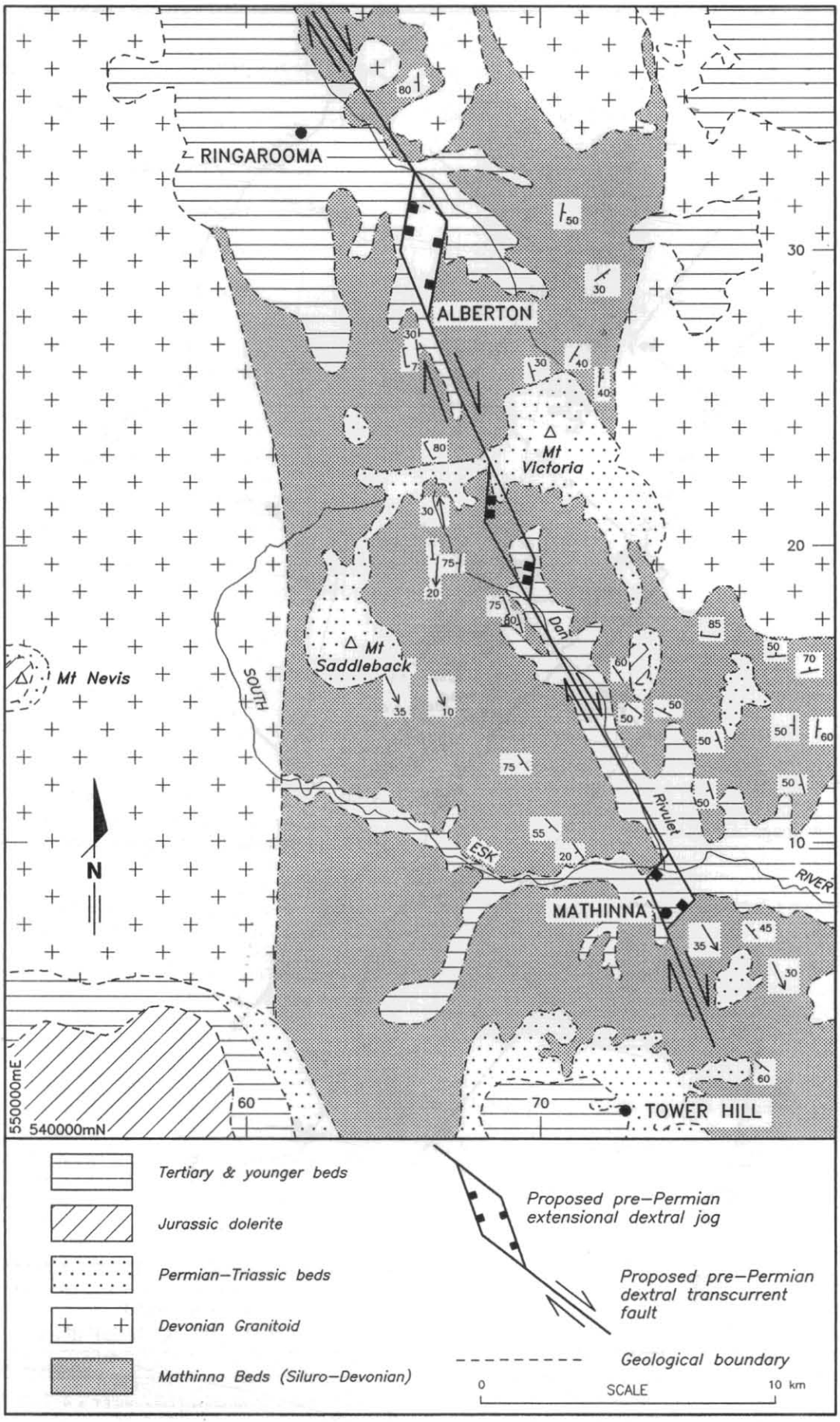


Figure 5

Geology of the Mathinna–Alberton area (after Taheri and Findlay, 1992).

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Hughes (1952) interpreted the lodes in the Alberton–Ringarooma Goldfield to form the western limb of an anticline striking NNW, which has subsequently been subjected to cross folding. The greatest density of the quartz veins occurs where the cross folding is most intense. The ultimate source of gold-bearing solutions was interpreted, both by Hills (1923) and Hughes (1952), to be underlying granitoids.

Threader (1967) concluded that the gold mineralisation is related to shear zones rather than folding and emplacement of granitoid bodies. He noticed that the regional trend of the goldfields in Northeast Tasmania is 330°, whereas the trend in individual goldfields is about 320°. This was interpreted to be due to the effect of a series of N-S dextral post-mineralisation shearing movements within the area.

Based on limited studies, Taheri and Findlay (1992) suggested that the gold-bearing quartz veins occur in post-fold faults, and that the ore-forming solution was probably derived from a metamorphic-derived fluid. It was interpreted that that the mineralisation is controlled by a system of NNW-trending dextral strike-slip displacement zones, jogging right progressively northward, and their related Riedel shear systems (fig. 5). In this model, tensional jogs form the sites of the main goldfields in the area.

Preliminary fluid inclusion and oxygen isotope studies undertaken in the Mathinna and Alberton goldfields suggest that the gold-bearing quartz veins were derived from metamorphically-derived fluids. The fluid inclusions are, in general, rich in CO_2, appear to contain CH_4 in some samples, and are of very low salinities. The vapour-liquid and H_2O-CO_2 ratios vary widely, and their behaviour upon heating was considered to be the result of fluid immiscibility phenomenon. The homogenisation temperature ranged from 261° to 359°C, with more than 60% of the population falling in a narrow range of 297° to 329°C.

Calculated oxygen isotope compositions of water associated with the quartz veins range from 7.0 to 9.5‰, assuming an average formation temperature of 310°C (fluid inclusion data). Considering the compositions of the fluid, consistent homogenisation temperatures and oxygen isotope values, a metamorphic-derived fluid was considered to be more likely than a magmatic-derived fluid. However, it is recognised that more detailed work is needed to substantiate this model.

This model is in contrast with Davidson (1988), who conducted some limited carbon and oxygen isotope analyses and fluid inclusion studies which he took to indicate a magmatic origin for ore fluids in the Gladstone, Burns Creek, and Scamander areas. His data can, however, be reinterpeted to indicate metamorphically-derived fluids.

ALLUVIAL GOLD

Most of the gullies draining these goldfields were worked for alluvial gold (Bottrill, 1991), but the deeper valleys have not been well explored. Some alluvial gold production continues today, principally at Majors Gully, Mangana. Twelvetrees (1907) reported the occurrence of gold nuggets in the area, variously reported as up to 7 or 11 ounces in weight, but most gold particles are relatively fine, as is general in most of Tasmania.

Twelvetrees (1907) and Finucane (1932) also reported some occurrences of alluvial gold in the overlying Permian conglomerate, and suggested that these palaeoplacers made an important contribution to the recent alluvial gold deposits.

Hogans Road (Brilliant Creek)

This small goldfield lies in the outer part of the zoned Scamander mineral field (Groves, 1972). Most of the quartz veins are hosted in hornfelsed Mathinna Beds, in the contact metamorphic aureole of some Devonian granitoids, while some veins are actually hosted by granitoids. Davidson (1988) conducted some isotope analyses and fluid inclusion studies; these are discussed above.

Gladstone–Derby

The gold-bearing quartz veins in this district occur in Mathinna Beds, many in a contact aureole to various granitoids. The lodes were rich in free gold at the surface, but the deeper lodes had gold locked in sulphides and proved unpayable. The lodes at Gladstone contained minor tin and rarely platinum, with abundant wolframite in some lodes (Twelvetrees, 1916; Threader *in* Baillie, 1986). Gee and Groves (1971) considered that this block of Mathinna Beds, with its enclosed veins, was rafted from the west by granitoid intrusions. Davidson (1988) conducted some limited carbon and oxygen isotope analyses and fliud inclusion studies, which indicate a magmatic origin for the ore fluids.

Lisle–Golconda–Denison area

These goldfields were discovered in 1877 and were dominated by the Lisle alluvial field, with a probable production of nearly 10 tonnes. A small production of gold continues at present from Lisle.

The workings are spatially closely related to granitoid intrusions in Mathinna Beds (Roach, 1991; fig. 3). Hornblende-biotite-magnetite bearing granodiorites are present, but more alkali-feldspar rich phases also occur. The metamorphic aureoles are commonly sharply defined, varying from 800 m to about 5 km in width, depending upon the dip of the contact (McClenaghan *et al.*, 1982). Within these aureoles the sediments are commonly spotty and/or hornfelsed, and may contain biotite, epidote-clinozoisite, tourmaline, andalusite and cordierite, as well as recrystallised quartz, muscovite and chlorite. Small quartz and greisen veins and granitic dykes occur in the aureole.

LISLE

Workings at Lisle included alluvium and eluvium in a basin-shaped depression, possibly representing an old lake bed of Tertiary age (Reid, 1926; Marshall, 1969). There were numerous, patchy, gold-rich horizons in the possible lacustrine sediments, and in carbonaceous horizons underlying talus, which produced relatively pure, free, angular (crystalline?) gold (Noldart *in* Marshall, 1969). This type of gold suggested a secondary origin (i.e. *in situ* reprecipitation of dissolved gold from groundwater (Reid, 1926; Bottrill, 1986). Some gold grains are highly porous and/or colloform, while some have silver-rich cores and silver-depleted rims (Bottrill, 1991; Roach, 1991), confirming that some gold is detrital and some reprecipitated.

Auriferous quartz was relatively rare, both in alluvium and bedrock, and Twelvetrees (1909) found evidence for gold originating in the contact metamorphosed sandstone of the Mathinna Beds surrounding the basin, near the contact with

9/23

Devonian granitoid intrusives. Inclusions of mica, rutile and magnetite in the gold grains suggest that the gold was more likely to have been disseminated in the hornfels or granitoids than in quartz veins, while rare gold-limonite composite grains in placers suggest gold-bearing pyrite may have been originally present (Bottrill, 1986). Some gold was, however, found in small quartz veins in the granitic intrusive underlying the alluvial materials (Thureau, 1882*b*; Montgomery, 1894*b*). Recent drilling by the Department of Mines revealed very minor quartz-carbonate-pyrite alteration zones in the magnetite-pyrite bearing granodiorite, with trace gold (to 0.05 g/t).

OTHERS

Other poorly-recorded deposits worked nearby include the Lone Star, Tobacco, Cradle, Panama, Golconda and Den Creek, and the Lebrina and Denison goldfields (Noldart *in* Marshall, 1969). Most of these deposits were alluvial or eluvial.

The Denison Goldfield consisted of a number of auriferous quartz veins in Mathinna Beds, similar to Lefroy in style, and probably overlying granodiorite (Roach, 1991).

The Panama field miners worked veins in both granitoids and hornfels. Reconnaissance geochemical surveys have indicated minor gold in hornfels (up to 3 g/t) and some very gold-rich quartz-sulphide veins (up to 210 g/t).

Stockwork-hosted gold mineralisation (to about 1 g/t) in arenite at Bessells's Reward, near Cradle Creek, has been reported (Roach, 1991). Minor gold veins occur in the St Patricks River–Myrtlebank area, south of Lisle, and one of these deposits contained ruby silver and gold in a porphyry dyke, suggestive of epithermal mineralisation (Reid, 1926). There is a supposed lamprophyre occurrence in the Den Ranges, perhaps related to nearby gold occurrences (Noldart *in* Marshall, 1969).

Back Creek–Lefroy

Gold was known to occur in the Lefroy area in the 1840s, but the reefs were not worked until about 1869, still one of the earliest workings in Tasmania. There were about fifty lode mines working on thirty separate reefs to produce over five tonnes of gold (Noldart and Threader *in* Gee and Legge, 1979). Most of these lodes were rich at the surface (about 30 g/t) but the deeper ores were patchy and low in grade (about 3 g/t; Noldart and Threader *in* Gee and Legge, 1979). The deepest mine reached 380 metres. The quartz veins contained stibnite and cervantite, as well as the more typical pyrite, chalcopyrite and arsenopyrite. The Back Creek lodes were similar, and a possible lamprophyre is present nearby (Noldart *in* Marshall, 1969).

Four Tertiary leads, all partly basalt covered, were worked in the Back Creek area, with production of about 300 kg of gold estimated by Broadhurst (1935). Similar Tertiary Leads were worked at Lefroy between 1853 and 1900 for an estimated 155 kg of gold (Noldart and Threader *in* Gee and Legge, 1979). These included the Pinafore, Golden Point and Native Youth leads, all worked up to where they pass beneath basalt. Quaternary (Recent) alluvial gold is also present (Noldart and Threader *in* Gee and Legge, 1979). A small amount of gold is still being produced in the Back Creek area.

Beaconsfield

Gold was also known in this area in the 1840s, but the reefs were not worked until about 1877, and many of the numerous workings were eventually incorporated into the Tasmania mine, the most productive gold mine in Tasmania to date. This mine produced 26.6 t of gold from about 1.1 Mt of ore, up until 1914, and Beaconsfield Gold Mines Ltd have been endeavouring to reopen the mine to develop an estimated resource of about 0.7 Mt at 24 g/t for 16.8 t gold (Hicks and Sheppy, 1990).

The principal reef in the area, the Tasmania reef, is developed in conglomerate and arenite of the upper Cabbage Tree Formation, of probable early Ordovician age. These sediments have been thrust against the Precambrian Badger Head Block and the Cambrian Andersons Creek Ultramafic Complex to the west. Recent studies by Powell and Baillie (in press) have indicated that the The Cabbage Tree Formation is a probable time equivalent of the Mathinna Beds, separated by the Tamar Fracture Zone. The other reefs present in the area are also confined to the same formation.

The Tasmania reef occupies a minor fault and averages two metres in thickness, about 400 m in length, and more than 800 m in depth (this and following data from Hicks and Sheppy, 1990). The ends of the reef, where they approached the overlying limestone of the Gordon Group and some underlying pebble conglomerate, are highly branched and ragged. The reef is zoned, with an ankerite-rich core, a quartz-rich outer zone, and a gold-sulphide enriched contact zone between these two zones. Wallrocks are locally altered with carbonates and pyrite, and partly assimilated. Sulphides include pyrite, arsenopyrite, chalcopyrite and minor sphalerite, galena and tetrahedrite. Most of the gold occurs as fine inclusions (<5 μm) in pyrite. Later fracturing and brecciation of the reef has resulted in recrystallisation, forming secondary, coarse-grained quartz, calcite, pyrite, chalcopyrite and gold (to several millimetres), as high-grade shoots parallel to bedding.

There was also a recorded production of 1.1 t of alluvial gold at this goldfield up to 1907 (mostly pre-1890). The major producer was a deep Tertiary lead to the east of Cabbage Tree Hill, with minor production from a deep lead near Salisbury Hill to the south. The gold was enriched in probable eluvial detritus on the western wall of the northern lead, and in carbonaceous false bottoms; the true bottom was probably never reached (Noldart and Threader *in* Gee and Legge, 1979).

Northwestern to Southern Tasmanian gold deposits

Bond Range–Cethana–Beulah

This rather complex mineral field contains a great variety of mineralisation, mostly related to the Devonian Dolcoath granite. Deposits of gold, tin, tungsten, bismuth, copper, silver, fluorite, topaz, rare earths, beryllium, magnetite, garnet, lead and zinc are known, and host rocks include Cambrian Mt Read Volcanics, Ordovician Moina Sandstone and Gordon Limestone, and the granites themselves (Collins *in* Jennings, 1979). The Bell Mount alluvial goldfield was the largest gold producer in this area, with production estimated as 124 kg (Reid, 1919). This was produced from high level Tertiary gravel, and a number of smaller deposits

10/23

in the district worked other Tertiary to Recent alluvial deposits (Bottrill, 1991).

The second largest gold producer was the Round Mountain group of workings, described under the section on by-product gold, along with a number of other deposits in the area. A number of quartz and greisen-style veins, mostly in Moina Sandstone, were also worked primarily for gold, particularly in the Lake Cethana area (Jennings, 1979; 1963). Some of these veins contain tin, tungsten, bismuth and other granite-related minerals, and mostly occur in faults. Other deposits contain disseminated gold in skarn, sandstone, feldspar veins and Cambrian porphyries (Thureau, 1882*a*; Jennings, 1979; 1963).

Wynyard

There were numerous workings in this area in the 1890s, including Big Creek, Blackfish Creek (Moores Plains), Calder Creek, Camp Creek, Cam River, Deacons Creek, Inglis River, St Marys River and Seabrook Creek (Montgomery, 1896). The only gold production recorded from the area is 12 kg from the Doctors Rocks–Seabrook Creek beach sands in 1940–44, but it was estimated as 310 kg for the wider area (Reid, 1927). Most of this was recovered from Quaternary gravel reworked from extensive Tertiary sub-basalt gravel (Montgomery, 1896), but some gold may have originated in Permian fluvioglacial sediments (Morrison *et al.*, 1988) or quartz veins present locally in pre-Carboniferous basement rocks (Montgomery, 1896). Extensive low-grade offshore placer gold deposits exist (Morrison *et al.*, 1988).

Arthur River–Lyons River

The river terraces along the Arthur River are gold-bearing, particularly near the confluences with the Lyons, Keith and Hellyer Rivers, and with Campbells and Grays Creeks (Montgomery, 1896). Some higher level, possibly Tertiary deposits at Folly Hill were worked from 1910–1943 (Jack, 1964). No records of production are known for the area. The source of the gold is unknown, but Cu-Au bearing quartz veins are known in the Precambrian schist, quartzite and dolomite nearby (McNeil, 1961; Jack, 1964). The Tertiary sub-basaltic gravel and the Permian fluvioglacial deposits are also possible sources, as for the Wynyard area.

Corinna–Savage River

Gold has been recovered from a wide area about Corinna since 1877, to at least 1941. The principal workings were alluvial and include the Paradise River, Rocky River, Savage River, Whyte River and many tributaries (Bottrill, 1991). The Rocky River produced the two largest nuggets in the state (7.6 and 4.4 kg) (Montgomery, 1894*a*). Tin and platinum-group metals ("osmiridium") were minor by-products (Twelvetrees, 1900; Scott, 1926).

Montgomery (1894*c*) noted that much of the alluvial gold was concentrated in sandy carbonaceous 'bottoms', presumably palaeosols. The alluvial sediments included deep leads in high-level Tertiary deposits (Browns Plains Gravels), partly reworked into the more recent deposits (Blake, 1939*a*). There is a great variation in fineness and roundness of the gold, indicating multiple sources (H. D. Nolan, pers. comm.).

The source of much of the alluvial gold was the mineral-rich Precambrian Bowry Formation, the host for the Savage River magnetite deposits and other ores (Shannon *et al.*, 1985; Turner *et al.*, this volume). Some auriferous reefs in the Golden Ridge (Long Plains) and Specimen Reef fields also contributed gold (Finucane and Blake, 1933*a*), and Smith (1897) noted the presence of copper and gold in quartz veins in a porphyry at Lucy Spur.

Montgomery (1894*c*) noted the abundance of chalcedony in many of the gold placers around Corinna, and this suggests a possible replacement origin in some of the Precambrian limestones, which are locally silicified. Khin Zaw (1990) investigated the geochemistry and fluid inclusions in these rocks, and suggested that homogenisation temperatures were up to 298°C, with CO_2-rich, low to moderate salinity, probably methane-bearing fluids. These fluids were probably magmatically derived rather than metamorphic, and would have been capable of carrying gold. The fluids could be consistent with a Carlin-style gold deposit (i.e. disseminated gold in limestone). His study of placer gold composition and morphology indicates that the grains have not travelled far, but until gold is found *in situ*, the source remains enigmatic.

The Savage River and Rocky River magnetite deposits were first prospected for gold, and grades of up to 55 g/t were recorded at Savage River (Twelvetrees, 1903). No production was recorded. Twelvetrees (1900) noted that the Long Plains gold was stratabound, as disseminations and small veins in various weathered schists, and was typically skeletal in form, suggesting recrystallisation *in situ*. The purity of the gold supports this (Thureau, 1881). The Rocky River deposit is poorly understood, with gold being stratabound in magnetite-rich rocks with nickel, cobalt, copper and silver-bearing sulphides (Twelvetrees, 1900).

Wilson River–Murchison Dam–Tyndall Range

HENTY

The Henty deposit is the most recent discovery in the Mt Read Volcanics. It is approaching development, with extensive drilling and a decline in place (Roberts and Fleming, 1990). The development proposal (1990) gives an indicated resource of 45 000 t at 13 g/t, and an inferred resource of 259 000 t at 59 g/t (including a zone of 186 000 t at 78 g/t), making this the richest gold resource in Tasmania (Table 2). Most of the following data is extracted from McNeill and Corbett (1992).

The deposit lies immediately adjacent the Henty Fault Zone (fig. 6), a major NNE-trending structure separating the Central Volcanics Sequence in the west from the overturned Tyndall Group to the east. This shear zone dips about 65°W, may be hundreds of metres wide, and has undergone at least five phases of movement from the Early Palaeozoic to the Tertiary (Berry, 1989). The deposit lies on the footwall of, and is partly truncated by, the fault (fig. 7), in probable Tyndall Group volcaniclasic rocks which have been highly altered to cherty quartz-sericite-pyrite. Massive lenses of pyrite ± base metals and minor gold, for which the area was first prospected, occur sporadically, as do very gold-rich quartz shoots. The zone of mineralisation is relatively continuous, but grades are erratic. Pemberton and Corbett (this volume) suggests that the mineralisation lies at a chrono-stratigraphically equivalent level to the major VHMS deposits in Tasmania, such as the somewhat similar mineralised sequences at Comstock and Mt Lyell.

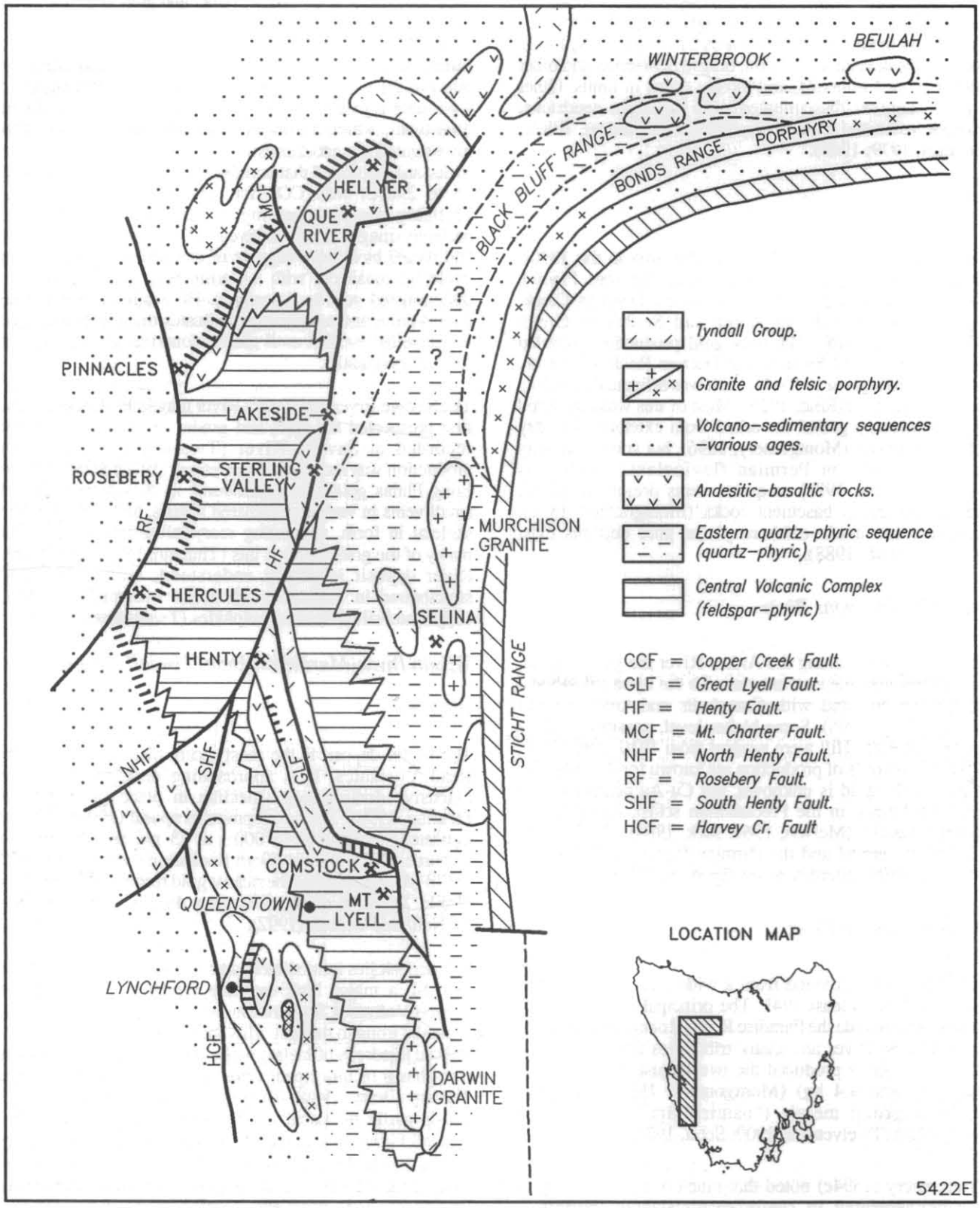


Figure 6

Location of western Tasmanian volcanic-hosted massive sulphide and related deposits

5 cm

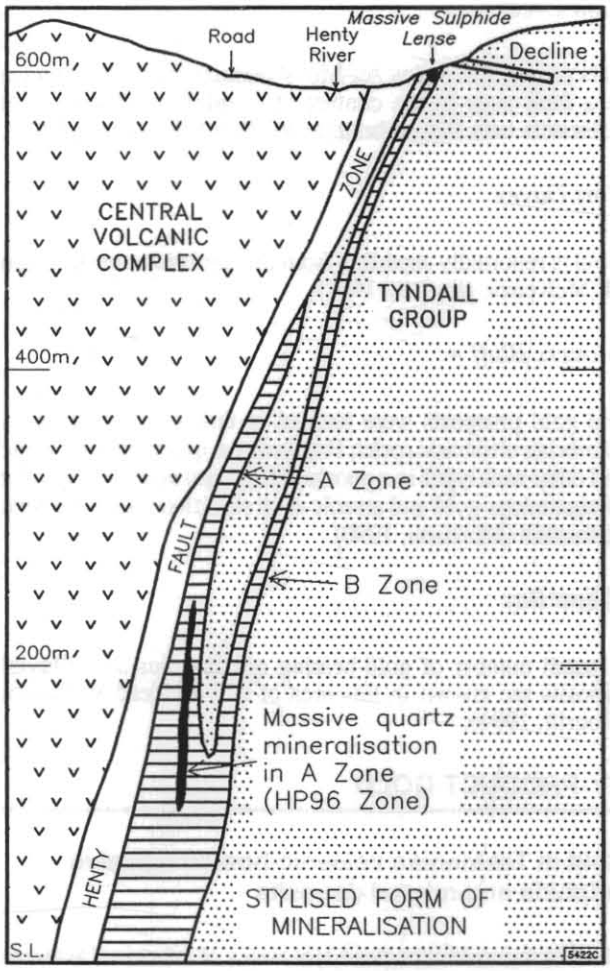


Figure 7

Generalised cross-section of the Henty prospect

Very little published information is available in regard to the style of the mineralisation (i.e. Cambrian VMS vs Devonian vein type), however the gravity modelling of Leaman and Richardson (1989) suggests that the granite is located at a depth of about 8 km, and the lead isotope results are of Cambrian signatures (Gulson and Porritt, 1987). This indicates that Cambrian ore-forming solutions may have had the major role in the formation of this deposit, and that several styles of mineralisation may exist along the fault. The genesis of the deposit has been studied by J. Taheri and G. R. Green (Department of Mines), but the results are presently confidential.

LAKESIDE AND STERLING VALLEY TIN–GOLD DEPOSITS

The polymetallic Lakeside and Sterling Valley Tin deposits are characterised by the metallogenetically rare Sn-Au association, and lie alongside the Henty Fault in western Tasmania (fig. 6). The Lakeside deposit lies on the eastern side of the fault and is hosted by the Farrell Slates (Tyndall Group), whereas the Sterling Valley deposit is hosted by the Mt Black Volcanics (part of the Central Volcanic Sequence) on the western side of the fault. The mineralisation is of vein style, and is associated with the crest of the subsurface granite ridge extending from the Granite Tor to the Pine Hill granites and possibly as far west as the Heemskirk granite (Taheri and Green, 1990; Leaman and Richardson, 1989). The Lakeside deposit is considered to be sub-economic, with a resource of 0.75 Mt at 2.1 g/t Au.

The Sterling Valley Prospect contains less gold, but is characterised by higher As and pyrrhotite. Based on metal zoning, mineralogical data, and Berry's (1989) reconstruction of the deformation history of the Henty Fault zone, Taheri and Green (1990) suggested that the two deposits were initially juxtaposed, with the Sterling Valley deposit being the deeper section of the mineralisation. The deposits were later displaced relative to one another by faulting. Based on this model, potential for further discoveries should exist on both sides of the Henty Fault (Taheri and Green, 1990).

ALLUVIAL GOLD

Widespread workings for alluvial gold were present in the Pleistocene fluvioglacial deposits along the Pieman River last century. A deep lead in the nearby Ring River was also worked extensively, and other minor alluvial gold occurrences produced osmiridium and tin, while gold was a by-product of osmiridium mining in some placers (Bottrill, 1991). No production records are known, although the Ring River field supported 300–400 men in 1891 (Blisset, 1962).

Some of the alluvial gold in this area was derived from the ultrabasic rocks, particularly where gold was subordinate to osmiridium, but most was derived from the gold-enriched base metal deposits in the area. These include the Mt Read, Hercules, Rosebery and Pinnacles deposits (see below). Reid (1918) noted the gold in Strong Creek to be very fine grained, reflecting the nature of the source gold in the nearby Pinnacles deposits.

Lyell–Darwin

This district produced more than 162 kg of gold, excluding that from the Mt Lyell and other copper mines, which were first worked as gold mines. Many of the mines appear to be spatially related to fault zones, particularly at contacts between the Mount Read Volcanics and Denison Group conglomerate (Fitzgerald and Pease, 1985). One of these faults is the Harvey Creek Fault, and where it intersects Gordon Limestone near Lynchford (fig. 6) some zones of anomalous gold, arsenic and antimony are considered prospective for Carlin-style gold deposits (Tasmanian Chamber of Mines, 1992). Other styles of gold mineralisation in the area include quartz stockwork and pyritic schist in the Mount Read Volcanics (Fitzgerald and Pease, 1985).

The district contains numerous areas of workings for alluvial gold, from south of Mt Darwin to north of Queenstown (Bottrill, 1991). There was 837 kg of alluvial gold production recorded from the West Coast between 1866 and 1890, probably predominantly from the Queenstown area but including the Pieman and other areas. The alluvium worked was probably all Quaternary, and included Pleistocene fluvioglacial deposits. Henderson (1938) thought that some gold was reworked from high-level Tertiary gravel in the Darwin plateau, but bedrock sources for many deposits are still uncertain (Fitzgerald and Pease, 1985). A large but low-grade gold resource is present in the King River Delta, reworked from the Mount Lyell mine tailings (Berkman, 1987).

5 cm

Jane River (Warnes Lookout)

Gold was discovered in this area in about 1894, and Bacon (1989) estimated between 60 and 250 kg for the total gold production. Gold is enriched where Cainozoic gravel has been reworked (Jennings, 1974), particularly where coarse gravel overlies bedrock (Bacon, 1989). The gold is rather angular to crystalline and porous (as at Lisle), rarely attached to quartz, and is commonly mercury-rich (up to 14 wt.%: Bottrill, 1989). It is associated with rutile, zircon, chromite, pyrite and, more rarely with cinnabar, xenotime, monazite and gersdorffite (Finucane and Blake, 1933*b*; Bottrill, 1989). The source is uncertain, but suggestions include local quartz veins (Finucane and Blake, 1933*b*), limonitic beds (Blake, 1936), and Precambrian to Palaeozoic bedrock (Turner, 1990). Jennings (1974) and Bottrill (1989) consider that most of the gold was formed *in situ*, but the mercury content suggests epigenetic mineralisation and the deposit is still quite enigmatic.

Cygnet

Gold was discovered at Cygnet in 1877, and the district produced about 100 kg of gold by 1902, mostly from Quaternary placers (Twelvetrees, 1908*b*). The gold was derived from mineralised breccia, veins and contact zones of Cretaceous alkaline intrusive rocks in the Permian sediments, (Twelvetrees, 1908*b*; Leaman and Naqvi, 1967). The intrusives range in composition from monzonite to syenite and lamprophyre, and intrude calcareous and carbonaceous mudstone, tillite and limestone of the Parmeener Supergroup. There is a pronounced domal structure associated with the intrusives, which crop out sporadically over an area of about 20 × 30 kilometres. Some recent gold exploration has focussed on the potential for "Carlin style" and porphyry-hosted gold deposits (Jones, 1988). Limited drilling and geochemistry failed to delineate a viable gold resource, but indicated that gold and base metals are enriched in shear zones. The best intersection was 17 m at 1 g/t, but grades of up to 22 g/t occur (Jones, 1988). Lamprophyric intrusive rocks also occur in several other parts of western and northern Tasmania, and some may have a spatial association with gold, but the associations have not been investigated (see sections on Back Creek and Lisle).

Miscellaneous

Furneaux Islands

Gold-bearing veins are found in Mathinna Beds on Cape Barren and Flinders Islands, similar to those on mainland Tasmania (Blake, 1947). There are also isolated occurrences of lode and alluvial gold on King Island.

Little Den (Lake River)

There is an isolated occurrence of alluvial gold in this area, derived from quartz veins in an inlier of Cambrian volcanic rocks (Nye and Blake, 1933; Threader, 1963).

Ten Mile Creek

This prospect shows the presence of gold in hematitic stockwork in Bonds Range Porphyry (Pemberton *et al.*, 1991).

Anio Creek

This prospect contains Au-Mo-V anomalous pyritic breccia in a fault zone at the contact of Cambrian volcanics and sediments with Precambrian rocks (Pemberton *et al.*, 1991).

Port Davey

Gold is reportedly shedding from Precambrian sandstone on Mt McKenzie (Bottrill, 1991).

Glovers Bluff

Old gold prospects were located in this area, which hosts Cambrian ultrabasic rocks, Precambrian quartzite, limestone and other rock types in a poorly understood area. A large area of anomalous gold and arsenic over silicified rocks has been delineated (Morrison, 1990).

Elliott Bay

A small number of gold-bearing quartz veins and alluvial deposits are known in this area of Mount Read Volcanics (Bottrill, 1991).

BY-PRODUCT GOLD

Gold in Tasmanian volcanic-hosted massive sulphide and related deposits

The Cambrian Mount Read Volcanics of western Tasmania host a number of world-class volcanic-hosted massive sulphide (VHMS) deposits (fig. 6). Although mined primarily for their base metals, the deposits contain high levels of by-product gold (Table 2). The Rosebery, Mt Lyell and Hellyer deposits each contain in excess of 40 t of gold, which is a respectable resource even for a gold-only deposit. The Rosebery deposit contained the largest pre-mining gold resource of any Tasmanian mineral deposit, including the Tasmania Mine at Beaconsfield.

The distribution and occurrence of gold in these deposits is quite variable, and has been the subject of considerable research over the past ten years. This section summarises the results of this research with respect to the distribution, mineralogy and metallurgical characteristics of gold for each deposit. Theoretical discussions about transport and depositional mechanisms for gold in VHMS systems are not discussed; the reader is referred to Huston and Large (1987, 1989), Large *et al.* (1989), and Hannington and Scott (1989) for such discussions.

Rosebery

The Rosebery deposit is the largest VHMS deposit in western Tasmania, with a pre-mining resource of nearly 20 million tonnes (Table 2). The deposit occurs in interbedded siltstone and tuffaceous sandstone ("host rock") between an underlying mass-flow unit of sericite-pyrite altered, feldspar-bearing pumice-rich volcaniclastic breccia and an overlying polymict mass-flow unit of quartz and feldspar-bearing, crystal-lithic rich volcaniclastic sandstone and breccia (McPhie and Allen, 1992). Black slate occurs in a discontinuous lens at the contact between the host rocks and the overlying volcaniclastic unit.

14/23

Table 2

Pre-mining gold resources of western Tasmanian volcanic-hosted massive sulphide and related mineral deposits (data from Lees *et al.*, 1990; Farquhar, 1983; Hills, 1990; McArthur and Dronseika, 1990; McNeil and Corbett, 1992). Metallurgical recovery data is for mid-1991 courtesy of the relevant companies. The Tasmania Mine is added for comparison (Hicks and Sheppy, 1990).

Deposit	Tonnage (m.t.)	Gold grade (g/t)	Contained gold (tonnes)	Metallurgical recovery (%)
Rosebery	19.4	2.9	56	85
Pyrrhotite-pyrite body	0.075	9.0	0.68	
Mt Lyell				
Massive pyrite-chalcopyrite	5.6	2.0	11	
Disseminated pyrite chalcopyrite	109.71	0.36	39	73
Chalcopyrite-bornite mineralisation	6.16	0.46	2.8	
Hellyer	16.9	2.5	42	14-21
Que River	3.3	3.3	11	
Henty	0.26	59.0	15.9	
Hercules	2.57	2.7	6.9	
South Hercules	0.70	2.7	1.9	
Tasmania Mine	1.8	24.1	43.4	

The ore occurs in a number of blanket-like lenses. Barite-rich lenses are commonly separated by several metres of host rock from the underlying barite-poor massive sulphide lenses. Small, massive pyrite-chalcopyrite pods occur at the base of the massive sulphide lenses, which are mostly composed of massive sphalerite-galena-pyrite (fig. 8; Brathwaite, 1972; Green *et al.*, 1981). The deposit has been moderately deformed and recrystallised.

The original Rosebery deposit contained over 56 tonnes of gold (Table 2). The distribution of gold at Rosebery was initially studied by Brathwaite (1969) and Green (1983), as part of larger studies on the genesis of the Rosebery orebody. The detailed distribution and mineralogy of gold at Rosebery has been studied by Huston and Large (1987, 1988) and more recently by Huston *et al.* (1992).

Gold is enriched in the upper part of massive sphalerite-galena-pyrite zones and in overlying baritic zones. Within these zones grades in excess of 3 g/t are common (fig. 8). High gold grades have a positive correlation with high zinc grades, but gold grades are generally low in the copper-rich bases of the massive sulphide lenses. As such, Rosebery is the type example of the zinc-gold association noted in many VHMS deposits (Huston and Large, 1989; Large *et al.*, 1989).

Electrum (gold-silver alloy of any composition for this contribution) is the dominant host of gold at Rosebery. Cyanidation tests of the mill feed indicate that 85% of gold occurs as electrum (Huston *et al.*, 1992). In massive sphalerite-galena-pyrite ores electrum occurs mostly as 0.5–60 μm (median size = 4.5 μm) grains in cracks within or along grain boundaries in pyrite. Minor associations of electrum in this ore type include galena, sphalerite, chalcopyrite and tetrahedrite. Electrum does not have a strong association with pyrite in the overlying baritic zones; rather it occurs with galena, tetrahedrite, sphalerite and chalcopyrite. Huston *et al.* (1992) ascribed these differences in occurrence to differing mechanisms of precipitation in the two zones, and inferred that the pre-deformation occurrence of gold in the massive sphalerite-galena-pyrite zone at Rosebery was in the pyrite lattice.

Mass balance calculations by Huston *et al.* (1992) indicate that Rosebery pyrite contains at most an average 0.2 ppm Au, a conclusion supported by pixeprobe analysis. Most gold not occurring as electrum at Rosebery occurs in auriferous arsenopyrite. Electron microprobe analyses indicate that arsenopyrite contains up 3000 ppm Au.

As recrystallisation of the Rosebery ores has expelled gold from the pyrite lattice to form electrum, and arsenopyrite is not a major repository of gold, metallurgical recoveries of gold are high in comparison to the nearby Hellyer deposit, which has not been as extensively recrystallised and has a high arsenopyrite content (Table 2).

The southern end of Rosebery has been partially replaced by zones of massive magnetite and massive pyrrhotite-pyrite associated with the emplacement of Devonian granitoids (Solomon *et al.*, 1987). Fluids exsolved from the granite dissolved lead and zinc from pre-existing Cambrian massive sulphide, but the pre-existing gold was reconcentrated to form a high-grade zone within the pyrrhotite-pyrite assemblage (Khin Zaw, 1991). A resource of 0.68 t of gold has been defined for the pyrite-pyrrhotite zone (Farquhar, 1983; Table 2).

Khin Zaw (1991) observed that electrum within the pyrrhotite-pyrite zone has the following occurrences:

(1) as inclusions in pyrite,

(2) along microfractures in pyrite,

(3) as inclusions in pyrrhotite,

(4) in chalcopyrite veins that cut chalcopyrite, and

(5) in association with chalcopyrite.

This electrum tends to be coarser grained than electrum elsewhere at Rosebery, with a total range of 0.5 to 160 μm and a median grain size of 20 μm (Khin Zaw, 1991).

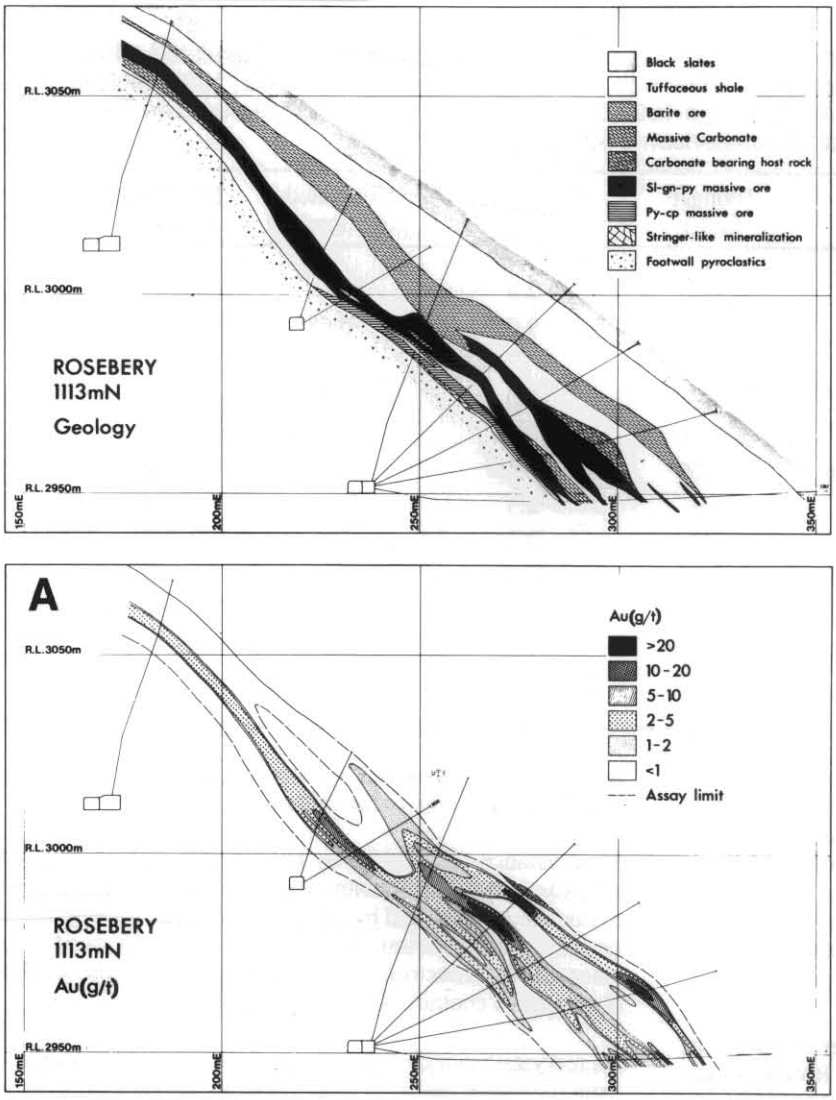


Figure 8

Cross-section from the north end of the Rosebery ore deposit showing the geology (upper) and gold distribution (lower) (after Huston and Large, 1988).

Mt Lyell

The Mt Lyell mineral field consists of twenty separate mineralised bodies in a 2 × 5 km area. Three styles of mineralisation are present: massive pyrite-chalcopyrite mineralisation; disseminated pyrite-chalcopyrite mineralisation; and chalcopyrite-bornite mineralisation (Walshe and Solomon, 1981; Hills, 1990). In total the ore field contained nearly 52 t of gold (Table 2). Although alluvial and gossan gold was recovered from the field during the early period of mining activity (Large *et al.*, 1990), this contribution only summarises the primary occurrence and distribution of gold.

The distribution and mineralogy of gold in the Mt Lyell field has been recently studied by Large *et al.* (1990), Bottrill and Duncan (1991), and Huston *et al.* (1992). The highest concentrations of gold occurred in massive pyrite-chalcopyrite lenses, with an average of 2.0 g/t. The disseminated pyrite-chalcopyrite and the chalcopyrite-bornite styles of mineralisation contain substantially lower grades of 0.35 and 0.46 g/t respectively (Table 2). Large *et al.* (1990) found that gold has a strong association with copper in both massive and disseminated pyrite-chalcopyrite mineralisation, whereas in chalcopyrite-bornite mineralisation gold grades are independent of copper values. The association of copper and gold in pyrite-chalcopyrite dominated mineralisation at Mt Lyell exemplifies a second major association of gold with copper in VHMS deposits (Huston and Large, 1989; Large *et al.*, 1989).

The dominant host of gold at Mt Lyell is electrum (78% of the mill feed based on cyanidation tests) with the following occurrences:

(1) grains included in pyrite;

(2) grains associated with chalcopyrite in fractured and brecciated pyrite grains;

(3) grains associated with galena, sphalerite, pyrite and/or chalcopyrite; and

(4) coarser grains associated with remobilised quartz veins (Edwards, 1939; Green, 1971; Large *et al.*, 1990; Bottrill and Duncan, 1991; Huston *et al.*, 1992).

Electrum grains in the remobilised quartz veins tend to be silver-rich, whereas electrum from all other occurrences tends to be silver-poor.

Although electrum is the dominant host of gold, telluride minerals and pyrite also host gold at Mt Lyell. Arsenopyrite is unlikely to be a significant host, as it is extremely uncommon in the ores. Bottrill and Duncan (1991) recorded the presence of petzite and calaverite is copper concentrates from Mt Lyell. The maximum possible average level of gold in Mt Lyell pyrite is 0.62 ppm, which would account for 12% of the gold in the mill feed (Huston *et al.*, 1992).

Hellyer

The Hellyer deposit consists of an elongate, bulbous massive sulphide lens at the contact between underlying massive andesite, and overlying pillow basalt (fig. 9). A thin, discontinuous lens of volcaniclastic rocks drapes the sulphide lens and andesite at this contact (McArthur and Dronseika, 1990). The sulphide lens occurs above a well-defined, sub-vertical stringer in altered andesite (Gemmell and Large, 1992).

Hellyer occurs along the crest of a NNE-plunging open anticline, and the sulphide lens has complex internal folding. The contacts of the orebody indicate the presence of open anticlines with tight to locally isoclinal synclines. The deposit has been bisected by the Jack Fault (fig. 9), which has moved the east block 150 m north and 30 m up (McArthur and Dronseika, 1990). Despite this internal folding, much of the massive sulphide retains primary, undeformed textures;

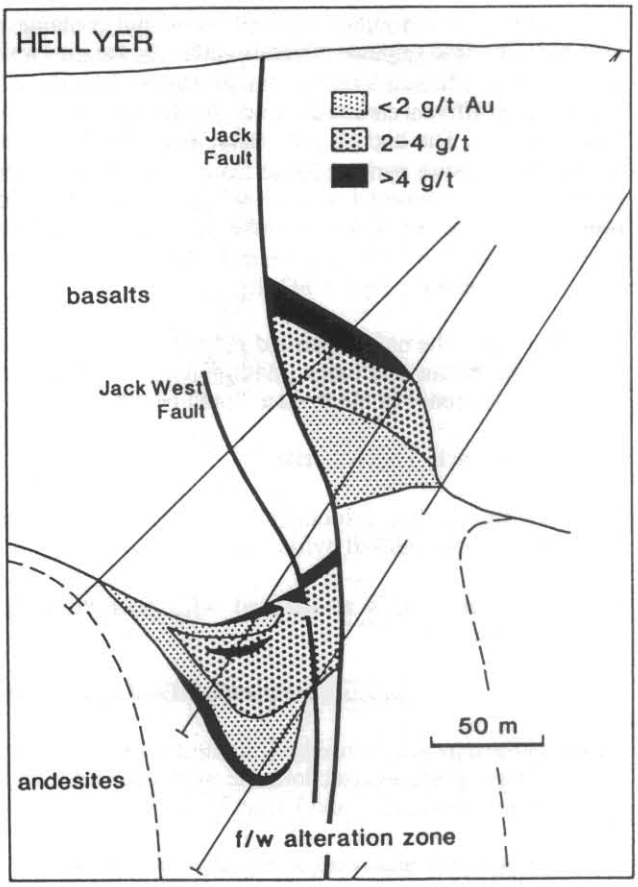


Figure 9

Cross-section of the Hellyer deposit showing gold distribution (after Large *et al.*, 1990)

recrystallisation is most strongly developed in the tight internal folds (G. McArthur, pers. comm., 1992).

The spatial distribution of gold has been described in detail by Large *et al.* (1989, 1990) and by McArthur and Dronseika (1990). Like Rosebery, gold is enriched in the upper portions of the lens, but gold is also enriched along the lower contact of the structural keel in the western half of the lens (fig. 9). In detail, gold values increase from ~1.6 g/t in the core to ~3.0 g/t at the top of the massive sulphide zone. The baritic cap contains ~2.5 g/t gold, and the glassy silica pyrite (GSP) cap contains ~3.2 g/t gold (fig. 10). The baritic and GSP units overlie the massive sulphide lens and are complexly interfingered (Sharpe, 1991). The GSP unit consists of colloform pyrite in a gray chert with finely disseminated pyrite. Small quantities of a similar gold-rich unit also occur at Rosebery (Huston and Large, 1988).

Detailed studies on the mineralogical hosts to gold at Hellyer have been undertaken by Ramsden *et al.* (1990) and Sharpe (1991). Electrum grains are uncommon in Hellyer ores, with only a few grains being observed by McArthur (pers. comm., 1986), Sharpe (1991) and Huston *et al.* (1992). Sharpe (1991), who observed the greatest number of electrum grains, noted that electrum occurs mostly with pyrite, in a similar association to that at Rosebery. Ramsden *et al.* (1990) suggested that electrum might be more common in barite-rich zones, based on the results of cyanidation tests.

Ramsden *et al.* (1990) inferred that 90% of Hellyer gold occurs either in auriferous arsenopyrite or auriferous pyrite. This accounts for the low gold recoveries at Hellyer (Table 2). Electron microprobe analyses by Ramsden *et al.* (1990) and by Sharpe (1991) reported gold values up to 1100 ppm in arsenopyrite and up to 4500 ppm in pyrite. Examination of Sharpe's (1991) results indicates that the highest gold values in pyrite are associated with framboidal and acicular habits, but not euhedral habits. The predominance of gold in arsenopyrite and pyrite in Hellyer ores results from the unusually high concentration of the former (2%; McArthur and Dronseika, 1990) and by the lack of metamorphic recrystallisation of the latter.

Que River

The Que River deposit occurs in the core of a tight W-shaped synclinorium at the contact between underlying quartz-sericite altered andesitic volcaniclastic rocks and overlying massive unaltered dacite (fig. 11). A carbonate-fuchsite altered polymict volcanic breccia stratigraphically overlies the massive sulphide lens (Large *et al.*, 1988). The Que River deposit has the highest overall gold grade of zinc-lead-rich Tasmanian VHMS deposits, which places it among the richest gold-bearing VHMS deposits in the world.

The complex folding present at Que River makes interpretation of the distribution of gold in the ores difficult. The highest gold grades occur along the two synclinal axes in the W-shaped synclinorium, which indicates that the gold was enriched along the top of the original massive sulphide lens in a similar manner to the Rosebery deposit (Large *et al.*, 1988). Large *et al.* (1988) reported an exponential increase of gold grades with zinc grades.

An unusual characteristic of the Que River deposit is the presence of the so-called 'precious metal zone', a zone in the footwall stringer zone enriched in gold (0.1–10 g/t) and silver but with relatively low concentrations of zinc, lead and silver (section 7725 mN, fig. 11; McGoldrick and Large, 1992). The Que River precious metal zone has a cross-sectional area of 50 × 200 m and is associated with a coarse-grained epiclastic unit along the northern edge of the footwall alteration zone (McGoldrick and Large, 1992). Although the precious metal zone was not economic to mine, it represents a new exploration target in the immediate environment in which VHMS deposits form.

The occurrence of gold in the Que River deposits has been discussed by Large *et al.* (1990) and Huston *et al.* (1992). As at Rosebery there is a close association of electrum with pyrite. The finest grained electrum (<10 μm) occurs as intergranular grains in pyrite; grains with an intermediate grain size (>10 μm) occur along the grain boundaries between pyrite and other sulphide minerals; and the coarsest grains (10–400 μm) occur with galena and sphalerite. As at Rosebery, auriferous arsenopyrite and/or possibly auriferous pyrite probably account for a significant portion of the gold. As Que River ore was processed in the Rosebery mill, no estimates can be made for Que River gold recovery.

Hercules and South Hercules

The Hercules deposit consists of numerous small lenses of massive sulphide within a host rock consisting of siltstone and tuffaceous sandstone. The overall sequence is similar to the Rosebery deposit, with an altered underlying mass-flow unit of pumice-rich volcaniclastic breccia and an overlying quartz and feldspar-bearing, crystal-lithic-rich volcaniclastic

sandstone and breccia (Lees *et al.*, 1990; McPhie and Allen, 1992). As at Rosebery, a lens of black slate occurs at the top of the host sedimentary package. The South Hercules deposit occurs one kilometre south of the Hercules deposit in a similar stratigraphic package (Khin Zaw and Large, 1992).

The rocks containing the deposits have been folded into north-trending open folds with steep east-dipping axial planes. The ore lenses have been moderately deformed and rotated into the cleavage. Maximum metamorphic grade was lower greenschist (Lees *et al.*, 1990; Khin Zaw and Large, 1992).

Studies of the J(K)-P lens at Hercules have been undertaken by Khin Zaw (1991), who found that the highest gold values mainly occurred in the zinc-rich upper portion of the lens. Khin Zaw (1991) also reported a minor association of gold in copper-rich zones (>4%). Electrum is the only confirmed gold-bearing mineral, and it has two occurrences in the J(K)-P lens:

(1) coarse grains associated with galena and sphalerite in the cores of recrystallised pyrite grains, and

(2) very coarse, visible grains associated with fluorite (Khin Zaw, 1991).

The South Hercules differs from other Tasmanian VHMS deposits in that it contains high grades of gold (2.7 g/t) and silver (147 g/t), but low grades of zinc, lead and copper (total base metal = 5.5%; Khin Zaw and Large, 1992). The deposit contains thin lenses of semi-massive sphalerite-galena ± pyrite which are surrounded by a siliceous unit containing stringery zinc-lead sulphide mineralisation. The hangingwall to these zones contains lenses of massive pyrite ± barite and a number of different carbonate zones (Khin Zaw and Large, 1992; fig. 12). The highest gold (and silver) values occur within the massive pyrite ± barite lenses and in the upper parts of the stringery siliceous unit. Patchy gold mineralisation occurs in the semi-massive sphalerite-galena ± pyrite lenses, but carbonate-bearing units are devoid of gold (Khin Zaw and Large, 1992; fig. 12).

As at Hercules, the only identified gold-bearing mineral is electrum. Khin Zaw and Large (1992) reported four general modes of occurrence of electrum at South Hercules:

(1) 5–40 μm inclusions in pyrite,

(2) 5–70 μm grains associated with galena in cracks between recrystallised pyrite grains,

(3) 3–200 μm grains associated with recrystallised sphalerite, and

(4) 5–20 μm grains associated with remobilised tetrahedrite.

Arsenopyrite may also be a significant host to gold, as many of the highest grade intersections are associated with high arsenic grades (Khin Zaw and Large, 1992).

Other important sources of by-product gold

Round Mountain, near Cethana, is a Pb-Ag-Bi vein system grading about 0.5 g/t Au, and which produced about 90 kg of gold. Many other deposits in the Cethana area were auriferous, including greisen W-Sn-Mo-Bi-Au veins, disseminated Bi-W-Ag-Au skarn, and Cu-Au stockworks. The Mt Ramsay Bi-W bearing skarn carried significant gold. At Mt Horror, near Scottsdale, tungsten-arsenic rich veins in metamorphic aureoles carry high gold values. Small amounts of gold were apparently produced in some tin mines in the Waratah and Rossarden areas. The Scamander mineral field carried gold in several of the base metal veins (Groves, 1972), as did some of the copper mines in the Dial Range. In the Mount Read Volcanics and the Dundas mining field, gold is associated with many of the base metal veins and some tin veins (e.g. Sterling Valley, described above).

The alluvial tin deposits of northeastern Tasmania also produced large amounts of gold (about 0.3 t), and gold was an important by-product in most osmiridium fields in western Tasmania (probably derived, in part, from the ultrabasic rocks; Bottrill, 1991).

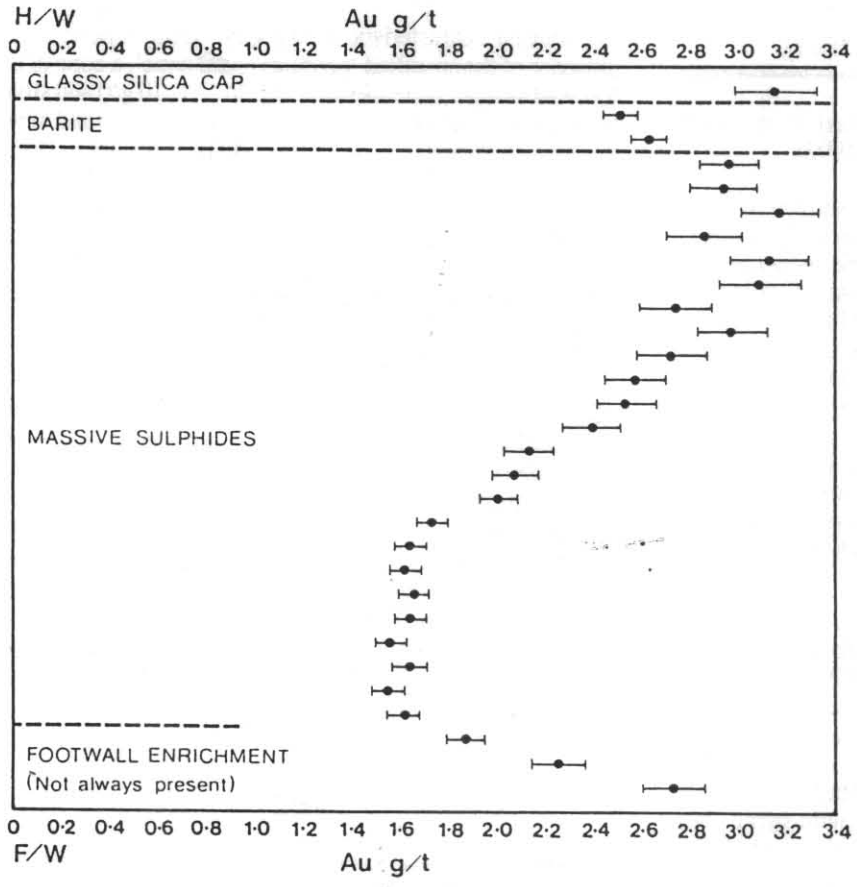


Figure 10

Generalised distribution of gold in the Hellyer deposit (after Large *et al.*, 1990)

5 cm

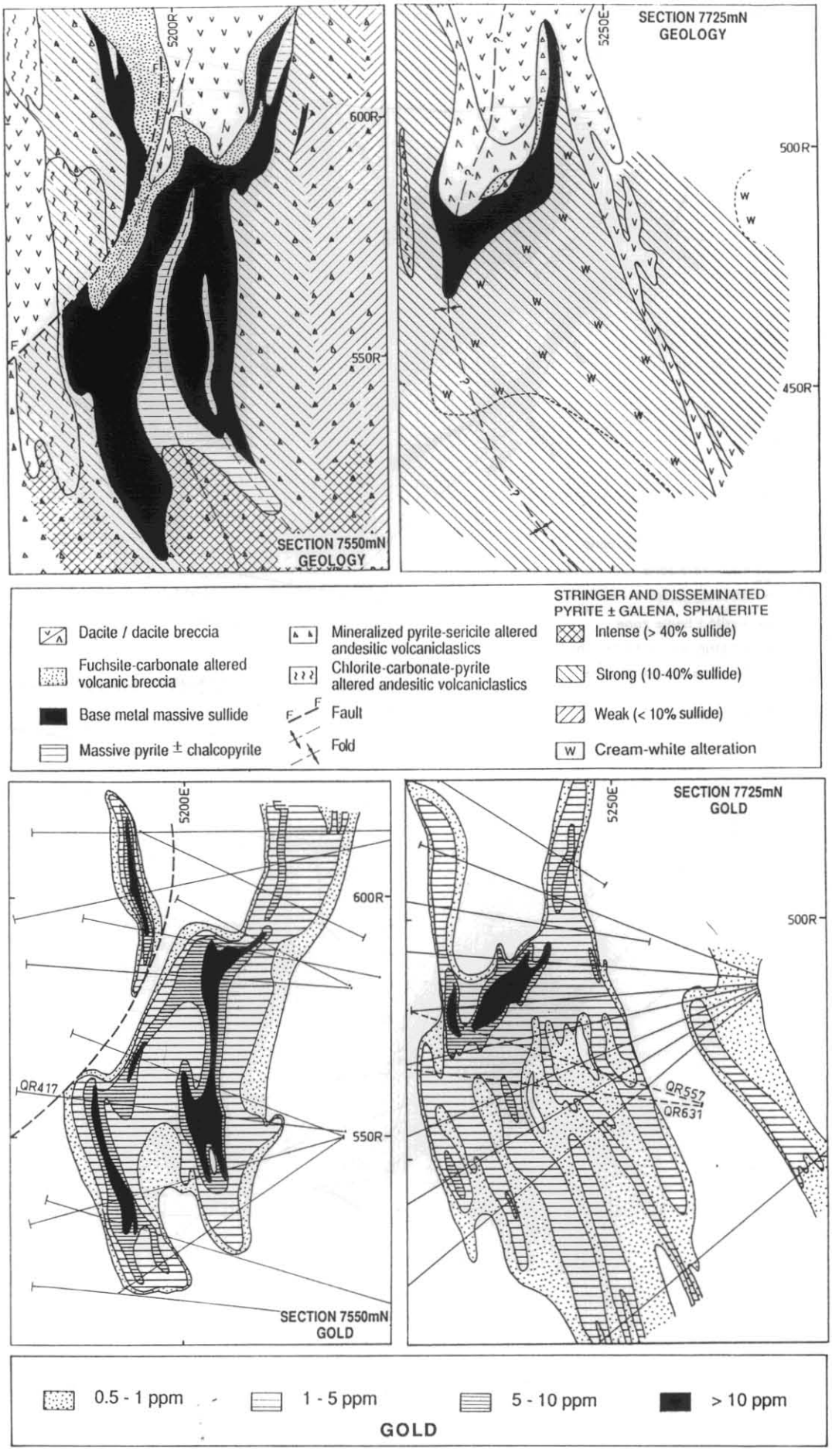


Figure 11

Cross-sections showing the geology (upper) and gold distribution (lower) in the Que River deposit (after McGoldrick and Large, 1992).

5 cm

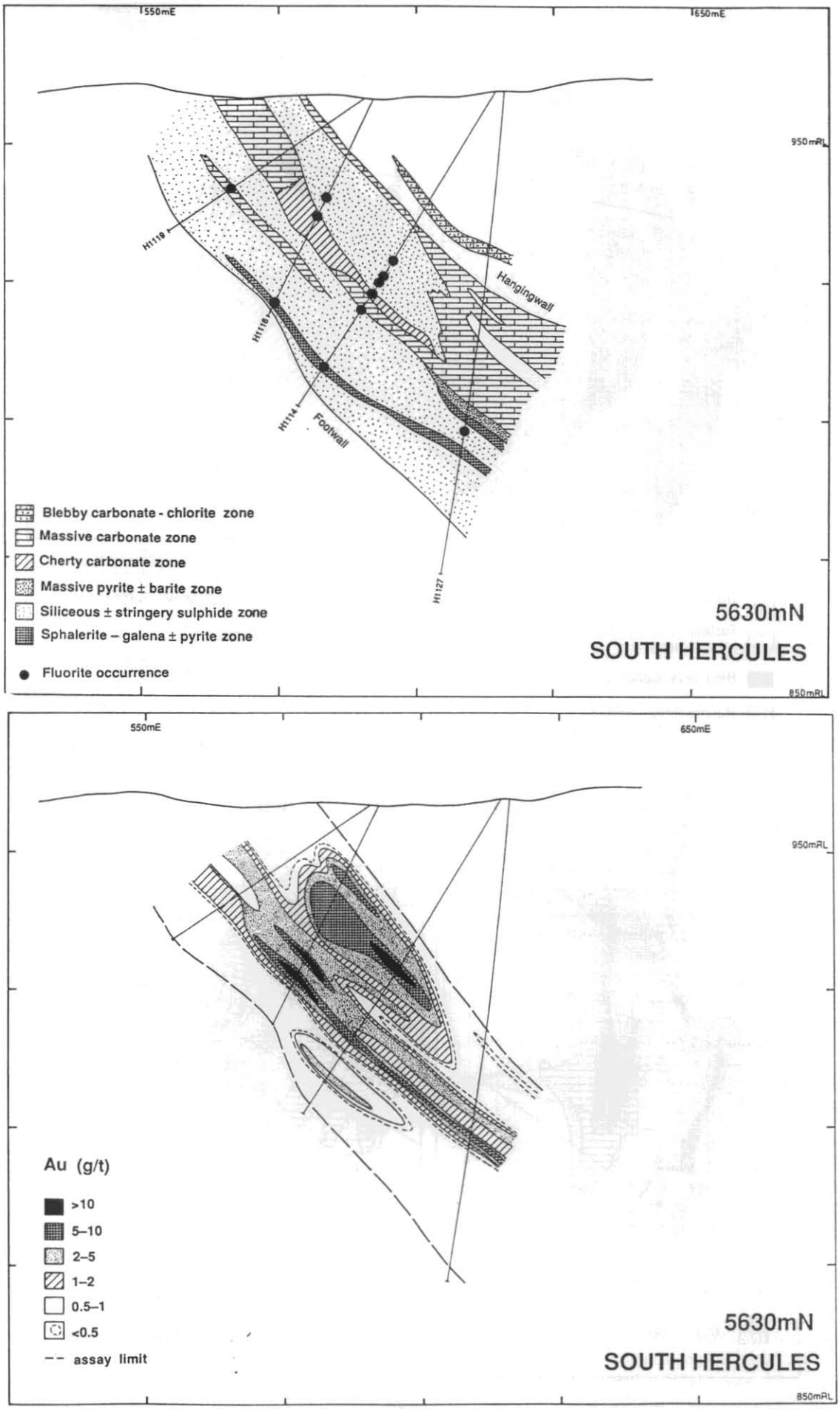


Figure 12. Cross-section showing the geology (upper) and gold distribution (lower) in the South Hercules deposit (after Khin Zaw and Large, 1992)

SUMMARY AND POTENTIAL EXPLORATION TARGETS

The major styles of gold mineralisation, organised by age, are:

1. Precambrian(?), stratabound gold in the Bowry Formation around Savage River and Corinna.

2. Cambrian VHMS and related sulphide deposits in the Mount Read Volcanics (economically the most important style).

3a. Devonian turbidite-hosted mesothermal quartz vein deposits (the most numerous deposit style).

3b. Devonian granite-related quartz and greisen veins in various rock types, usually fault-related and often subordinate to other commodities, including Pb, As, W, Bi and Sn.

3c. Devonian granite-related, disseminated deposits in skarns, with Bi and W.

4. Permo-Triassic placers, as in the Wynyard and Mangana areas.

5. Cygnet-style disseminated gold mineralisation, associated with Cretaceous alkaline intrusives in calcareous, carbonaceous Permo-Carboniferous sequences.

6. Tertiary to Recent placers (the most widely distributed style).

The principal style of gold mineralisation in the northeastern area is turbidite-hosted, mesothermal, quartz-sulphide-gold veins, very similar to those Phanerozoic deposits of central Victoria, Nova Scotia, Alaska, Wales and many other areas (Nesbitt, 1991). Early gold mining focussed on the rich but relatively small veins, while more modern exploration and mining has focussed on open-cuttable resources, such as disseminated, stockwork and multiple vein style deposits. Two medium to large gold mines of this mesothermal vein type have operated as underground workings in Tasmania; the Tasmania Mine at Beaconsfield, and the New Golden Gate Mine at Mathinna. There appears to be great potential for locating similar deposits but, unfortunately, most recent exploration has been rather superficial. Few lode deposits have been drilled, and few systematic geological, geochemical or geophysical surveys have been conducted over the mines, on either a regional or detailed scale. Many of the gold deposits can be related to major lineaments and crustal-scale structures, e.g. the Mangana–Waterhouse Belt, the Tamar Fracture Zone, the Arthur Metamorphic Belt, and the Henty Fault Zone. More work needs to be done to define such controlling structures.

Tasmanian VHMS deposits are gold enriched by world standards. In all deposits except Mt Lyell, Henty and South Hercules, the gold enrichment is associated with zinc and/or barite enrichment towards the top of the respective massive sulphide lenses. In the Mt Lyell deposits the gold has a strong positive correlation with copper, whereas the gold-rich parts of the South Hercules system contain relatively low base metal grades. These deposits include three new styles of VHMS-related gold mineralisation which have been recognised in the last ten years in Tasmania:

(1) Henty-style high-grade Au mineralisation,

(2) Que River-style precious metal zone style mineralisation in alteration zones below massive sulphide lenses, and

(3) South Hercules-style gold-silver mineralisation associated with minor base metal.

Gold-bearing stockworks and sheeted veins occur in sediments and volcanic rocks in some areas, and are highly prospective because of their potential for open-cut operations. There is a low prospectivity for economic disseminated gold in the Mathinna Beds; disseminated gold in turbiditic greywacke has been described in very similar settings, with quartz-gold veins, in the Meguma area, Nova Scotia, but is very low in grade (Crocket, *et al.*, 1986). There is a greater potential for disseminated gold (e.g. in granite aureoles), porphyry gold in high level intrusives, and epithermal deposits.

There is also significant potential for more placer gold deposits, including palaeoplacers in the Permian conglomerates, the probable source for most of the gold in Majors Gully (Twelvetrees, 1907; Finucane, 1932).

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Tasmania's development environment

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The Tasmanian Development Authority (TDA) is working with other Government agencies to refine the approval process for major developments in Tasmania, including mining and ore-processing ventures. While considerable advances have been made in developing and articulating a suitable procedure, this achievement is untested because no major project has yet passed through the full process; to final approval or rejection.

Tasmania's potential in the mining and mineral-processing area is exciting and presents us with a planning challenge. The TDA is concerned to remove, as far as possible, the causes of community disquiet about the siting of major resource-processing industries. We are also anxious to avoid the possibility of future residential encroachment on to the fringes of major industry sites, a process that has been the cause of countless disputes around the world in the past decade. We believe the creation of specific zones for heavy industry, including buffer zones to separate industry from future residential development, is essential to good planning. To this end, we have worked with local government authorities to create heavy industry zones at both Bell Bay, northeast of Launceston, and Port Latta on the North West Coast.

Tasmania, more than any other Australian State, has been a testing ground in recent years for systems of reaching decisions on the approval or rejection of major projects. The venture that generated the most heated public debate was North Broken Hill's proposed Bleached Eucalypt Kraft Pulp Mill at Wesley Vale. Many lessons were learned from the Wesley Vale experience. However, in the context of future mining and ore-processing projects, Wesley Vale should be regarded as merely one of the steps in the evolution of approval processes in this State.

Other recent projects have also played an important role as test beds for particular elements of the emerging process. Significant contributions (in chronological order) have come from:

- The Pioneer/Pechiney silicon smelter at Electrona in the mid-1980s;
- Renison Goldfields Consolidated's Mt Lyell mine continuation at Queenstown, a process that stretches back to early 1985;
- Aberfoyle's lead/zinc mine at Hellyer in 1986–87;
- NBH's Wesley Vale BEK pulp mill, from September 1987 to March 1989;
- Savage River Mines magnetite mine reconstruction in 1989–90;
- ANM's light-weight coated paper mill in 1989–90;
- APPM's proposed new northern Tasmanian pulp mill (December 1990 to the present);
- Shinwa Corporation's proposal last year for a tourism resort at St Albans Bay near Bridport.

Outcomes varied, but the three mining projects on the list, Mt Lyell, Savage River and Hellyer, all came to fruition and are still operating.

Through this evolutionary decade, the challenge for Government has been to design processes which achieve a reasonable balance between the sometimes competing requirements of a project proponent, on one side, and lobby groups, most notably the environmental movement, and local communities on the other side.

The Tasmanian process is designed to achieve this and to involve the Commonwealth in such a way that its approvals are accommodated within a unified process, the centrepiece of which is the parallel development and public scrutiny of an Environmental Impact Study and a Social, Economic and Community Impact Statement.

The requirements of proponents are met to a very large degree, and there are no major deficiencies from their perspective. At the same time, the legitimate needs of the community for input to and participation in the approval process are catered for fully.

The proponents of mining or ore-processing projects should have confidence in the adequacy of this painfully developed Tasmanian approach.

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Platinium Group Elements and their host rocks in Tasmania: A summary review

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INTRODUCTION

There are four factors in favour of exploring for Platinum Group Elements (PGE's) in Tasmania:

- PGE's occur in the State, and the areas of occurrence are known;
- Access to land for exploration is dominantly free of restriction;
- Industrial demands are expanding as new products are found in which PGE's are used;
- With changing political and economic situations is South Africa and Russia, traditional supplies are no longer certain.

At present, Platinum Group Elements are currently being used in the petrochemical and automobile industries, in electronics and communications, for medical and dental purposes, in the space industry, in fuel cells, as well as for jewellery and investment bars and coins.

In occurrence and association PGE's can be divided into two groups: IPGE, being iridium (Ir), osmium (Os) and ruthenium (Ru); and PPGE, being platinum (Pt), palladium (Pd) and rhodium (Rh). Gold can be associated with both of these groups.

Platinum Group Minerals (PGM's) mined in Tasmania in the past were commonly known as 'osmiridium', an alloy of Os and Ir with minor amounts of other platinoids, especially Ru. However, when detailed analyses were obtained it was found that a compositional range existed, and the alloys ranged from being dominantly iridosmine to rutheniridosmine with only minor true osmiridium (Ford, 1981; Cabri and Harris, 1975).

Recent work has shown the Tasmanian ultramafic host rocks contain not only Ir-Os-Ru alloys but also Ru-(Ir-Os) sulphide and platinum, as native Pt, as alloys with other PGE's, or in complexes as sulphide minerals (Brown *et al.*, 1988; Creasy, 1990; Peck, 1990; Peck and Keays, 1990; Peck *et al.*, 1992).

In the late 19th century PGM's were obtained as a by-product of gold mining from alluvial and eluvial deposits associated with the ultramafic-mafic complexes. Until c.1900, when a market for osmium and iridium developed, the grains were considered a nuisance and were discarded.

Between 1910 and the end of 1980 approximately 965 kg of 'osmiridium' was recorded as being been mined from western Tasmania. Alluvial mining between 1910 and 1925 on the Heazlewood–Mt Stewart–Wilson River complexes (no. 3–5, fig. 1) accounted for ~420 kg of this total. In 1925 the Adamsfield deposits (no. 14, fig. 1) were discovered. Between 1925 and 1939 ~490 kg of 'osmiridium', including ~430 kg from Adamsfield, were registered. The remaining 55 kg were registered between 1940 and 1980.

The 'osmiridium' alloys were mined from placer deposits spatially associated with olivine-rich ultramafic rocks. Over the last few years, studies of the various areas of ultramafic rocks in Tasmania have shown that there exists a potential for 'hard rock' sources of IPGE's, associated with these high magnesian, olivine-rich ultramafic rocks, as well as a potential for deposits of PPGE's, associated with zones of chromite schlieren in pyroxene-rich ultramafic rocks (Brown *et al.*, 1988; Carthew, 1989*a, b*; Peck, 1990; Peck and Keays, 1990).

During the late 1940s, exploration for copper-nickel mineralisation in the Cuni area (2 km southwest of Serpentine Hill — no. 7, fig. 1) revealed platinum and palladium in a medium to fine-grained association of magnetite, pyrite, pyrrhotite, pentlandite and chalcopyrite associated with gabbroic rocks.

Relevant land use and access issues, based on the Department of Mines *Mineral Exploration Code of Practice* (Bacon, 1991) are discussed in an appendix to this paper.

KNOWN OCCURRENCE OF PGE'S AND ASSOCIATED MINERALISATON IN TASMANIA

Of the fifteen separate areas of ultramafic rocks which occur in Tasmania, PGE's have been obtained from six. Four areas have produced significant amounts of alloy, with the other two areas producing lesser volumes. A seventh area contained PGE's in alluvial deposits derived from now eroded ultramafic rocks.

The four main areas are:

- the Heazlewood River Complex (no. 3, fig. 1) — also know as 'Nineteen Mile Creek', which includes Fenton's Prospect and the Caudry's workings;
- the Mt Stewart Complex (no. 4, fig. 1) — also known as Laughin's Creek or Ramsay's Prospect;
- the Wilson River Complex (no. 5, fig. 1) — in the north, the Harman River area and in the middle the Wilson River area, and Barnes and Riley Creeks;
- the Adamsfield area (no. 14, fig. 1). Early reports on 'osmiridium' in the Adamsfield area can be found in Nye (1929).

The two areas with smaller output were Boyes River (no. 13, fig. 1) and Rocky Boat Harbour (no. 15, fig. 1) areas. These

BROWN, A. V. 1992. Tasmania's development environment. *Bull. geol. Surv. Tasm.* 70:48–55.

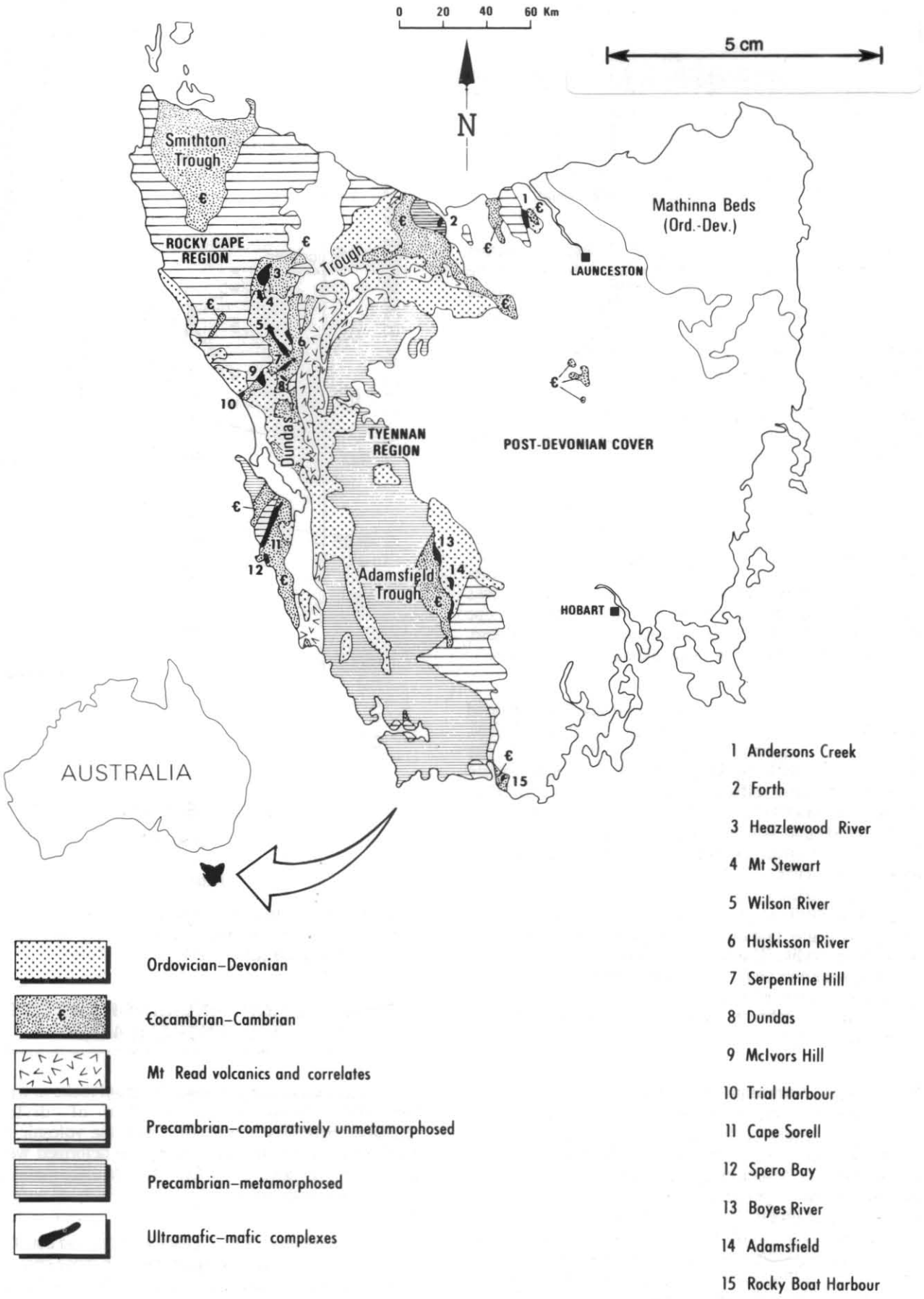


Figure 1

Schematic geological map of Tasmania showing locations of ultramafic-mafic complexes. Rock distribution after 1:500 000 Geological Map of Tasmania (1976).

3/8

two bodies are now in the World Heritage Area and are, at present, unavailable for exploration.

The seventh area, containing Keygan and Betts Creeks, is on top of the Meredith Granite (Jack and Groves, 1964). The alluvial deposits were derived from remnants of ultramafic rocks left after granitic emplacement. Prior to emplacement, the ultramafic rocks would have formed a continuous belt from the Heazlewood River area in the north, through the Mt Stewart area, to the Wilson River area in the south.

As well as the areas with historical production, two further areas; the Huskisson River Complex (no. 6, fig. 1), and the Trial Harbour ultramafic body (no. 10, fig. 1); are composed of the same primary ultramafic rock type as the bodies from which 'osmiridium' was produced. A recently completed exploration program over the Huskisson River Ultramafic Complex obtained between 20 and 190 ppb Pt for soil samples from eluvial deposits, as well as grains with varying proportions of Os and Ir ± Rh, and grains of Pt, as Pt-Fe, Pt-Rh-Fe-Ni and Pt intergrown with Os and Ir (Creasy, 1990).

An average pattern for whole rock PGE contents from the Tasmanian ultramafic rocks was calculated from 42 rock samples analyses for Brown *et al.* (1988). When this average pattern was plotted on a chondrite-normalised PGE diagram (fig. 2), and compared with other areas of ultramafic rocks with known PGE production, the pattern has a similar slope to samples from ophiolite bodies, but, in comparison to these, the Tasmanian 'sample' has anomalously high Pt values.

Outside ultramafic complexes, Pt and Pd have been reported with Cu-Ni sulphide ore in the Cuni copper-nickel field, which is just to the west of Serpentine Hill (no. 7, fig. 1). The ore is a magnetite-pyrite-pyrrhotite-pentlandite solid solution. The first reference from this area was by Reid (1921), who recorded 0.1–0.16 ounces per ton platinum in a Cu-Ni ore sample, which also contained trace gold and ~1.4 ounces per ton silver. A sample of ore from a second mine in the field assayed ~3 g/t platinoid metals, with Pt and Pd being determined as being in approximately equal proportions (Stillwell, 1946). A third sample from a nearby pit also contains platinum, partly as native platinum and partly as sperrylite (Hughes, 1965). Data obtained from the old mine workings and later drilling indicates that the ore of the Cuni copper-nickel field is contained within, or associated with, gabbroic dykes or sills (Taylor and Burger, 1952; Robinson, 1958).

In the nearby Serpentine Hill Ultramafic Complex, small, cobalt-bearing pentlandite-millerite grains pervade the serpentinitic matrix of the dominantly orthopyroxene-rich ultramafic rocks. Olivine-rich zones within this sequence, consisting of plagioclase-bearing dunite and peridotite, contain chromite grains with laurite [$Ru(Os,Ir)S_2$] and Os-Ir-Ru alloy grains. Values for Pt (~10–70 ppb) and Pd (~1–10 ppb) from whole-rock samples from the different ultramafic and gabbroic rocks were obtained from this area (Brown *et al.*, 1988; Brown, 1991). The highest values of Pd were obtained from the late-stage gabbroic samples. Values for Pt (17.5 ppb) and Pd (21.5 ppb) were also obtained from whole-rock samples of the associated low-Ti tholeiitic basalt.

Average values of PGE's obtained in the above studies are listed in Table 1.

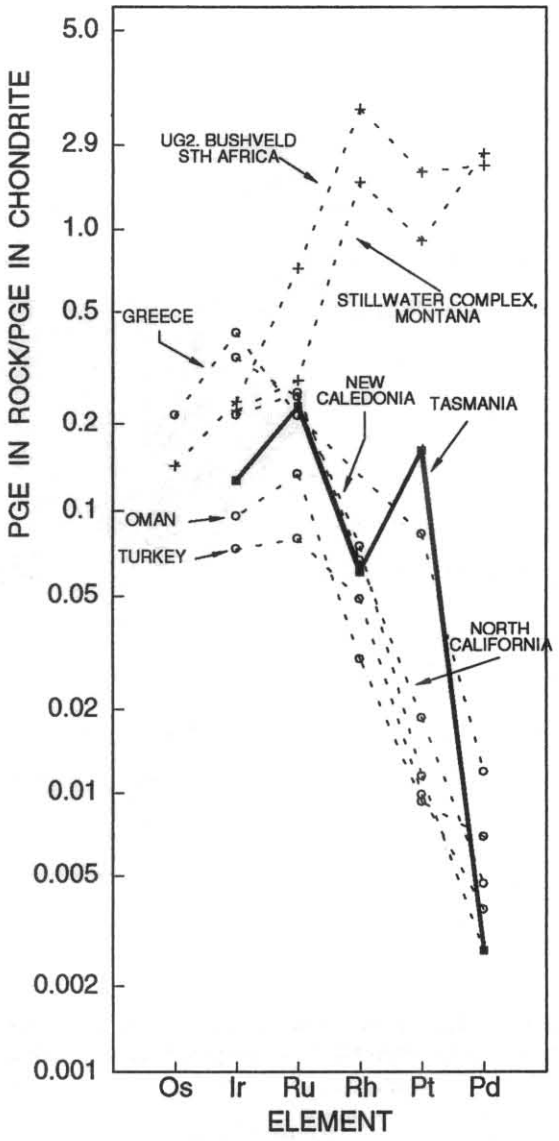


Figure 2

Chondrite-normalised platinum-group element data (after Page *et al.*, 1984) showing average data for 42 samples (after Brown *et al.*, 1988).

ULTRAMAFIC HOST ROCKS FOR THE PGE'S AND ASSOCIATED MINERALISATION

The arcuate belt of Eocambrian–Cambrian rocks in western Tasmania comprises a number of different volcano-sedimentary successions, with the volcanic rocks ranging from mafic to felsic. Along the deformed western margin of this zone a number of ultramafic-mafic rock complexes are exposed (fig. 1).

Using a combination of field characteristics and constituent mineral chemistry, the ultramafic rocks in these complexes have been subdivided into three different successions (Brown, 1986):

(1) a high-magnesian layered dunite-harzburgite succession (LDH), which contains a tectonic fabric parallel to layering formed during plastic deformation of the cumulate layers;

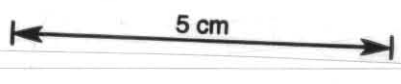


Table 1

Whole-rock analyses of platinum in Tasmanian ultramafic-mafic rocks

	(average values in ppb)		(no. of samples)
Andersons Creek	29.0	±10.3	4
Heazlewood River (North)	16.0	±4.2	4
Heazlewood River (South)	18.3	±2.3	6
Wilson River (North)	16.2	±8.5	5
Wilson River (South)	41.5	±2.1	2
Huskisson River (North)	16.3	±1.2	3
Huskisson River (South)	22.5	±10.6	2
Serpentine Hill Ultramafics	33.1	±17.4	7
Serpentine Hill Chromitite*	44.5	±11.8	6
Serpentine Hill Gabbro	36.0	±19.6	4
Low-Ti basalt, Serpentine Hill	21.5	±13.3	3

* With one chromitite having 1240 ppb Pt (not included above)

(2) a layered pyroxenite-dunite succession (LPD), which is dominated by orthopyroxene; and

(3) a multiply-intrusive ultramafic-gabbro succession (LPG).

The main features of Tasmanian ultramafic rocks are that they are high-magnesian, well-layered, and dominated by olivine and orthopyroxene. Clinopyroxene and plagioclase are subsiduary mineral phases, and only occur as post-cumulate minerals in one of the three different successions recognised. These features separate the Tasmanian rocks from the dominantly clinopyroxene-rich ultramafic rocks which are usually associated with mid-ocean ridge and back-arc environments. The closest correlates to the Tasmanian rocks occur within the Marum 'ophiolite' of Papua and New Guinea (England and Davies, 1973; Jacques and Chappell, 1980; Jacques, 1981) and the Betts Cove area in Newfoundland (Church, 1977).

When considering all areas of ultramafic rocks in Tasmania, the largest volume of rocks belongs to the IPGE-bearing, olivine-rich, LDH succession. This succession consists of well-layered dunite, orthopyroxene-bearing dunite and minor harzburgite. The sequence has a consistent and narrow range of mineral composition, with olivine of Fo_{92-94}; orthopyroxene of En_{92-94}, and Al_2O_3 and CaO contents below 0.2 wt% (electron microprobe analyses), indicating an original composition consistent with clinoenstatite. Chrome spinel grains have Cr/Cr + Al (Cr*) = 88–94 (Brown, 1986). Layering is defined by primary mineral alignment of cumulate olivine, orthopyroxene and spinel grains. A tectonic fabric, parallel to layering, pervades the succession. This fabric is defined by a flattening and elongation of the primary cumulate minerals. The LDH succession is considered to have been formed as the magma chamber component of boninitic magmatism (Brown and Jenner, 1989).

The LPD succession is also well layered but dominated by orthopyroxene. The main rock types are orthopyroxenite and olivine orthopyroxenite, with a lesser amount of dunite. Harzburgite layers have not been found within this succession. The mineral chemistry has a wider compositional range, but is also very consistent from area to area. Orthopyroxene grains are En_{85-89} with CaO contents between 0.6 and 2.0 wt% and Al_2O_3 between 0.75 and 2.0 wt%. Olivine has a forsterite content of Fo_{87-90}, and is usually similar to the co-existing orthopyroxene. Subsiduary, post-cumulus clinopyroxene is chrome diopside (Ca:Mg:Fe = 47:49:4), and the chrome spinel grains have an average Cr* of 64. However, the spinel grains have a wide range of chemistry, being Cr* = 58–72, with a tendency of defining two different sequences, one between Cr* = 58–64 and another between Cr* = 68–72. Plagioclase has not been observed in rock from either the LDH or LPD successions.

The third ultramafic succession is characterised by multiple intrusions of various ultramafic and mafic rocks (Brown *et al.*, 1988). The succession consists of an early, well-layered sequence of orthopyroxenite with subsiduary olivine pyroxenite and dunite. This sequence varies from the LPD succession in that dunite layers usually contain an upper, mineral-graded zone, and numerous sedimentary-like structures occur within and across the layering. The mineral chemistry of this early sequence is similar to the LPD succession. The second phase of the LPG succession is characterised by plagioclase-bearing peridotite with plagioclase-bearing oikocrystic harzburgite, and minor plagioclase-dunite with a high chrome spinel content. The second magma phase intruded the first, forming reaction zones. A third magma phase resulted in multiple intrusions which intruded both the earlier ultramafic phases, resulting in the formation of two-pyroxene gabbro with a granular texture.

Overall, the olivine-rich ultramafic rocks with chrome spinel grains having a Cr* between 84 and 94 are IPGE enriched,

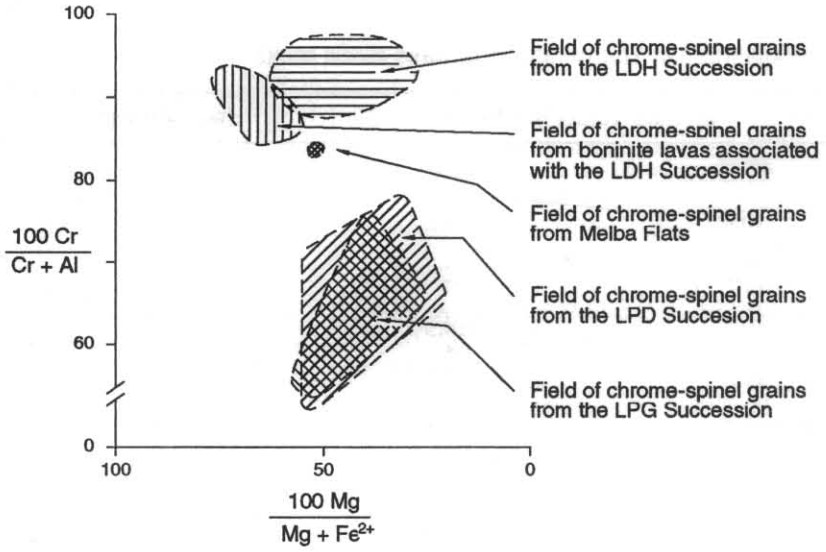


Figure 3

Fields of chrome-spinel grains from Tasmanian ultramafic rocks.

while those which are orthopyroxene-rich or bearing chrome spinel grains have a composition with Cr* between 58 and 72 are PPGE enriched, especially those with Cr* between 68 and 72 (fig. 3). This succession is considered to have formed as the magma chamber component of low-titanium, tholeiite magmatism (Brown and Jenner, 1989).

ASSOCIATED BASALTIC ROCKS

Two basaltic lava varieties have been recognised associated with or within the ultramafic rock complexes. Both lava types contain pillow lava and tabular flows with intercalated breccia units, consisting of volcanic flow detritus, and minor interbedded sedimentary rocks. One of the varieties is chemically and petrographically similar to some of the Western Pacific boninite lavas (Kuroda and Shiraki, 1975; Shiraki and Kuroda, 1977; Hickey and Frey, 1982). These lavas consist of chrome spinel and pseudomorphed clinoenstatite and orthoenstatite phenocrysts in a fine-grained to quenched groundmass of pyroxene microlites. The lavas have anhydrous SiO_2 contents of 53–59 wt.% with an average of 56 wt.%. TiO_2 is less than 0.2 wt.%, MgO is between 18 and 24 wt.%, Zr and Y have average values of ~6 ppm, Nd is less than 3 ppm, and the lavas have concave chrondite-normalised REE patterns with (La/Yb)n ~1 (Brown and Jenner, 1989.) The boninitic lavas, which occur mainly in the southern part of the Heazlewood area (no. 3, fig. 1) and to the south of McIvor Hill (no. 9, fig. 1), are considered to have been produced as a second phase melt product (Duncan and Green, 1980), with the early-formed dunite cumulate derived from this magma phase containing the Os-Ir-Ru alloys (Peck *et al.*, 1992).

The second lava variety is a low-Ti tholeiitic basalt. Flows are aphyric, but they contain a large grain-size variation down through a flow. The flows usually have pillow-structured tops, then progress down through fine-grained (1–2 mm); medium-grained (3–5 mm) to coarse-grained (5 mm) basalt, the coarser-grained varieties resembling gabbro in hand specimen, to a chilled base. In places, thin, intercalated, sedimentary rocks occur between flows. Lavas belonging to this group occur on the eastern side of the Heazlewood and Serpentine Hill area and at McIvor Hill. Good chemical and petrographic correlations occur between the lavas from these three areas. The PPGE-enriched chromitite schlieren in the LPG succession are considered to have been derived from the parental magma of this phase of volcanism.

When chemical data on the basaltic rocks from the Serpentine Hill (Brown, 1991) and McIvor Hill complexes (no. 9, fig. 1) (Olubas, 1989) are combined with earlier data from the Serpentine Hill (Brown 1986) and Heazlewood areas (Creenaune, 1980), they show that the Tasmanian low-Ti basalt and associated gabbroic rocks define a partial melting curve which is almost identical to the curve defined by samples dredged from the Mariana Fore Arc–Bonin Island area (Hickey and Frey, 1982). The Tasmanian boninitic rocks and lavas from Cape Vogel (Jenner, 1981; Hickey and Frey, 1982) define a similarly shaped partial melting curve to that of the low-Ti lavas, but have a slightly different compositional range.

In summary, the PGE-bearing ultramafic rocks in western Tasmania are considered to have formed as magma chamber cumulates from parent liquids which produced boninitic and low-titanium basalt lavas and associated gabbroic rocks. Similar lavas and associated rock are found within the Tertiary to Recent Western Pacific island-arc system between New Guinea and Japan. The present juxtaposition of rock successions in western Tasmania is considered to be the result of obduction of parts of a Cambrian island-arc system onto a continental terrane at the end of the Middle Cambrian, followed by further deformation during a Mid-Devonian orogeny (Brown and Jenner, 1988; Berry and Crawford, 1988).

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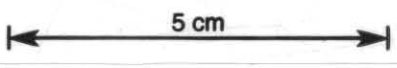
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APPENDIX

Land tenure and access to land

For exploration and mining purposes in Tasmania, there are three main classifications of land (fig. 4):

1. *Land available for exploration without any special conditions*

This classification includes all land listed by the Australian Heritage Commission on its Register of the National Estate. The majority of the areas of ultramafic rocks within Tasmania occur within this classification. These areas include the 'osmiridium'-producing areas of Heazlewood (no. 3, fig. 4), Mt Stewart (no. 4), and the Wilson River (no. 5), as well as other areas prospective for both IPGE and PPGE, such as the Huskisson River (no. 6), Serpentine Hill (no. 7), Dundas (no. 8), and Trial Harbour (no. 10).

2. *Land available for exploration with special conditions*

This classification includes Conservation Areas, Protected Areas and certain Special Reserves. Areas of ultramafic rocks where special conditions for exploration apply include the 'osmiridium'-bearing areas at Adamsfield (no. 14) and Spero Bay (no. 12), as well as the Cape Sorell area (no. 11). The main areas of the Adamsfield ultramafic complex and associated alluvial mineral fields are included in the Adamsfield Conservation Area within the World Heritage Area, and are available for exploration. Application for Exploration Licences and/or Mining Leases are required to be approved by the Mineral Exploration Working Group and the relevant Land Managing Authority.

3. *Land, at present, unavailable for exploration or mining*

This classification includes National Parks, World Heritage Areas, and Wildlife Reserves. Areas of ultramafic rocks presently unavailable for exploration are the old 'osmiridium'-producing areas of the Boyes River (no. 13) and Rocky Boat Harbour (no. 15), as well as the ultramafic rocks on Macquarie Island.

The Department's *Mineral Exploration Code of Practice* provides an outline of the current procedures which must be followed to obtain exploration approval, and at the same time to give useful, practical information on the expected standards of exploration activities. The Code also details the controls and monitoring procedures which are currently in place.

Conditions under which exploration work may proceed are decided on a site-by-site basis, usually after consultation with other Government departments.

The Department of Mines rigorously enforces a policy of responsible and careful exploration, requiring all proposed exploration activities to be approved in writing before work commences. However, the Department also acts as a facilitator for any exploration company who may wish to apply for an Exploration Licence over areas which require special conditions.

Exploration activities proposed in Protected and Conservation Areas, and other areas considered to be sensitive, must be approved by the Mineral Exploration Working Group, which consists of representatives from the Department of Mines; the Department of Environment and Planning; the Department of Parks, Wildlife and Heritage; the Forestry Commission; and other Departments and interested bodies where required.

The purpose of the Working Group is to examine matters relating to mineral exploration and mining activities within Conservation and Protected Areas, and in other environmentally-sensitive areas, including those parts of the World Heritage Area which are open for exploration.

The fundamental aim of the Working Group is to allow the aims of the explorer to be met without compromising the conservation values of a given area.

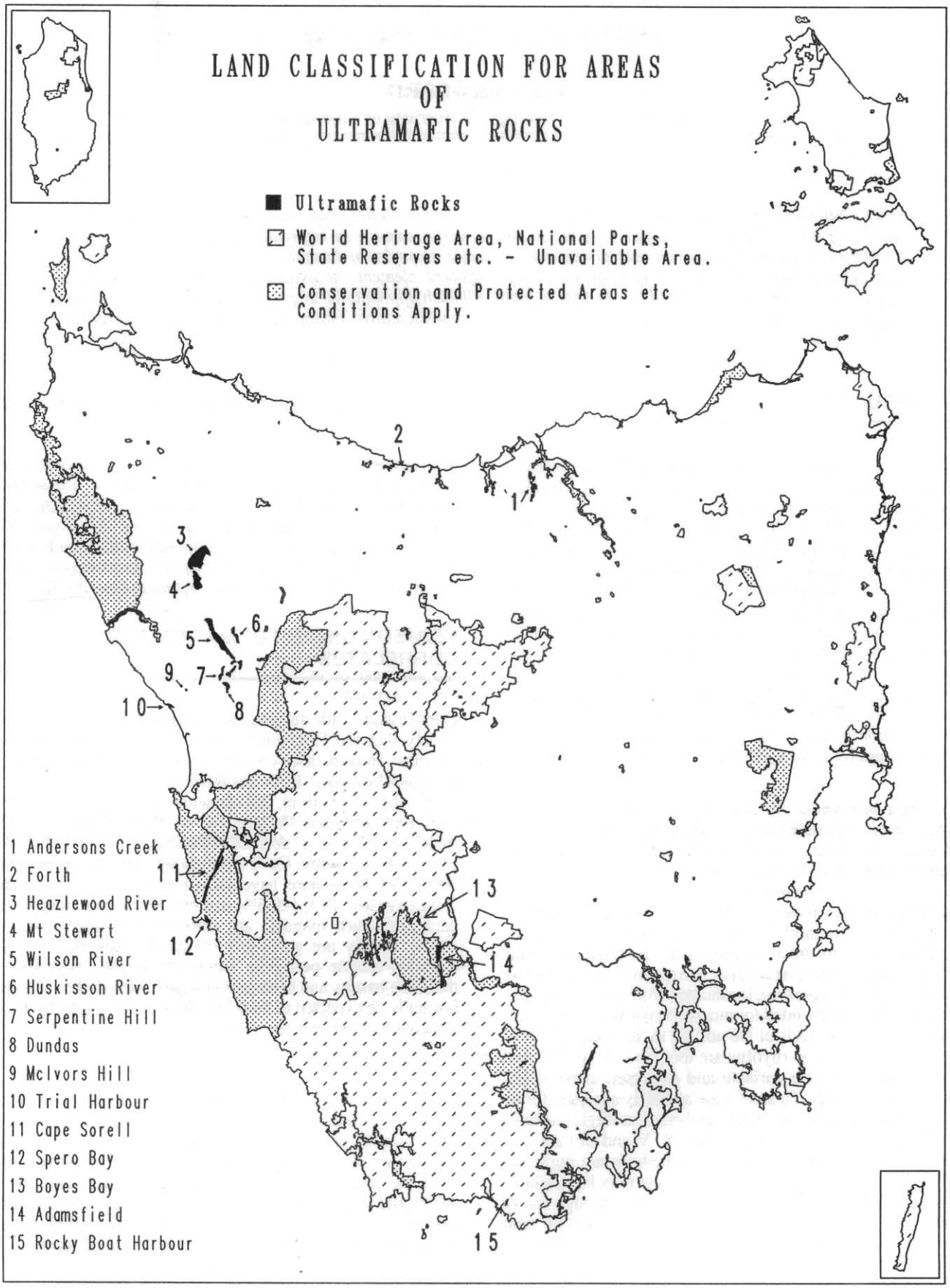
An applicant for an Exploration Licence or Special Prospectors' Licence shall submit to the Director of Mines a program of proposed works, and this must be approved in principle before the issue of a licence. The Director of Mines shall submit the programme, and any subsequent variation of it, together with his comments and recommendations, to the relevant Managing Authority, for comment and approval, via the Mineral Exploration Working Group.

The function of the Working Group is to examine the exploration proposals, investigate the impact that any work may have on the historical, archaeological, botanical, zoological or ecological significance of the place, and if need be, impose conditions on the activities so that these values are not permanently adversely affected.

Once approval has been given by the Working Group, the Department of Mines is the Government Agency responsible for the administration and supervision of mineral tenements within Tasmania.

When exploration activity has commenced, supervision of the activities is the responsibility of the staff of the Department of Mines. If considered warranted, field trips may be arranged so that members of the Working Group, or their field representative, can view the progress of work in a particular location

Further information can be obtained from both the Registrar of Mines and the Manager—Environmental Policy.


LAND CLASSIFICATION FOR AREAS
OF
ULTRAMAFIC ROCKS
Ultramafic Rocks
World Heritage Area, National Parks, State Reserves etc. - Unavailable Area.
Conservation and Protected Areas etc Conditions Apply.
1 Andersons Creek
2 Forth
3 Heazlewood River
4 Mt Stewart
5 Wilson River
6 Huskisson River
7 Serpentine Hill
8 Dundas
9 McIvors Hill
10 Trial Harbour
11 Cape Sorell
12 Spero Bay
13 Boyes Bay
14 Adamsfield
15 Rocky Boat Harbour

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Geochemical constraints on tectonic models and the importance of lithochemical data in exploration

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ABSTRACT

When coupled with careful geological mapping and petrographic studies, major and trace element geochemical studies of metavolcanic rocks offer a versatile and powerful adjunct to regional mapping and exploration programs. This paper focuses on several western Tasmanian examples of the application of geochemical studies in mapping and exploration, and emphasises that different element 'analytical' packages serve different purposes, and should be tailored for the task at hand. All such applications of geochemical data are exercises in comparative geochemistry, and thus require large and representative databases of reliable, quality analyses to be useful.

INTRODUCTION

Most of the volcanic rocks in foldbelts are degraded to varying degrees by low-grade regional (burial) metamorphism. Element mobility during such alteration is demonstrable for the alkalis and CaO and related trace elements (Ba, Rb, Sr), but a large suite of elements, including the so-called high-field strength elements (Ti, Zr, Y, Nb, Hf, Ta, Th), the transition metals (Ni, Cr, V), and Sc, have been shown to be essentially immobile in most alteration systems. These elements are most useful in trying to decipher the tectonic setting of the metavolcanic rocks in a particular region, but are also of use in determining the protolith (e.g. andesitic or felsic?) of highly-altered lavas. Of particular value are the rare earth elements (REE), both for purposes of identification of magmatic lineages or tectonic settings of eruption, and for local correlation of mappable units.

I suggest that major element analyses are useful for all applications of whole-rock geochemical data, whether for alteration studies (e.g. Na depletion around VHMS deposits), identification of discrete geochemical (magmatic) units to aid in mapping programs, or more broad tectonic interpretations. Whole-rock major element analysis, normally performed by XRF techniques, should be complemented by trace element data packages designed specifically for particular purposes. If tectonic discrimination is involved, the analysis for Ti, Zr, Th, Hf, Cr and REE is recommended for most metavolcanic rock suites. I have found that levels of Nb and Ta in 'arc-type' suites of basalt-andesite-dacite-rhyolite are too low to be useful, and that Y values are too variable and dispersed to be of any value. The REE, Hf, Th and Cr are all easily analysed for by instrumental neutron activation analysis as a single package, whereas the useful Zr, Ti (and Nb, Y, V and Sc) are best analysed for by XRF. As analytical methods are improved using ICP-MS, a large range of elements may be available from a single aliquot of dissolved sample, although for Zr and Cr, for example, accurate determinations of ppm abundances will depend critically on the total dissolution of the sample, including relatively insoluble zircon and chromite.

We have assembled a large database of compositional data for Cambrian metavolcanic rocks in western Tasmania, including those from the Crimson Creek Formation and correlated basalts, the lava carapace of the so-called 'ophiolites', and for the complex and important Mount Read Volcanics. Successful application of geochemical data towards interpreting each of these suites are described below.

CRIMSON CREEK FORMATION AND CORRELATES

Comparisons with modern rift tholeiite suites have shown clearly that the Crimson Creek Formation basalts in the Dundas Trough, and correlates on Macquarie Harbour (Double Cove area), in the Smithton Basin, in the Dial Range region (Motton Spilite), and elsewhere (O'Connors Peak for example) are Late Proterozoic or Early Cambrian rift tholeiites. Moreover, detailed transects of the ~1 km-thick basalt pile at Double Cove have shown that the uppermost 100 m of lavas here have refractory compositions with distinctive low TiO_2 (<0.6%) contents and strong light REE depletion. Such magmas are referred to as second-stage melts, as they are generated via partial melting of very depleted mantle peridotite from which (the underlying) tholeiitic basalts had been previously extracted; they would normally be expected to be at the top of the lava pile, as they effectively represent the 'last gasp' of magmatism in an evolving rift setting.

Similar refractory compositions have been documented among the Crimson Creek Formation correlates at Grassy on King Island, and as dykes in the Smithton Basin. Such differences in the compositional spectrum of these basalts offer the possibility of testing 'younging directions' in a basalt pile where other evidence may be unavailable. This may be of particular value in the Dial Range region, were early geological mapping had difficulty in determining

CRAWFORD, A. J. 1992. Geochemical constraints on tectonic models and the importance of lithochemical data in exploration. *Bull. geol. Surv. Tasm.* 70:56–57.

relative age relationships between the Barrington Chert and the Motton Spilite.

THE MAFIC–ULTRAMAFIC COMPLEXES

Petrological-geochemical studies of the lava carapace of the western Tasmanian 'ophiolites' have demonstrated that these rocks are not typical oceanic crust at all, but are more typical of the crustal section of the forearc of an intra-oceanic island arc. This interpretation played a major role in developing a new tectonic model for the geological evolution of western Tasmania (Crawford and Berry, in press, *Tectonophysics*), which hinged on identification of unusual high-Si, high-Mg, low-Ti lavas, including boninites and magnesian quartz tholeiitic basalts making up most of the lava pile. Given the elevated PGE contents of such magmas relative to typical mid-ocean ridge basalts or rift tholeiites, this identification has enhanced the PGE prospectivity of the cumulate pile which make up significant volumes of the mafic-ultramafic complexes in western Tasmania. Furthermore, the possible presence of PGE (and Au)-enriched mafic-ultramafic rocks in the ophiolite sheet(s) in the substrate of the Mount Read Volcanics provide one reason as to why the VHMS deposits in the Mount Read Volcanics are so Au-rich relative to many other similar Kuroko-type deposits.

THE MOUNT READ VOLCANICS (MRV)

Detailed petrological-geochemical studies of the MRV have shown that they are not, as was generally thought, an Andean-type convergent margin basalt-andesite-dacite-rhyolite suite. Rather, they are a magma suite emplaced in post-collisional relaxation rifts after collision of an oceanic arc with a thinned, rifted passive margin emplaced the mafic-ultramafic complex onto the passive margin.

Geochemical studies have proven very effective in two other applications within the MRV. Firstly, ratios such as Ti/Zr, for example, show a smooth variation from basalt to rhyolite, and remain little changed during even intense alteration. Thus a near terminally-chloritised lava may be successfully assigned to derivation from an andesite or a rhyolite, for example, where petrographic evidence for the protolith has been obliterated. Secondly, geochemical studies have proven valuable in regional correlation of volcanic units in the MRV. For example, identification in the Lynchford area of very unusual P_2O_5-light REE-enriched shoshonitic basalts, such as are abundant in the Hellyer basalt pile, clarified stratigraphic relationships in this area, where the Lynchford basalts had previously been thought to dip below, and pre-date the Central Volcanic Complex. Furthermore, the commonly intrusive hornblende andesites, such as those at Crown Hill and Anthony Road, have been shown to be transitional compositionally, and almost certainly temporally, between the less enriched CVC andesite-dacite-rhyolite sequences, and the more enriched Hellyer-type shoshonite lava sequences. If a sufficiently comprehensive database is available, use of carefully selected geochemical parameters can be of great value on the scale of an exploration licence or mine lease in correlating lava units both locally and regionally.

SUMMARY

Geochemical studies of lava sequences in outcrop or drill hole have great potential to clarify local and regional correlation, as well as lend clues towards determining the tectonic setting of eruption and geological significance of volcanic rocks in fold belts. For the latter purpose, careful sample selection based on detailed petrographic studies is an important pre-requisite to a successful application of comparative geochemistry. For local and regional correlation, immobile elements are most useful, and the choice of element packages to be used may vary from sequence to sequence. Their successful application relies heavily on a comprehensive database for the regional volcanics, and sensible choice of elements to be used in the exercise. In alteration zones, immobile elements may be used to identify the protoliths of intensely-altered lavas, and to assess possible volume changes and mass balances involved in the alteration system.

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Tasmania Department of Mines programs — MRVP, NETGOLD and AMB

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Tasmania Department of Mines

ABSTRACT

In recent years, the Tasmania Department of Mines (TDM) has embarked on a program of specially-funded research. The first program component, the Mt Read Volcanics Project (MRVP), started in 1985 and has just been completed. Two others — NETGOLD (North East Gold) and AMB (Arthur Mobile Belt) — have been planned for several years but have not yet been successful in attracting additional Government funding. This account of TDM programs is not a comprehensive review of all Geological Survey activities but covers only those projects which have been the subject of special funding arrangements.

MT READ VOLCANICS PROJECT

INTRODUCTION

This scientific project arose from the West Coast Resource Development Program which was a major initiative of the Tasmanian Government in June 1985, in response to the projected closure of the Mt Lyell copper mine in 1989. The project became known as the Mt Read Volcanics Project (MRVP) and had the aim of encouraging mineral exploration and development on Tasmania's West Coast. The detailed objective was to:

- provide industry with scientific databases on the geology, geophysics and geochemistry of the Mt Read Volcanics Belt and associated rocks, which are the major hosts of mineralisation in western Tasmania (fig. 1).

Initial funding of $2 million dollars was approved in August 1985, to be allocated from the Gordon-below-Franklin Dam compensation funds by arrangement between the State and Commonwealth Governments. From 1987 until the project ended in June 1992, operational funding came entirely from the Tasmanian Government.

For the seven-year duration of the project (1985–1992), specially-funded allocations totalled $4.2 million and were distributed among the program activities as follows (fig. 2):

- geological mapping — $1,316K (31%);
- database development — $460K (11%);
- isotopic and alteration studies — $403K (10%);
- exploration geochemistry — $232K (5%);
- mineral maps — $148K (4%), and
- geophysics — $1,644K (39%).

In addition, normal Department resources and services assigned throughout the life of the project are estimated to be close to $1 million, including sub-basalt drilling at $390,000. This represents a total resource allocation to the project of over $5 million.

Up to seventeen temporary personnel were on contract to the Department at any one time, including geologists, analysts, draftsmen, database clerks, technical officers and field assistants. At least nine permanent officers were engaged on the project at various times. Technical and support services were contracted as required, such as geophysical companies, track cutters and helicopter services.

All maps and reports resulting from the project are listed at the end of this review. As the reporting and compilation are expected to continue for several more years, the list is regarded as provisional.

THE PRODUCTS

Geological mapping

Twelve 1:25 000 scale colour geological maps have been produced. These cover about 80% of the Mt Read Volcanics Belt from Elliott Bay in the south to north of the Hellyer Mine (fig. 3). A compilation map at 1:100 000 scale has been published for the Hellyer–Queenstown section, including the operating mines, and a further map at this scale is planned for the Queenstown–Elliott Bay section in southwestern Tasmania.

The geological mapping program, which commenced in 1985, evolved from pioneering work carried out in the Queenstown region in the previous ten years, which demonstrated that careful mapping of the highly altered and deformed Cambrian volcanic rocks could reveal details of stratigraphy, structure, alteration and mineral deposit settings of significance to mineral exploration and mining.

From 1985 onwards, the mapping stages occurred as follows:

- The initial six maps in the series covered the central part of the belt from Mt Charter to the Tyndall Ranges, which contains the most important known mineralisation including the Hellyer, Que River, Rosebery, Hercules and Henty deposits.
- Allocated resources in 1988/89 were such that only logistically accessible areas could be tackled. As a result, field work leading to Maps 7, 8 and 9 was conducted in the north of the belt in the Black Bluff Range to Moina

DUNCAN , D. McP. 1992. Tasmania Department of Mines programs — MRVP, NETGOLD and AMB. *Bull. geol. Surv. Tasm.* 70:58–69.

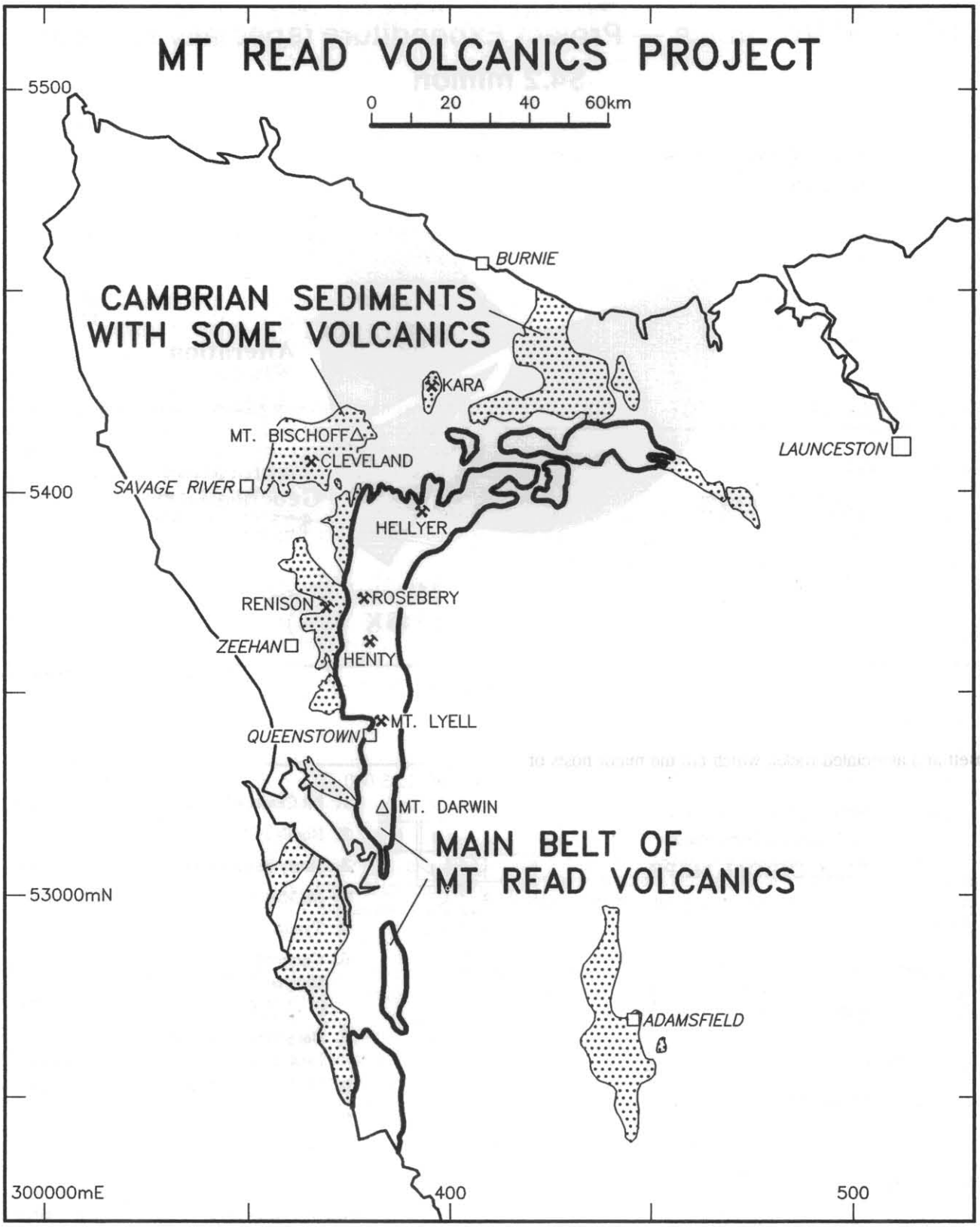


Figure 1

Geological outline of Mt Read volcanic belt.

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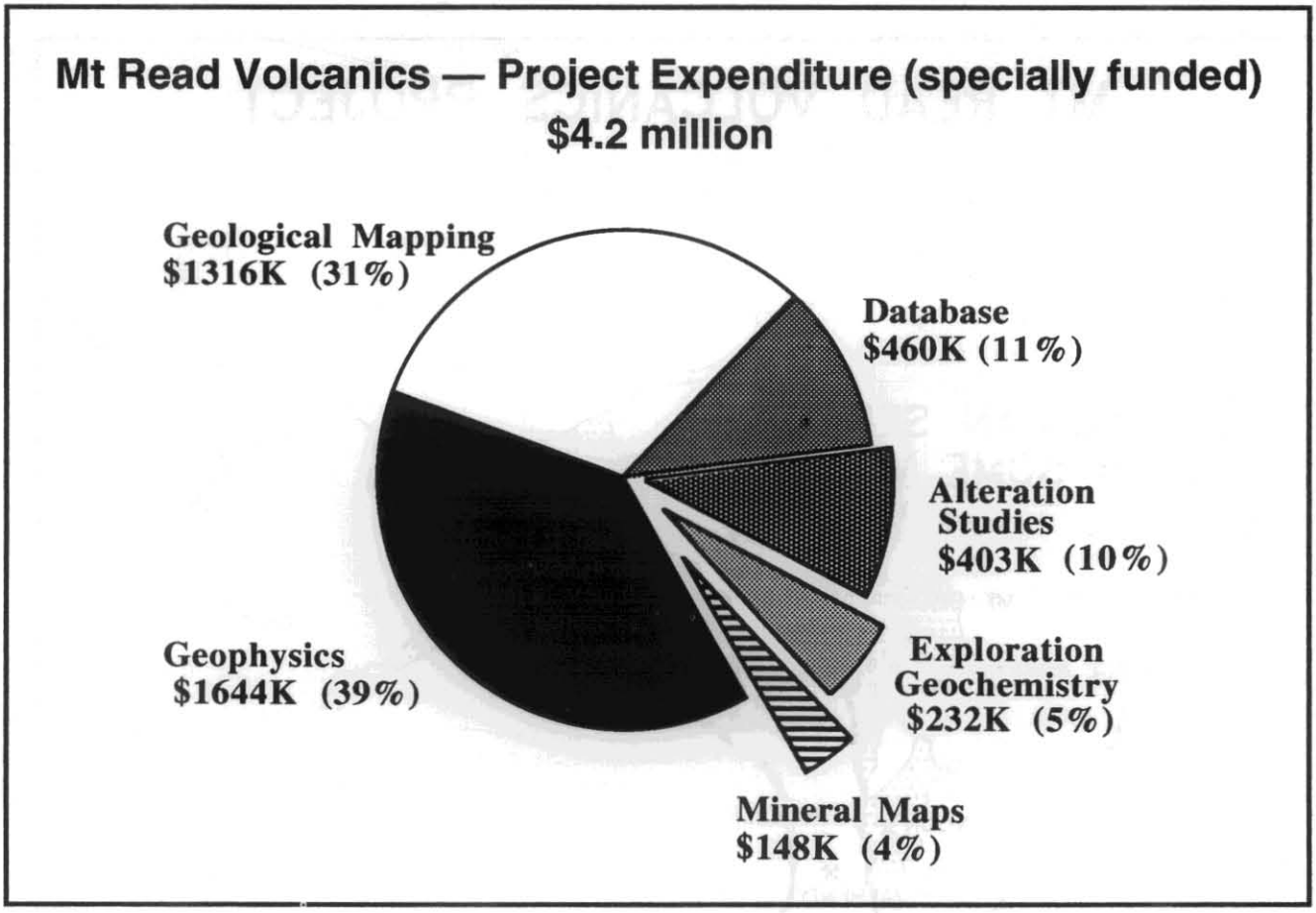


Figure 2

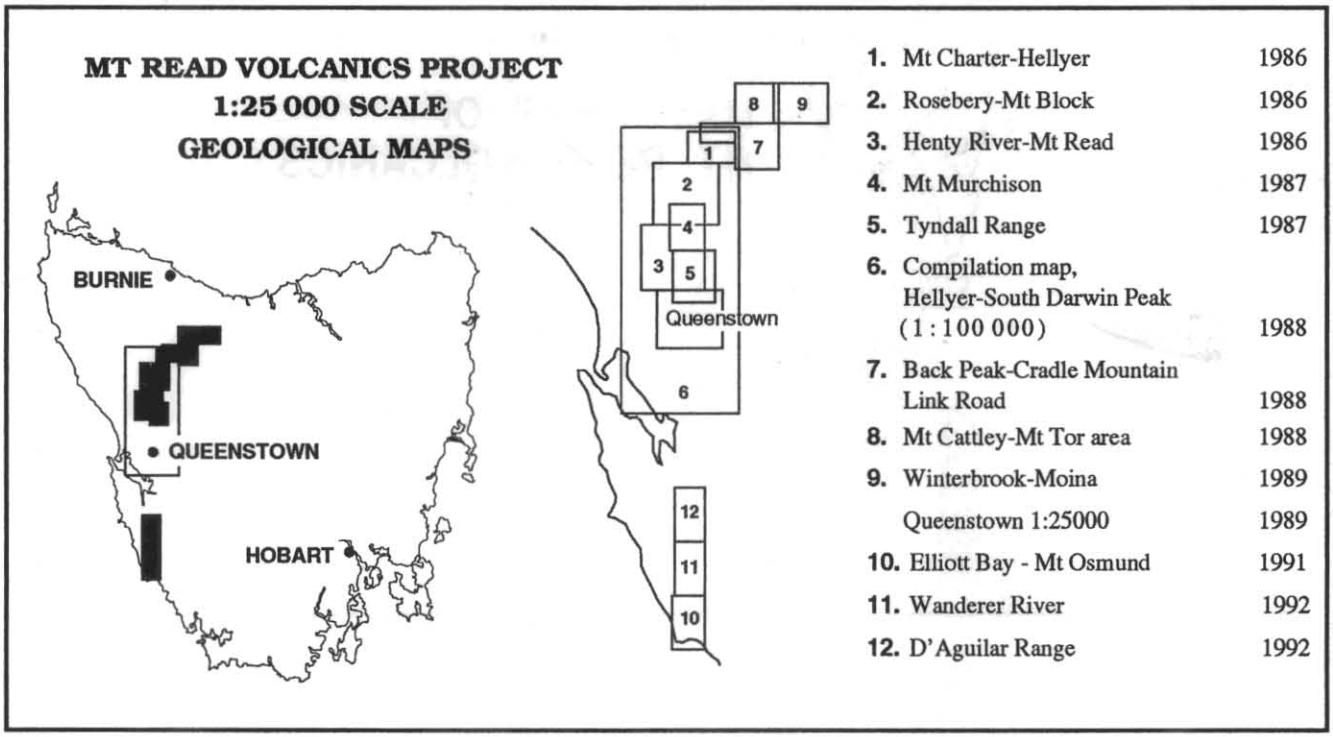


Figure 3

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areas. Also, at this time, a collaborative effort with the Regional Geological Mapping Branch, involving some remapping, produced a 1:25 000 scale map of the area around Queenstown, including the Mt Lyell deposits.

- In 1989, a two-year allocation of funds allowed a campaign to be planned in SW Tasmania, with helicopter-supported field camps and traverses. Over two field seasons, with an enhanced number of mapping crews (4), the three southern maps (10, 11 and 12) were successfully surveyed, covering the region from Elliott Bay to the D'Aguilar Range.
- The final 1991 season was carried out in the Jukes–Darwin area south of Queenstown, and the map (13) is currently being drafted.

Future mapping studies are planned over the next several years to complete coverage of the Mt Read Volcanics Belt in the Sheffield–Deloraine–Devonport region using normal Department resources.

This program has resulted in several significant outcomes:

- a set of high-quality, coloured geological maps at 1:25 000 scale containing detailed stratigraphic, structural, alteration and mineral deposit information;
- a standard set of maps with uniform mapping style and presentation along the entire length of the belt, on which companies can base their exploration planning and strategies;
- geological correlation along the entire length of the belt, thereby allowing companies a geological framework within which to rate and grade their prospects and targets for further investigation;
- more immediate results have been the recognition that the Que–Hellyer Volcanics extend from the type area, both to the southwest for 9 km through the Sock Creek area, and to the northeast for up to 10 km under Tertiary basalt.

This is an example of successful mission-oriented, mineral province mapping in which a core departmental program was escalated by special funding. On average, two maps were produced each year, with the field work to map production phase taking place within twelve months. Some delays were experienced when field mapping and compilation overran the ability of the draftsmen to draw the map and the Department to pay for the printing. While the maps were released progressively each year, the map notes were unable to be produced on a similar schedule. Four volumes of map notes have been published, representing about half of the mapping, with the remainder currently being written up. The geological mapping was supported by ten diamond-drill holes totalling 3652 m and some costeaning.

Mineral deposit maps

The main part of the Mt Read Volcanic Belt is covered by eight 1:50 000 scale mineral deposit maps as shown in Figure 4. The maps were initially produced on a monochrome geological base but later members of the series were presented on a full-coloured geological base. These maps represent the first systematic charting of mineral deposits in Tasmania.

The maps show deposits displayed in their geological setting, with commodities keyed by colour, deposit style by symbol shape, strike by bar symbol, and size by *in situ* dollar values.

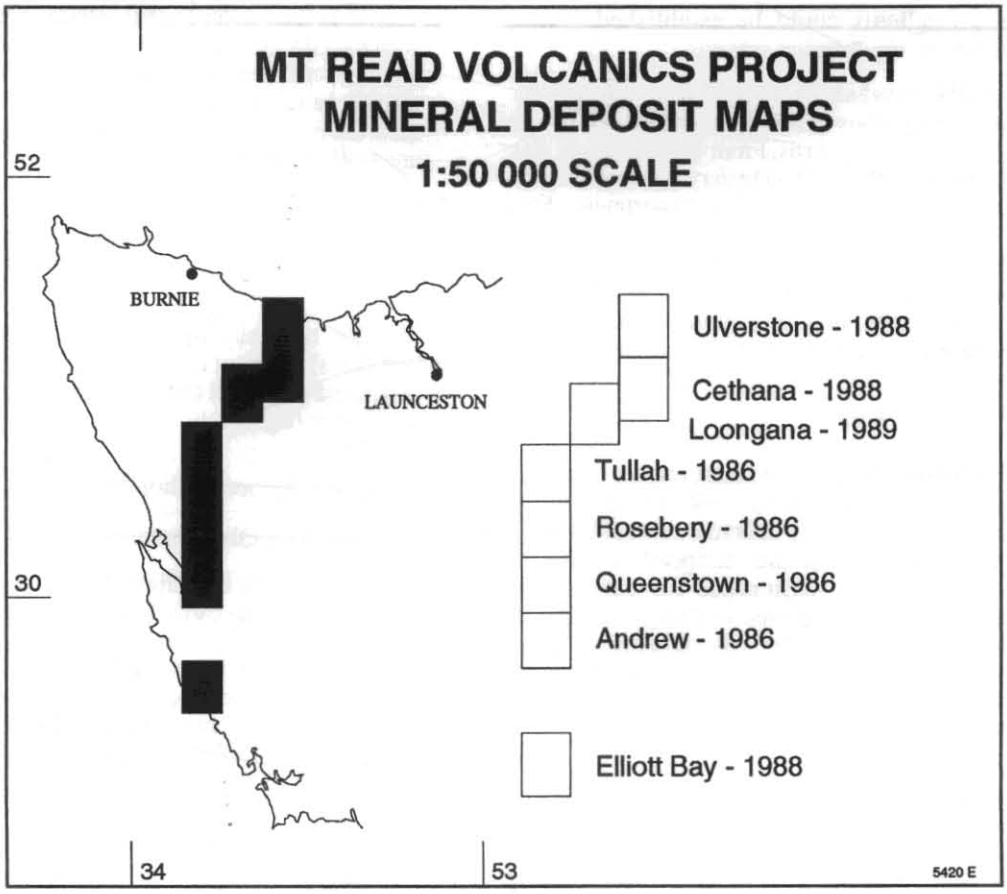


Figure 4

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Details of all deposits on the maps are contained in the MIRLOCH data base. In addition to their scientific and mineral exploration uses, these maps provide an essential data source for land-use planning.

Ore genesis studies

These studies were designed to determine the nature and extent of the geochemical haloes around massive sulphide deposits. The techniques were stable isotopic (particularly oxygen) determinations, whole-rock geochemistry, mineral chemistry (using microprobe analyses), together with petrographic work to control the interpretations.

The concepts were derived from similar work carried out a decade ago on the alteration patterns associated with the Tertiary Kuroko deposits of Japan. Difficulties were envisaged in application of the concept to the Mt Read Volcanics, considering the increased metamorphism and tectonic disturbance of these Cambrian volcanic sequences.

As a test of the concept in Tasmania, studies were conducted at Hellyer and in the Rosebery–Hercules area as examples of base metal-rich systems and compared with the Boco area, a base metal barren alteration zone. These case studies are now being fully written up.

It was found that using these techniques:

- enlarged alteration haloes could be detected, increasing the target for exploration;
- low temperature, barren, alteration zones could be distinguished from higher temperature base-metal associated alteration zones;
- temperature gradients could be established giving possible vectors to ore-forming systems.

These investigations produced a demand from industry for isotope-based investigations which were carried out by the Department on a consultancy basis. From 1988 onwards, this coincided with a period of severe budgetary constraint which involved a phase of cost recovery by the Department. Also within this period, two more complete ore genesis investigations were carried out, including fluid inclusion studies on gold mineralisation at the Lakeside and Henty deposits. Of these studies, only the report on the Lakeside deposit is available as Mount Read Geological Report 5.

Exploration geochemistry

The Huminex System involves the measurement of metals complexed by organic compounds in soil and water in the natural environment. The activity of humic substances in the degradation of minerals in the wet temperate climate of western Tasmania causes difficulties for exploration geochemistry, by producing extreme leaching of metals in the weathering environment. The concentration of these migrating humic substances and examination of their metal content provides clues to metal dispersion and eventual location of the source.

The soil application of the system has been tested at Waratah, Wart Hill and Elliott Bay, and obtained similar anomaly patterns compared to "C" horizon sampling. In addition, peak to background ratios were improved and the sampling of the "A" horizon is less expensive and destructive than "C" horizon sampling. The range of elements measurable by the system is copper, lead, zinc, silver, gold, arsenic, bismuth and molybdenum.

The method for using the organic content of waters is not yet fully developed. Initial orientation studies provided the incentive to sample creek and river water on a regional basis between Low Rocky Point and Que River. A trial batch of waters from the Cape Sorell to Elliott Bay region, analysed by solvent extraction and carbon furnace AAS, produced some anomalous values consistent with known geology and mineralisation. Since then a new analytical scheme has been devised and, in the last several years, has been tested commercially in mineral exploration in northwest Tasmania. However, the results were variable and indicated that further development of the system is required before it can be considered fully operational and effective.

Exploration databases

The object of this project was to provide industry with electronic databases relevant to mineral exploration and mining in the State. Three significant outcomes of this program component were:

- a computerised database of all mineral exploration reports produced since the beginning of the century — TASXPLOR — has been established (about 4000 entries) and is capable of being searched for a wide variety of keywords, such as author, company, tenure, dates, title, tenement number, map area and subjects;
- all reports were microfilmed, and microfiche of open file reports are available for purchase;
- DORIS, a drill hole data base, includes information on all drilling, whether company or Government, carried out in Tasmania (just under 15,000 entries). Gradual integration with the GIS system will allow display of drill holes with geology and tenement information, for example, and provide valuable detail on the focus of mineral exploration on a State-wide basis. Microfiche of open file drill logs are available for purchase.

Geophysics

AEROMAGNETICS

In 1985/86, two areas were covered by aeromagnetics (and radiometrics) as part of the MRVP, using a flight line spacing of 500 m and a nominal terrain clearance of 150 m. The areas covered were (fig. 5):

- Macquarie Harbour–Elliott Bay, and
- Sheffield–Deloraine–Devonport

These surveys were in addition to aeromagnetic surveys of similar specifications carried out in western Tasmania by the Department of Mines in 1981 (with Commonwealth Callaghan financial assistance), and in northwestern Tasmania by the Bureau of Mineral Resources, with some Tasmanian Government funding. Collectively these surveys gave an almost complete coverage of the exposed Mt Read Volcanics Belt.

Interpretation reports were produced for the new surveys. The funding also allowed reprocessing of the TDM data for the removal of terrain effects, and reports were commissioned on both previous surveys.

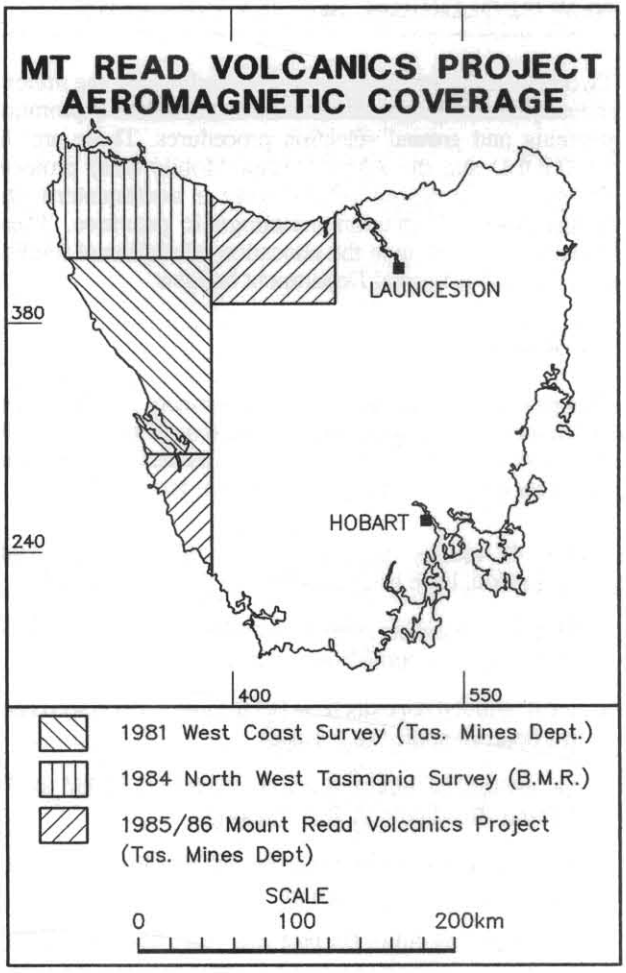


Figure 5

Regional aeromagnetic surveys produce large amounts of information which:

- contain anomalies of direct significance to mineral exploration;
- reveal major structures and lithological divisions not necessarily recognisable in geological mapping;
- allow, in conjunction with gravity surveys, the formulation of geophysical models able to predict subsurface rock distributions.

GRAVITY

Gravity coverage has been substantially increased in western Tasmania since January 1985 with the acquisition during the MRVP of more than 7800 stations by land, boat and helicopter transport (fig. 6). Where possible the new data provide a nominal station density of one station per square kilometre, and cover the Mt Read Volcanics Belt from Elliott Bay in the south to Penguin in the north. This information has permitted both:

- definition of the regional gravity field within which mineralised areas can be further surveyed in detail, and;
- interpretation of the three-dimensional extent of the belt and its tectonic setting.

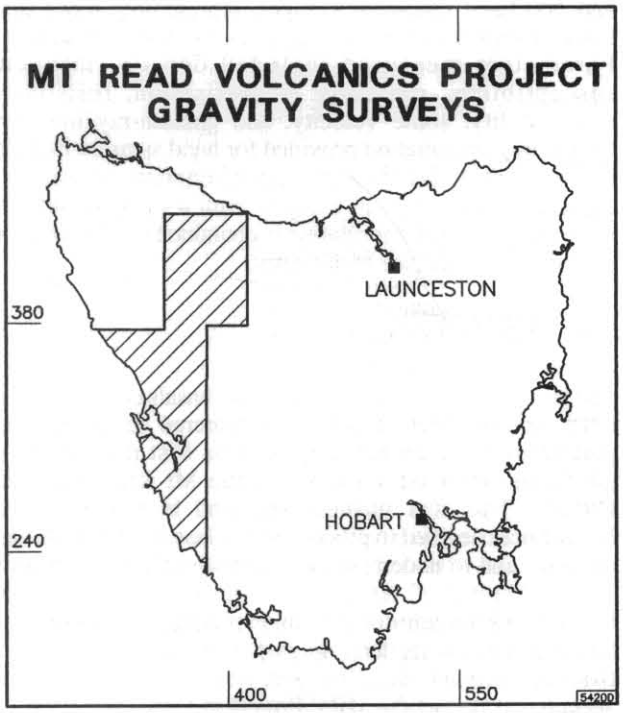


Figure 6

SIGNATURE STUDIES

A large body of geophysical information on western Tasmanian mineralisation was accumulated under this project. The four aims were to:

- determine the geophysical response of known mineralisation, alteration, host rocks, black shales and barren sulphides;
- assess the current geophysical techniques;
- evaluate geophysical detection under areas of concealment by alluvium or Tertiary basalt;
- experiment with new, lesser known or modified methods to increase the effectiveness of geophysics in Tasmania.

The study concentrated on mineral deposits in the Mt Read Volcanics but extended to all major mineral deposits in western Tasmania. It included all operating mines, a wide range of deposit classes and styles, barren mineralisation, common host rocks, and some concealed areas.

The techniques evaluated included gravity, magnetics, IP, SP, CSAMT, several varieties of EM, and seismic methods.

Some surveys were commissioned specifically for this project, but much of the information came from reviews of open file reports in the Department of Mines and from data provided willingly by mining and exploration companies active in Tasmania.

A series of reports records the details of this study.

PHYSICAL PROPERTIES

This project is designed to improve interpretation of geophysical data acquired during exploration programs. Measurements have been carried out on more than 1500 core

5 cm

and 400 hand specimen samples, representing rocks from both mineralised and unmineralised environments. Parameters measured included density, magnetic susceptibility, remanent magnetisation, resistivity, chargeability, sonic velocity, and gamma-ray intensity. Supporting information provided for hand samples includes a petrographic identification and description, as well as a complete major element analysis with a range of selected trace elements. All information is contained in a Department database for reference by industry.

Sub-basalt Drilling

The possibility of pattern drilling the basalt-covered terrain north of Que River had been considered for some years previously but a formal proposal was first put forward in December 1984 for inclusion in the Mt Read Volcanics Project. This was unsuccessful and in mid-1986, the Department decided to proceed with a less ambitious drilling program and to undertake those investigations which could be done "in-house". As most of the area covered by Tertiary basalt had been relinquished by exploration companies and had received no tenders, all available land was exempted from the Mining Act. The modified project then became accepted as part of the MRV Project in December 1986.

The main aims of the project were to record the distribution of Palaeozoic bedrock (particularly Mt Read Volcanics), the thickness of Tertiary basalt, and provide open holes for geophysical surveys and basement core for geochemical surveys.

In all, 13 holes were drilled in the exempt area, mostly to the southeast of Guildford with the best chance of intersecting Mt Read Volcanics correlates (fig. 7). The deepest hole was 750 m and the total program came to 5283 metres. The basalt thickness, including underlying Tertiary sediments, varied from 89 to 375 m, with 2055 m of basement rocks being cored. Of the 13 holes, most of which were precollared, six intersected Mt Read Volcanics correlates (MXRD 1, BTRD 1, SBDP 7, 14 and 15) or associated Cambrian rocks (SBDP 5). The remaining seven recorded Ordovician to Devonian sediments (SBDP 1, 2, 4, 6, 7 and 9), except for one sedimentary section thought to be Precambrian (DDHF 1).

The drilling pattern was nominally on a 4 km square grid positioned to gain the most effective coverage of the basalt terrain and to take account of previous drilling by exploration companies. Down-hole geophysical logging (mainly gamma-ray) was carried out in all holes, with mixed success as expansive clay in the Tertiary sediments under the basalt swelled to block the holes when the casing was withdrawn.

The most significant result of the drilling was from the deepest hole (MXRD1), which was designed to support the 1:25 000 scale geological mapping of the MRVP. The angled hole was sighted and pressed on to 750 m to record a 242 m section of the Que–Hellyer volcanics from the Que River shale to the Animal Creek Greywacke, within which a 0.3 m thick volcaniclastic siltstone is interpreted to be the time-equivalent of the Hellyer mineralisation. A pilot hole (BTRD 1) had previously been drilled to 138 m to obtain an oriented core of bedded greywackes, which confirmed a southerly-plunging synclinal structure. This has extended the area of these highly prospective host rocks north for at least another 10 km beyond the Hellyer Mine.

NEW GEOLOGICAL SURVEY PROJECTS

Two new initiatives have been proposed to give the mineral industry basic regional information to assist their exploration planning and ground selection procedures. These are the NETGOLD and the AMB (Arthur Mobile Belt) projects, designed to promote respectively a northeastern and northwestern Tasmanian metallogenic province. These initiatives depend upon the allocation of additional funding over and above normal Department budgets.

NETGOLD

This project was initiated by the Department in 1988, using existing core funding, with the objective of promoting the prospectivity of the NE region of Tasmania to potential explorers (fig. 8). In doing so, there was recognition that:

- over 42 tonnes of lode gold, or 35% of total State production, have been won from northeast Tasmania;
- mineralising events have been widespread, with over 450 gold deposits recorded throughout the area;
- not all alluvial deposits have been confidently traced back to a bedrock source (e.g. Lisle);
- the geological environment is broadly similar to the Ballarat–Bendigo region of Victoria;
- modern mineral exploration of the belt has been fragmentary and impersistent.

The work carried out in the past two years has comprised:

- a pilot aeromagnetic/radiometric survey in the Alberton–Mangana area;
- three compilation reports (including maps) on the Alberton–Mathinna–Mangana Lineament;
- all lode gold deposits entered on MIRLOCH database;
- two diamond-drill holes in the Lisle area;
- preliminary ore genesis and geochemical studies;
- completion of the 1:50 000 Alberton geological map sheet.

Future programs will depend on the level of additional funding, but techniques to be considered are:

- geological mapping of selected goldfields to demonstrate structural and stratigraphic control of gold lodes (vein orientation, timing and mode of emplacement), either at 1:25 000 scale of main gold lineaments or at a more detailed scale of one main goldfield as a pilot project;
- ore genesis studies involving isotopes, mineralogy, geochemistry and fluid inclusions to determine parentage of mineralising fluids;
- mineral deposit maps showing regional distribution of gold occurrences drawn from new geological mapping and existing compilations;
- geophysics to determine the regional structure with a combination of aeromagnetics / radiometrics and gravity. Physical properties of rock materials would also be determined, to aid geophysical interpretation and

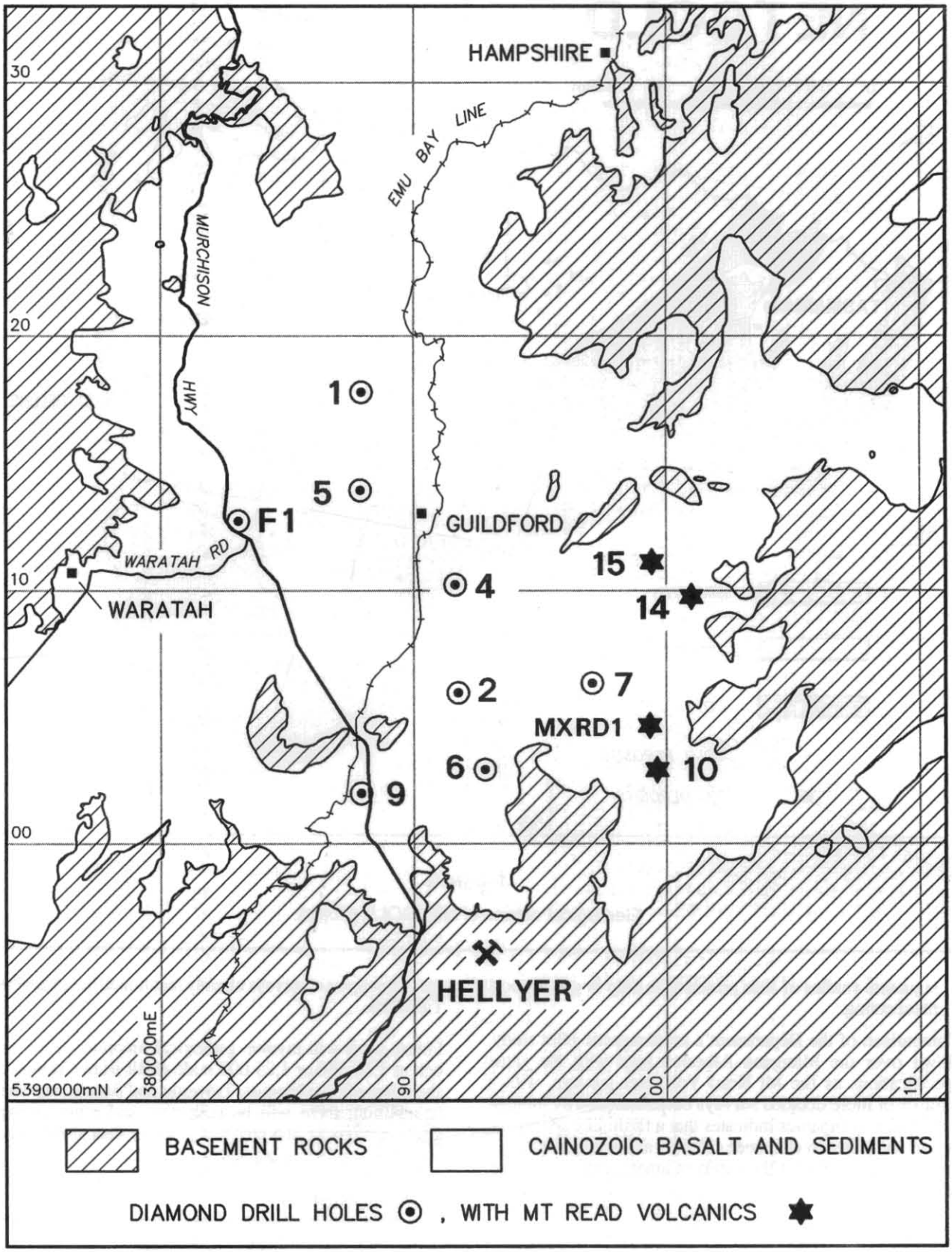


Figure 7

Sub-basalt drilling project.

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9/12

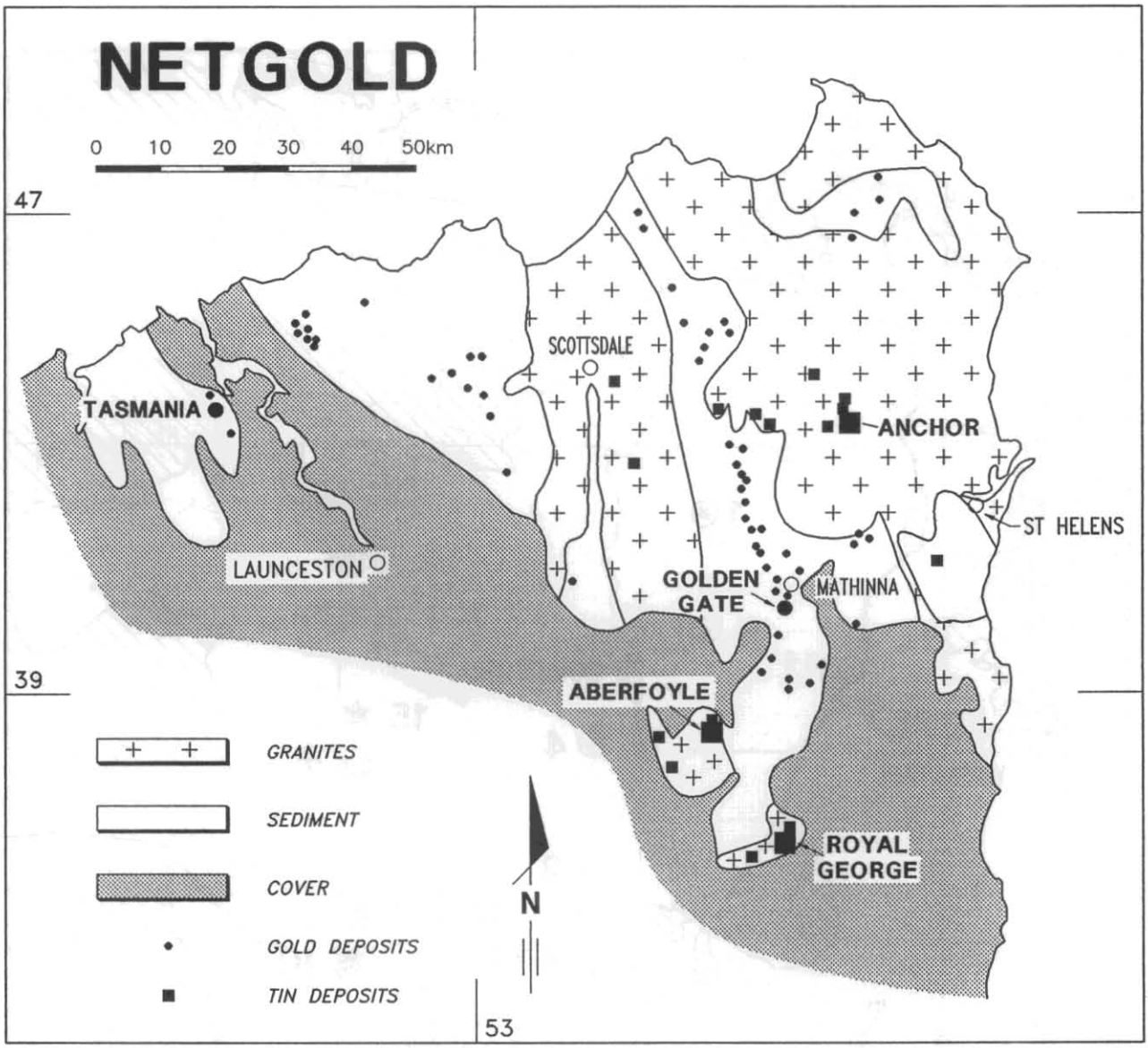


Figure 8
Geological outline of NETGOLD project.

signature studies of lode positions to help in geophysical prospecting.

Comparison of the Department's aeromagnetic pilot study, flown over the Mangana–Alberton area with the same specifications as the Mt Read Volcanics surveys, with a number of more detailed surveys commissioned by mineral exploration companies indicates that a flight line spacing of 400 m and a terrain clearance of 80 m, at the very most, will be necessary to reveal the subtle magnetic character of the Mathinna Beds.

AMB

The Arthur Mobile Belt project is designed to cover an arcuate belt of rocks containing, iron, gold, copper, magnesite, ochre, dolomite, limestone and silica deposits (fig. 9).

Previous work includes the just completed 1:50 000 scale Corinna regional geological map in the south of the belt, and the aeromagnetic surveys already mentioned in northwestern Tasmania.

Future work will involve geological mapping of the entire belt at 1:50 000 or 1:25 000 scale north from Corinna map sheet through the Magnet, Trowutta and Burnie map sheets. In addition, there will be collection and reprocessing of gravity, magnetic and physical property data along selected structural profiles of the belt.

CONCLUSION

The benefits of specially-funded projects are that they build on standard Department activities, but that the extra dedicated funding allows the completion of the surveys within a time scale and over sufficiently large areas to be of immediate benefit to mineral explorers. Also, as these mission-oriented projects employ people who are assigned exclusively to them and are therefore less likely to be diverted by other priorities or events, they are extremely cost effective in producing the required resource information.

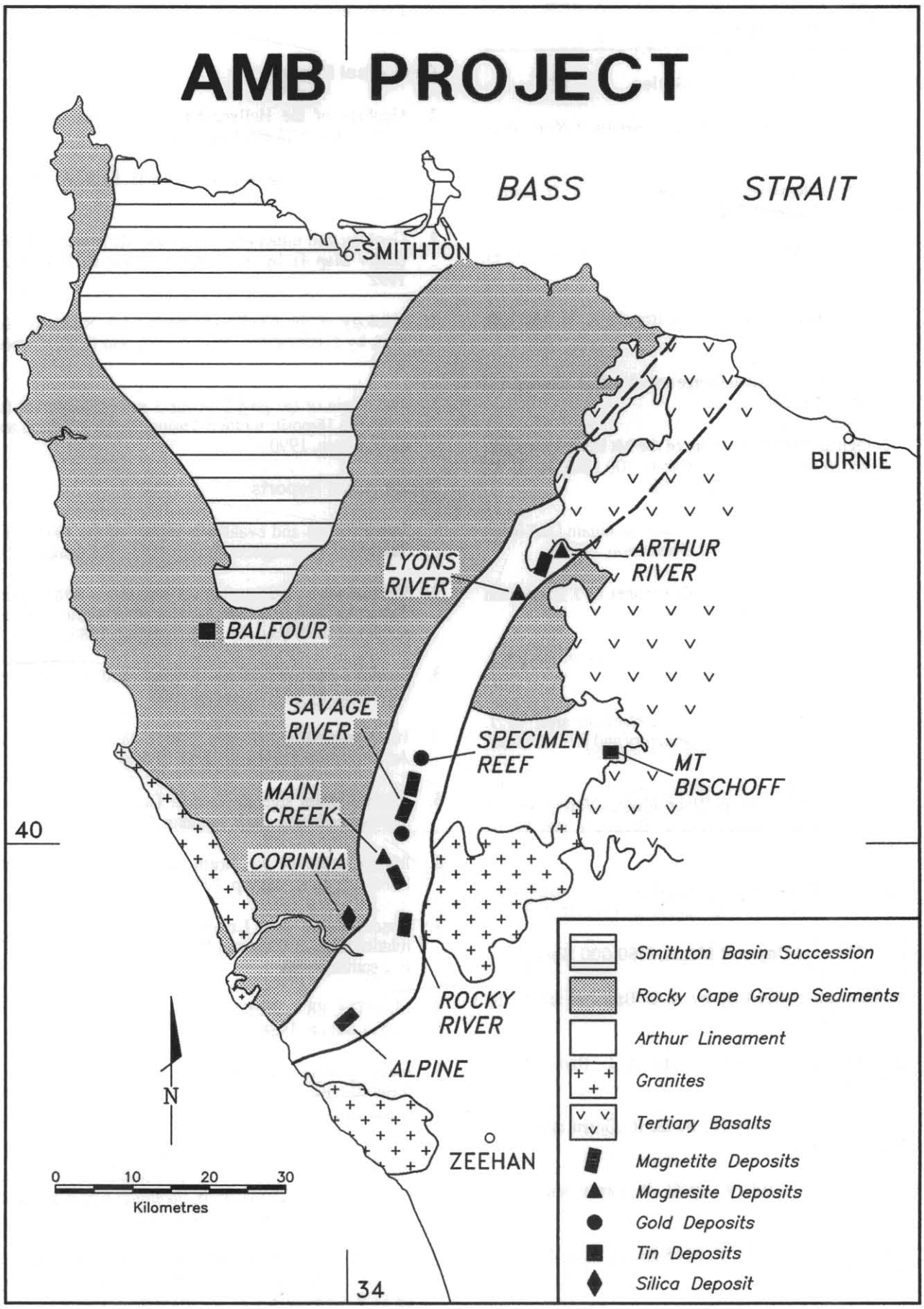


Figure 9

Geological outline of AMB project.

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11/12

INTERIM LIST OF MT READ VOLCANICS PROJECT PRODUCTS

Geological Maps, 1:25 000 Series

1. Geology of Mt Charter–Hellyer area, by P. Komyshan, 1986
2. Geology of Rosebery–Mt Block area, by K. D. Corbett and A. W. McNeill, 1986
3. Geology of Henty River–Mt Read area, by K. D. Corbett, 1986
4. Geology of the Mt Murchison area, by A. W. McNeill, 1987
5. Geology of the Tyndall Range area, by K. D. Corbett and J. C. Jackson, 1987
6. Geological compilation map of the Mt Read Volcanics. Hellyer to South Darwin Peak (1:100 000), by K. D. Corbett and A. W. McNeill, 1988
7. Geology of the Back Peak–Cradle Mountain Link Road area, by M. J. Vicary and J. Pemberton, 1988
8. Geology of the Mt Cattley–Mt Tor area, by J. Pemberton and M. J. Vicary, 1988
9. Geology of the Winterbrook–Moina area, by J. Pemberton and M. J. Vicary, 1989
10. Geology of the Elliott Bay–Mt Osmund area, by J. Pemberton, M. J. Vicary, J. Bradbury and K. D. Corbett, 1991
11. Geology of the Wanderer River–Moores Valley area, by M.J. Vicary, J. Pemberton, J. Bradbury and K. D. Corbett, 1992
12. Geology of the D'Aguilar Range area, by J. Bradbury, J. Pemberton, M. J. Vicary and K. D. Corbett, 1992

Metallic Mineral Deposit Maps, 1:50 000 Series

1. Andrew, Sheet 8013-III, by A. L. Bamford and G. R. Green, 1986
2. Queenstown, Sheet 8013-IV, by A. L. Bamford and G. R. Green, 1986
3. Rosebery, Sheet 8014-III, by G. R. Green and A. L. Bamford, 1986
4. Tullah, Sheet 8014-IV, by G. R. Green and A. L. Bamford, 1986
5. Cethana, Sheets 8114-IV, 8115-III, by A. L. Bamford and G. R. Green, 1988
6. Ulverstone, Sheets 8115-III, IV, by A. L. Bamford and G. R. Green, 1988
7. Elliott Bay, Sheets 7912-II, 8012-III, by J. Taheri and G. R. Green, 1988
8. Loongana, Sheets 8015-II, III, J. Taheri and G. R. Green, 1989

Geological Reports

1. Geology of the Hellyer–Mt Charter area, by K. D. Corbett and P. Komyshan, 1989
2. Geology of the Tullah–Mt Block area, by A. W. McNeill and K. D. Corbett, 1989
3. Geology and mineralisation of the Mt Murchison area (MRV Map 4), by A. W. McNeill and K. D. Corbett, 1992
4. Geology of the Cradle Mountain Link Road–Mt Tor area, by J. Pemberton, M. J. Vicary and K. D. Corbett, 1991
5. The origin of the gold-tin-copper mineralisation at the Lakeside Deposit, western Tasmania, by J. Taheri and G. R. Green, 1990

Geophysical Reports

1. Interpretation and evaluation report on the 1981 West Tasmania Aeromagnetic Survey, by D. E. Leaman, 1986
2. Preliminary interpretation report — 1985 West Tasmania Aeromagnetic Survey (Macquarie Harbour south to Elliott Bay), by D. E. Leaman, 1986
3. Gravity interpretation — West and North-West Tasmania, by D. E. Leaman, 1986
4. Interpretation of the North-West Tasmania Aeromagnetic Survey, by J. R. Bishop, 1987
5. Mineralisation signature study: Geophysics — gravity and magnetics, by D. E. Leaman, 1987
6. Interpretation of the North Tasmania Aeromagnetic Survey, by J. R. Bishop, 1987
7. Precambrian and Lower Palaeozoic structural relationships of West and North-West Tasmania, by D. E. Leaman, 1988
8. MANTLE 88 — Regional gravity field, Tasmania, by D. E. Leaman, 1988
9. Geophysical signatures of western Tasmanian mineralisation. Volume 1. Signatures of mineral deposits, by J. R. Bishop and R. J. G. Lewis, 1988
10. Geophysical signatures of western Tasmanian mineralisation. Volume 2. Electrical properties of western Tasmanian materials, including Appendix: Data listing, by J. R. Bishop and R. J. G. Lewis, 1988
11. The granites of West and North-West Tasmania — a geophysical interpretation. (*Bull. geol. Surv. Tasm.* 66, by D. E. Leaman and R. G. Richardson, 1989

Sub-Basalt Drilling

1. Completion report: Hole 1, by P. W. Baillie (*Unpubl. Rep. Dep. Mines Tasm.* 1987/38)

12/12

2. Completion report: Hole 2, by P. W. Baillie (*Unpubl. Rep. Dep. Mines Tasm.* 1987/40)

3. Completion report: Hole 4, by P. W. Baillie (*Unpubl. Rep. Dep. Mines Tasm.* 1987/61)

4. Completion report: Hole 6, by P. W. Baillie and G. R. Green (*Unpubl. Rep. Dep. Mines Tasm.* 1988/06)

5. Completion report: Hole 7, by P. W. Baillie and G. R. Green (*Unpubl. Rep. Dep. Mines Tasm.* 1990/05)

6. Completion report: Hole 9. by P. W. Baillie and G. R Green (*Unpubl. Rep. Dep. Mines Tasm.* 1988/07)

7. Progress report on Sub-basalt Drilling Project, by P. W. Baillie, G. R. Green and P. L. F. Collins, (*Unpubl. Rep. Dep. Mines Tasm.* 1987/44)

Symposium

The Mt Read Volcanics and associated ore deposits. Geological Society of Australia, Tasmanian Division, Hobart. Edited by R. R. Large, 1986.

GSB70_70_82

1/13

Current systematic regional mapping — new potentials for mineral discovery

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ABSTRACT

The current programme for the systematic, multi-purpose, geological maps of the Geological Atlas 1:50 000 Series includes the revision of the 25-year old map of the Zeehan Quadrangle in western Tasmania, the mapping of the Trowutta Quadrangle in northwestern Tasmania, and the mapping of the Alberton Quadrangle in northeastern Tasmania.

Although the scale of publication is 1:50 000, compilation of field data occurs on 1:25 000 scale maps. The latter maps contain more data than can normally be represented on the 1:50 000 scale maps of the Geological Atlas Series, and the field maps can be made available for copying on request.

Mapping of the Alberton Quadrangle and compilation of field data has been completed. It is anticipated that this map will be published during the 1992/93 financial year. Field revision of the Zeehan Quadrangle has been completed and map compilation is in progress. A publication date of late 1993 is envisaged for this map, although provisional compilation sheets are available. Compilation of completed field mapping on the Trowutta Quadrangle is expected by June 1993.

GEOLOGICAL ATLAS 1:50 000 SERIES — ZEEHAN QUADRANGLE

INTRODUCTION

New discoveries of major importance arising from revision of the Zeehan Quadrangle geological map include:

1. extensive thrust faulting throughout the Cambrian volcano-sedimentary sequence.

2. early-stage Devonian thrust faulting of Precambrian rocks across Cambrian ultramafic-mafic and sedimentary sequences and Ordovician limestone. This phase of thrusting was first recognised in the Macquarie Harbour Quadrangle by M. P. McClenaghan in 1984.

3. possibly late-stage Devonian reverse faulting in the western part of the quadrangle.

4. post-Permian shortening of possibly 20%, as seen in the Zeehan Tillite.

These structures affect the main sequences hosting mineralisation; these are the Precambrian carbonate horizons, the Eocambrian Success Creek Group, the Cambrian volcano-sedimentary formations, the Ordovician Gordon Limestone, and the overlying Siluro-Devonian Bell Shale.

The implications of the proven thrust faulting extend well beyond the Zeehan Quadrangle because, as well as being recongised in the Macquarie Harbour area, it has also been demonstrated in the as yet uncompleted mapping of the Point Hibbs Quadrangle and was also described on the northwest coast by Burns (1964).

PRECAMBRIAN ROCKS (RHF)

The Precambrian sequence is represented by the Oonah Formation to the west and northwest of Zeehan, and a sequence of dominantly quartzwacke sandstone, siltstone, pelite, and their schistose derivatives near Dundas (Dundas Inlier; Turner *in* Burrett and Martin, 1989). The Oonah Formation has been assigned a Precambrian age on the basis of its complex deformational history, its relationship to rocks of possible Eocambrian age, and whole-rock K-Ar radiometric ages of about 680–690 Ma (Adams *et al.*, 1985). The supposed Precambrian rocks of the Dundas area have been assigned a Precambrian age on the basis of one K-Ar whole rock age of 684 ± 10 my from a slate bed (Adams *et al.*, 1985).

OONAH FORMATION

Introduction

The Oonah Formation is dominantly a quartwacke sandstone/siliceous siltstone/pelite association also containing highly carbonaceous, sulphide-bearing slate beds. It also contains subordinate, highly vesicular pillow lavas of small areal extent and which, in places, appear to be large boudins. Also present are carbonate beds which have acted as hosts for the Sn-Pb-Zn mineralisation derived from the Devonian Heemskirk Granite.

Other than within the thermal aureole of the Heemskirk Granite, metamorphism in the Oonah Formation is of low grade. In the east, the pelitic beds display a slaty cleavage and a sub-phyllitic appearance, whereas to the west (Reece Dam area; northern Granville Harbour) the rocks are strongly schistose and are of low greenschist facies grade.

EVERARD, J. L.; FINDLAY, R. H.; MCCLENAGHAN, M. P.; SEYMOUR, D. B.; BROWN, A. V. 1992. Current systematic regional mapping — new potentials for mineral discovery *Bull. geol. Surv. Tasm.* 70:70–82.

2/13

Structural geology

The Oonah Formation is generally more complex structurally than the adjacent Eocambrian and Cambrian sequences, although five deformations have been identified adjacent to deformed faults in some Eocambrian beds.

Three deformational events may be identified at many outcrops within the Oonah Formation, and analysis of outcrops along the Zeehan–Granville Harbour and Zeehan–Trial Harbour roads has indicated that as many as five cleavage-forming events have occurred. The first formed fabric (S_1) is related to isoclinal folding and boudinage, is invariably a weak to strongly-developed schistosity (equivalent in appearance to textural zones 2A to 3A of Bishop, 1972), and is oriented generally parallel to subparallel to bedding. The subsequent cleavages are crenulation cleavages following northeast, north, west, and WNW to NW trends. Additional structural complexity is conferred by at least two generations of probably Devonian thrusting and possibly synchronous and younger steeply-dipping faults.

This thrusting is of prime importance to the relationship between the Oonah Formation and younger rocks, and may be of key economic importance in respect of mineral exploration programmes within the younger rocks. It is presently thought that two episodes of thrusting have affected the Oonah Formation. The first event (10th Legion Thrust) was described in detail by Findlay and Brown (1992) in the Comstock Mine area (fig. 1 and 2), where there is clear evidence that the Oonah Formation has been thrust southeast, over probably Middle Cambrian ultramafic and mafic rocks which include boninitic lavas, a probable Middle Cambrian sedimentary sequence which includes possible correlates of the Dundas Group, and possibly Ordovician limestone beds. These last are thought to be hosts for the mineralisation in the 10th Legion Mine area (fig. 1).

Findlay and Brown (1992) argued that the thrust plane was folded and thus occurred during the early phase of Devonian deformation. In contrast, thrusts and reverse faults seen in the Oonah Formation by Findlay in the Piney Creek area, and by Goscombe (unpublished data) in the coastal section north of Granville Harbour, may have formed during the later stage of Devonian deformation. Goscombe (unpublished data) reports:

- high-angle thrusts related to monoclinal folds;
- the thrusts follow the axial planes of the folds;
- the reverse sense of movement is consistent with the vergence of the monoclines;
- the sense of shear is southwest over northeast (contrary to that of the 10th Legion Thrust);
- the thrusts are not folded by the folds affecting the Ordovician–Early Devonian sequence;
- the thrusts follow the 80–110° trend of the cleavage developed in the Duck Creek syncline.

This syncline has been described by Williams (1976) as due to late-stage Devonian folding, although Goscombe (unpublished data) has suggested that from the outcrop pattern, the Duck Creek Syncline has been cross-folded by northwest-trending folds. The northwest-trending folds elsewhere in western Tasmania have been referred to as post-dating the east-west folds (Williams, 1976).

These new reports of thrusting extend the work of Burns (1964), who described both early and late-stage Devonian thrust-faulting in the Devonport Quadrangle. They also reaffirm the observations made first by McClenaghan in 1984, during mapping of the Macquarie Harbour Quadrangle (McClenaghan and Findlay, 1989), that Devonian thrusting has juxtaposed Precambrian rocks over younger sequences. Data from the as yet uncompleted mapping of the Point Hibbs Quadrangle (Brown *et al.*, 1991; McClenaghan *et al.*, in press) have confirmed the earlier observations of Carey and Berry (1988) that later Devonian thrusting, such as that described by Goscombe (unpublished data) in the Zeehan Quadrangle, is also important.

The recognition that thrusting has had a major role to play in Devonian tectonics, and that this has involved Precambrian rocks, is of major importance in interpreting the regional geology of western Tasmania, and, given the possibility of regionally-extensive thin-skinned tectonics, may extend the prospectivity of this region to include areas formerly thought to be of little economic consequence.

PRECAMBRIAN ROCKS OF THE DUNDAS AREA (DUNDAS INLIER)

These units have been correlated with the Oonah Formation because of their similar lithology and their structural and metamorphic complexity (see Blissett, 1962; Turner, 1979; Turner *in* Burrett and Martin, 1989). Geochronological data, in the form of a single K-Ar whole-rock age from a very low-grade slate bed (Adams *et al.*, 1985), may support this proposal.

The non-metamorphosed rocks consist of slate-grade quartzwacke sandstone, pelite, and slate beds which also contain dark graphitic slates. The sequence passes apparently gradationally into a phyllite-dominated sequence including quartz-rich schist and dolomite horizons (Concert schist; Blissett, 1962). The transitional zone appears to be from only a few tens of metres wide to missing in the northern part of the inlier, in contrast to the central area where the transitional zone is 0.5 km wide. This suggests that faulting has cut out part of the transitional zone, although the fault(s) have not been clearly identified.

The Concert Schist contains numerous quartz 'sweats' which have been mined; the adits are short and were presumably unproductive. Much mining activity has been carried out in the ridge south of Comet Creek. Here the adits enter the calcareous beds overlying the fault separating them from the rocks of the Dundas Inlier. This mine area is close to the presently productive South Comet Mine, in which the mineralisation (Zn-Pb-Sn) appears to fault controlled and hosted in carbonate veins. The fault contact between the Dundas Inlier and the adjacent rocks may therefore also be prospective.

Structural Geology

An as yet incomplete analysis of field observations indicates multiple deformation within the non-metamorphosed part of the sequence. The dominant structures (as exemplified principally between CP708624 and CP703625) are variably oriented chevron folds, some of which display collapsed hinges or which show rapid changes in shape in the fold stack. These folds plunge shallowly to moderately southeast, northeast and also steeply; they include antiformal synforms and upside-down beds. Some of these structures are asymmetric and verge northeast; others are symmetric and

3/13

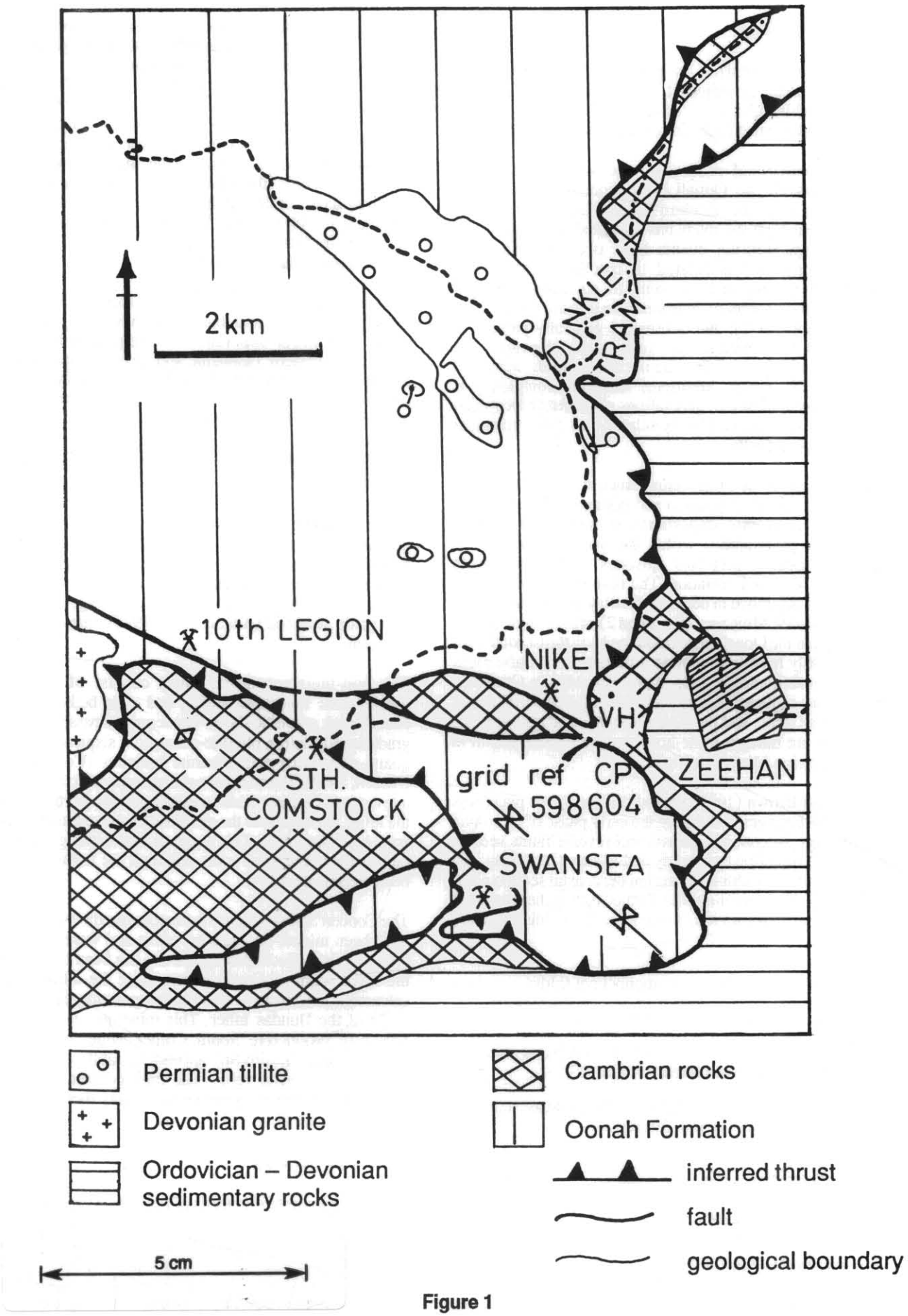


Figure 1

Regional geological summary map showing mapped extent of 10th Legion Thrust. VH = Vanoaness Hill

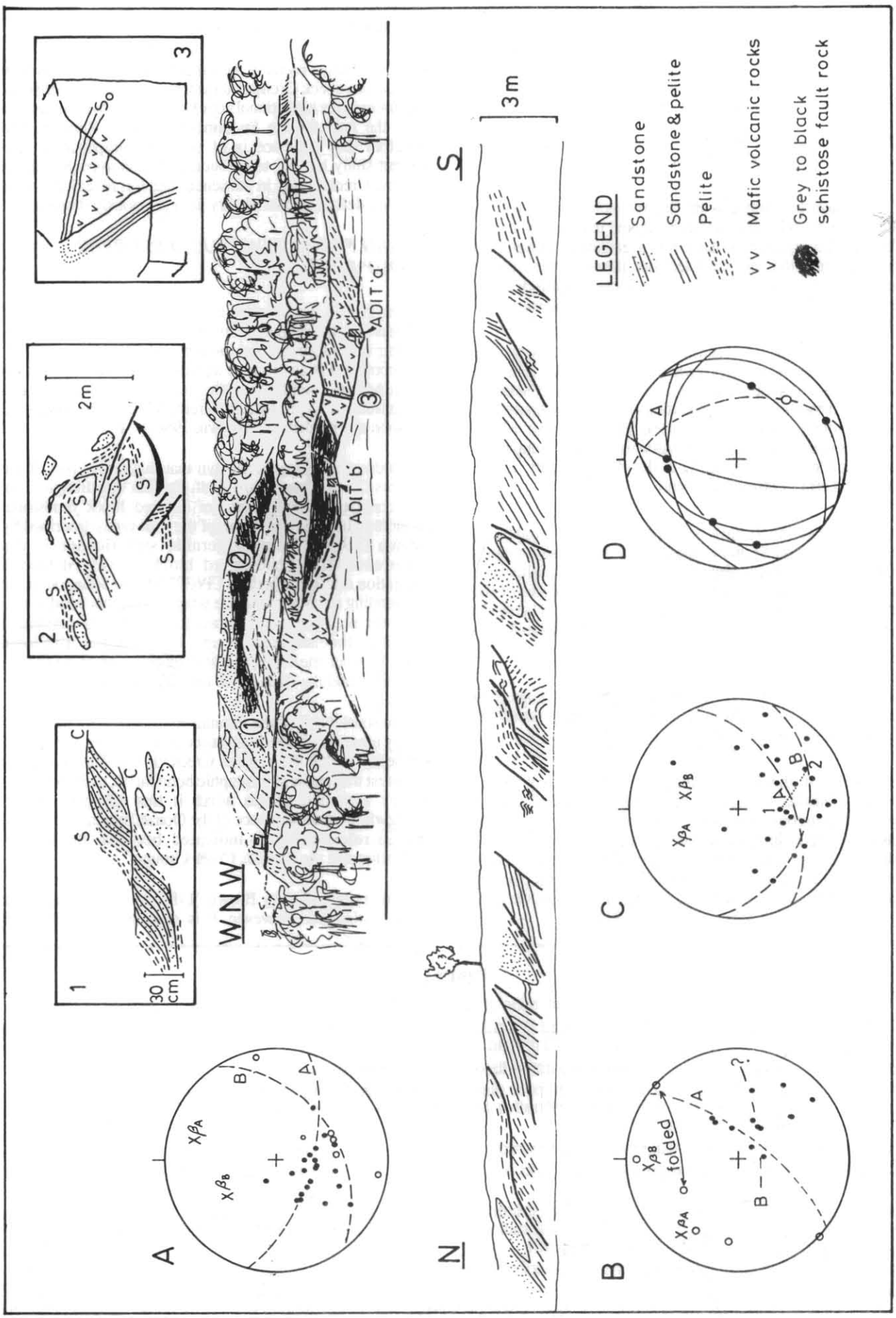

A
B
C
D
N
S
WNW
ADIT 'a'
ADIT 'b'
folded
3 m
2m
30 cm
5 cm
LEGEND
Sandstone
Sandstone & pelite
Pelite
Mafic volcanic rocks
Grey to black schistose fault rock

Figure 2

5/13

either upright or recumbent. Invariably, they all fold a fabric which is penetrative in the siltstone and pelite beds, and which is, in places, slightly (10°) oblique to bedding. Quartz-fibre striations on bedding surfaces and limb faults at low angles to bedding attest to flexural slip during folding.

This structural complexity is less than in the Oonah Formation to the west of Zeehan.

The relationship between the quartzwacke/slate sequence and Concert Schist was first investigated in detail by Turner (1979), who argued that there was a transition between the two units and that the third tectonic fabric in the Concert Schist corresponded to the second weak crenulation cleavage seen only in the slate beds of the quartzwacke/slate sequence.

The present work has confirmed the transition between the Concert Schist and the quartzwacke/slate sequence, although this transition is thought to be faulted. The Concert Schist is dominated by two fabrics, a bedding-parallel schistosity (S_1) and a closely-spaced crenulation cleavage (S_2) which appears to increase in intensity eastward. A third crenulation surface of less intensity to S_2 is developed locally, as are numerous cross-cutting kink bands.

No folds related to S_1 have been identified; S_2 is axial plane to crenulations on S_1 and to mesoscopic folds found mainly in the east. These folds plunge at very low angles, either ESE or WNW. Orientation of S_2 varies; in the major part of the inlier S_2 dips steeply west and strikes ESE to SE, whereas in the southernmost part it dips steeply to vertical and strikes to the south.

Both S_1 and S_2 are recognisable through the transitional zone but cannot be confirmed in this preliminary report as extending into the quartzwacke slate sequence.

The rocks of the Dundas Inlier are faulted against the adjacent Dundas Group. On the hillside south of Comet Creek, calcareous lithicwacke and a sequence of quartz sandstone beds interbedded with carbonate horizons and minor quartz-pebble conglomerate beds appear to be faulted over the rocks of the Dundas Inlier. Here, the fault plane is folded, although immediately east of Kosminski Hill the fault appears to dip south at possibly 30° to 40°.

EOCAMBRIAN ROCKS (RHF)

The Eocambrian rocks in the Zeehan Quadrangle consist of the Success Creek Group and the Crimson Creek Formation. The rocks in the transitional zone between the two formations form the host for the Sn mineralisation at Renison, and therefore this sequence is of economic importance. The present study has led to revision of the stratigraphy of the Success Creek Group in particular, and has revealed a more complex deformational history than previously thought.

OONAH FORMATION / SUCCESS CREEK GROUP BOUNDARY

Brown (1986) argued that in the Pieman River area the Success Creek Group overlies the Oonah Formation with an angular unconformity, and the top of the Oonah Formation here consisted of an "Upper" succession containing units of, "...carbonate, sandstone, fine conglomerate, tuff and volcaniclastic lithicwacke interbedded with laminated siltstone and mudstone" (Brown, 1986, p. 15).

The present mapping has shown that this unit is part of the Success Creek Group (unit Esdf, Zeehan Quadrangle); the unit consists predominantly of sheared black mudstone, including phacoids and lenses of the rock types described by Brown (1986). Of considerable significance is the occurrence of a boudinaged block of veined Oonah Formation sandstone beds at CP632769. The foliation in the surrounding sheared mudstone wraps round this boudin, and truncates a quartz vein within the block and orientated normal to the sandstone layers. This indicates a tectonic hiatus between the deposition and deformation of the Oonah Formation and the shearing of the black mudstone.

On the south bank of the Pieman River, opposite the Misty Valley area, the sheared mudstone unit occupies the core of a syncline within the Success Creek Group. Therefore, this unit must transgress stratigraphic boundaries, as in the Misty Valley area and to the north it lies adjacent to the quartzwacke-slate sequence of the Oonah Formation. Thus a faulted relationship is indicated between the Oonah Formation and the Success Creek Group.

The outcrops visited by Brown (1986) in the Pieman River are now flooded. However, it is clear that the structural

Figure 2

Top sketch: Bird's-eye view of South Comstock Mine area (see legend for rock types).

Bottom sketch: Summary of structures exposed in road north of South Comstock Mine, showing faulting in upper plate immediately overlying the fault rock. Section 40 m long.

Inset 1: C-S structures in rocks of upper plate immediately overlying fault rock.

Inset 2: Transposed isoclinal fold at margin of upper plate and fault rock; the age of this structure relative to thrusting is uncertain; bedding is transposed along a penetrative fabric generally parallel to the S-fabric of the fault rock and the structure is folded by a northward-trending fold.

Inset 3: NW-trending fold in lower plate within layered chert-siltstone-mafic volcanic sequence.

Stereonet A: Poles to C-planes (solid circles) and bedding (open circles) of fold in inset 3. Likely statistical fold axes shown.

Stereonet B: Poles to schistosity (solid circles), commonly parallel to bedding, in the pelitic units in lower sketch section (upper plate rocks). Open circles are crenulation lineations possibly associated with folding on north and northwest trends; note one crenulation lineation is folded, as shown.

Stereonet C: Poles to all faults. Faults 1 and 2 (linked by dotted line) form a fault splay with an interfault angle of 36°.

Stereonet D: Solid great circles with solid circles are faults carrying quartz-fibre striations. The broken great circle represents a tension gash array thought related to slip on fault A, with open circle showing orientation of compression axis.

All stereonets are equal-area southern-hemisphere projections.

history of the Oonah Formation is more complex than that of the Success Creek Group, and that the quartzwacke sandstones of the Oonah Formation show greater recrystallisation and corrosion of grains than do the sandstone of the Success Creek Group. These data support Brown's observations that there is an unconformity between the Oonah Formation and Success Creek Group.

SUCCESS CREEK GROUP

The Success Creek Group is divided broadly into two units; a lower, dominantly quartz sandstone sequence with siltstone, and mudstone beds; Brown (1986) has described local pebbly sandstone and conglomerate horizons. Brown also reports thin tuffaceous horizons; in one thin section of a volcaniclastic fine-pebble conglomerate from these units, which occur in Misty Valley, there is a clast containing chloritic pseudomorphs of pyroxene phenocrysts in a fine matrix. This clast does not contain chrome spinels.

Also present in this sequence are grey-green beds of volcaniclastic lithicwacke and siltstone. These beds contain chloritic pseudomorphs of detrital mafic mineral, together with clasts of devitrified glass and volcanic quartz displaying two or more crystal faces and embayments containing devitrified glass. Such units occur throughout the Success Creek Group and in the Crimson Creek Formation, although they have not been reported previously.

The sandstone beds of this lower sequence commonly display small-scale cross-bedding and also metre-scale cross-bedding in the rare large exposures. The sandstone beds are commonly rich in quartz grains (70–90%) which are generally rounded. Also present are tabular mud flakes (as large as 20 mm in some beds), and detrital mica is found throughout.

The upper unit is a sequence of well-sorted quartz sandstone beds, with grey siliceous siltstone units also containing interbeds of red to purple siltstone, thin red to pink chert horizons, chert pebble conglomerate, pink quartz-sandstone, green siltstone, dolomitic beds, and lithicwacke with mafic and felsic volcanic clasts. The sequence shows lateral facies variations, and the detailed stratigraphy of the mine sequence at Renison Bell may not hold throughout the mapped area.

The upper part of this sequence is notable for the persistent occurrence of one or more horizons (Unit Esdf on Zeehan 1:50 000 map) of black graphitic mudstone containing predominantly blocks and boudins of sandstone; other lithologies are also known in the Misty Valley region, as described above. This unit is invariably intensely sheared and contains cleavage surfaces which have been folded. In some places, it crosses bedding in the structurally underlying sequence at near right angles, although it may be concordant to the overlying beds into which it may grade. In the upper reaches of Crimson Creek the unit has been mapped as separating structurally overlying Success Creek Group beds from structurally underlying units of the stratigraphically higher Crimson Creek Formation.

This black sheared mudstone has been described by Brown (1986, p. 25) as "...highly disturbed sedimentary rocks which show all degrees of deformation from soft-sediment slumping to sliding, resulting in places in a highly deformed melange...[with]...an over and under zone of boudinaged sandstone and blocks of undisrupted laminated material in a schistose and brecciated siltstone-mudstone matrix". Brown described the unit as gradational with the Dalcoath Formation of the Renison Mine sequence. E. Williams (pers. comm., 1992) has indicated that near the Argent Dam, this unit grades into relatively undisturbed siltstone beds showing signs of soft-sediment deformation.

The section studied by Williams (unpublished data) is now covered by gorse. Wherever seen by the present author, this sheared black unit closely resembles the smashed black cataclasites seen along such major faults as the Federal-Bassett and Stanley River Faults, although in contrast to these structures, the unit Esdf is folded by the deformation affecting the Success Creek Group and Crimson Creek Formation. It is therefore likely that unit Esdf (Zeehan Map) has acted as the locus for strain during an early episode of slumping and soft-sediment deformation and later tectonic strain preceding the folding of these two formations, as indicated in Brown (1986).

CRIMSON CREEK FORMATION

The reader is referred to Brown (1986) for a detailed description of this unit, which is dominantly a succession of volcaniclastic lithicwacke sandstone, siltstone and pelite beds. The clastic content is predominantly mafic, although beds with felsic volcanic detritus are also present near the base. Also present are intercalations of basalt and rare carbonate horizons. The Crimson Creek Formation is gradational from the upper part of the Success Creek Group, and given the presence of volcaniclastic lithicwacke horizons in the latter, the contact between the two units is not always easy to define in the field.

Structure

The regional outcrop pattern of the Eocambrian rocks may be interpreted as a Type 2 (Ramsay, 1967) interference pattern, interrupted internally and in the east by faults. The Federal-Bassett Fault (or more correctly fault system) appears to truncate the eastern margin of this possible fold interference pattern.

The earliest structure recognised is the sheared unit Esdf, discussed above. In the area south of the Pieman River this unit, together with the upper part of the Success Creek Group, occupies the core of a tight syncline which is overturned to the northeast and is interpreted as an F_1 fold. This structure appears to be cross-folded about a northwest trend. Detailed geological mapping in the creek system east of Argent Dam has also revealed an outcrop pattern resembling a Type 2 fold-interference pattern, formed by cross-folding of early northeast-verging folds by late northwest-trending structures. Detailed structural analysis of this area is as yet incomplete; the small circle distribution of poles to bedding within this area indicates greater complexity of folding than realised previously (see Brown, 1986).

The latest deformation is restricted to northwest-trending faults, which dip between 40° and vertical. At least one of these structures has a reverse component, as it juxtaposes the Oonah Formation over rocks of the Success Creek Group.

Two cleavages may be recognised in the Eocambrian sequence. The earlier cleavage is slaty in the pelitic beds and is subparallel to oblique to bedding. The second cleavage, recognised principally in the low hills in between about CP670690 and the Upper Cuni River area, and in the Pieman River area, trends NNW to NW as close-spaced but non-penetrative surfaces. This cleavage follows the regional trend of the inferred second phase of folding.

7/13

FOSSILIFEROUS CAMBRIAN AND ASSOCIATED SUCCESSIONS (AVB)

Remapping of the fossiliferous Cambrian and associated volcano-sedimentary rock successions along the eastern side of the Zeehan Quadrangle revealed three sequences which appear to have been proximal, intermediate and distal to felsic volcanism in the Middle Cambrian, but are now juxtaposed by fault or thrust contacts resulting in a east-over-west stacking of originally time-equivalent successions. The result is that successions mapped in the Rosebery area as belonging to the 'Rosebery Group' are now known to occur throughout the eastern side of the quadrangle from the southern end of Colebrook Hill south along the western side of Moores Pimple and Mt Dundas. The South Comet Mine occurs in a succession of interbedded dolomitic mudstone and siltstone, and dolomite, with lenses and interbeds of felsic volcaniclastic conglomerate, sandstone and wacke and minor shard-rich siltstone and andesitic lava, which has been correlated with the "Wescott Argillite" in the Rosebery area (see Green, 1984 for a review of the stratigraphy in the Rosebery area).

The Dundas Group, as found in the Dundas area, still gives a coherent time-rock unit succession, but when similar age successions are encountered to the north, in the Huskisson River, and east, along the western side of the Moores Pimple–Mt Dundas area, the source changes from dominantly mafic volcanic and metasedimentary detritus to felsic volcanic detritus. The only fossil faunas found within the felsic volcaniclastic rocks are Middle Cambrian in age.

The Late Cambrian successions, both within the Zeehan Quadrangle and to the north in the Huskisson River–Burns Peak area (Higgins Creek) (Jell *et al.*, 1991), consist of interbedded, siliceous, open to closed framework, pebble to cobble conglomerate, pebbly sandstone, sandstone and lithic wacke, siltstone and mudstone. Structures, such as the ramp-style thrust fault indicated by the reverse juxtaposition of Late and Middle Cambrian rocks in the Higgins Creek area to the north, probably extend down the eastern side of the Zeehan Quadrangle and produce the observed east-over-west structures along the eastern boundary of the quadrangle.

LATE CAMBRIAN–ORDOVICIAN (DBS)

Remapping of Late Cambrian to Ordovician successions in the Zeehan region has provided greater structural detail, and has indicated significant differences between the main outcrop areas of the Mount Zeehan Conglomerate and its correlates. These differences relate mainly to the presence or absence of recognisable internal stratigraphy in the successions and to clast composition in the conglomerates (possibly suggesting differences in provenance), and may indicate the existence of separate sub-basins during deposition of the formation.

Most of the length of the Professor Range shows Mount Zeehan Conglomerate correlates exposed in a single, consistently southwest-dipping fold limb probably faulted against Gordon Group rocks along its northeastern margin. Consideration of large fold structures in the Eldon Group to the northwest of the range suggests that this pattern may have resulted from telescoping of one limb of a large northwest-trending anticline over the other, perhaps by movement on a low-angle scissor fault hinging near CP648523. Only on the southeastern end of the range is a complete large fold closure present, corresponding to a syncline in the Eldon Group just to the north. The Professor Range sequence shows a recognisable stratigraphy of four units (the lower two being thin and impersistent), and overall contains a higher proportion of sandstone than the Mt Zeehan sequence. Conglomerate clasts are dominantly quartzite (including foliated metaquartzite), with lesser vein quartz, chert ranging from minor to 24%, and minor quartz sandstone, indicating a dominantly Tyennan provenance. Contact relationships are inconclusive with the underlying fossiliferous Cambrian sequence, but are gradational with the overlying Moina Sandstone.

The Mount Zeehan Conglomerate at Mt Zeehan is exposed in a large open northwest-trending anticline. In comparison to the Professor Range, the sequence shows no recognisable internal stratigraphy, is thicker and generally coarser (to boulder grade) overall, and commonly shows distinctly purplish weathering due in part to clast composition dominated by ferruginous quartz sandstone, with lesser quartzite, vein quartz and minor chert. The provenance may be dominantly non-Tyennan. Upper and lower contact relationships are similar to those at Professor Range.

In comparison to the other areas, the Mount Zeehan Conglomerate–Moina Sandstone sequence in the Duck Creek area is very much thinned, and the conglomerate is commonly only pebble grade with clasts dominantly of quartz. The sequence here rests with angular unconformity on the Precambrian Oonah Formation.

Mineralisation in the Late Cambrian to Ordovician sequences in the Zeehan region is essentially restricted to the carbonate rocks of the Gordon Group, which are poorly exposed at the surface. The following account is summarised from Taylor (1989). The greatest concentration of Pb-Zn-Ag mineralisation in the Gordon Group carbonates is in the Zeehan Mineral Field, where several deposits were mined for their Pb-Ag content. Compared to other deposits of the Zeehan area, the carbonate-hosted orebodies were less attractive mining propositions because of lower Ag content and the high production costs caused by poor ground and high water inflows. The most significant deposit was Oceana [CP622574]. A re-evaluation of this deposit in 1978–1984 defined two distinctly different styles of mineralisation: one, grossly discordant to the host rock, consisting mostly of generally coarse galena, sphalerite and siderite occurring as open-space infillings of veins, cavities and intraclastic areas of breccias in a recrystallised, silicified and dolomitised limestone; the other comprising two separate stratiform horizons of semi-massive fine-grained galena, sphalerite and siderite, with replacement-indicative textures, lying at the top and bottom of a 30 m thick unit of limestone breccia. The previously accepted genetic model for the Oceana deposit involved deposition in structurally-controlled fissure veins from mineralising fluids emanating from the Devonian Heemskirk Granite. However, the whole deposit is now regarded as a variant of the sedimentary exhalative class and therefore Ordovician in age, an interpretation supported by recent Pb isotope determinations on galena. The distinctive limestone breccias are now thought to be of submarine debris-flow origin during deposition of the Gordon Group. Recent exploration activity in the vicinity of other, more minor old workings in the Gordon Group has discovered low-grade sub-economic mineralisation in three stratigraphic positions at the base, middle and top of the sequence. In some of these occurrences the mineralisation is

syndiagenetic, similar to the stratiform part of the Oceana deposit.

ELDON GROUP (MPM)

Remapping of the Eldon Group rocks in the Zeehan area has confirmed the stratigraphy described by Blissett (1962). More structural data has been obtained from the eastern outcrops of the group, and the pattern of faults has been partly modified based on re-interpretation of the data.

DEVONIAN GRANITOIDS (MPM)

The Heemskirk Granite intruded the Precambrian Oonah Formation in the Late Devonian, and has been recognised as a composite body consisting of red and white granite (Brooks and Compston, 1965; Klominsky, 1972). The present mapping has confirmed the essential accuracy of Klominsky's mapping and has made only minor alterations to his boundary between the red and white granite types. The texture of both granite types ranges from porphyritic to equigranular and from fine-grained to coarse-grained. The red granite is intruded and underlain by the white granite, although intrusion of the white granite must have closely followed the red as they are indistinguishable on radiometric age (Brooks and Compston, 1965). In spite of the colour difference the two granite types are very similar in chemical and mineralogical composition. The white granite generally has a greater abundance of miarolitic cavities, has more quartz-tourmaline segregations and nodules, and is more altered. The red granite was formed by multiple intrusions which produced layers, each of which intruded and chilled against an upper previous layer. Evidence for multiple intrusion in the white granite is present in a few localities, although there is a general increase in the grainsize away from the contact with the red granite.

The mode of formation of the granite body appears to be by intrusion of sheets into space formed by subsidence within a cauldron-type structure (Klominsky, 1972; Hajitaheri, 1985).

Both the red and white granite consist of quartz, feldspar and biotite, with minor amounts of hornblende present in some areas of the red granite. Accessory magnetite, sphene and allanite are confined to the red granite, which suggests that it is an I-type granite, whereas the mineralogy of the white granite is consistent with it being an S-type granite. The composition of the body ranges from adamellite to alkali-feldspar granite.

Both granite types are peraluminous and show LREE enrichment and HREE depletion with a negative Eu anomaly.

Exsolution of hydrothermal fluids following crystallisation of the granite was greatest for the white granite, but occurs in both types and has produced widespread alteration of the feldspar and mica. In addition, segregations and nodules of quartz-tourmaline are common in both the main granite types, particularly near the finer-grained tops to sheets and near the contact of the white granite with the red. Quartz-tourmaline veins following the cooling joints are widespread, particularly in the lower part of the red granite. Cassiterite mineralisation occurs in these veins in the southern part of the body, and the veins also include topaz and sulphides. The hydrothermal fluid has also penetrated the country rocks, and the present mapping has partly defined the zone within which tourmaline, derived from the granite, has been deposited.

Gravity data indicate that granite occurs within two kilometres of the surface over a large part of the Zeehan Quadrangle in a zone extending eastward from the Heemskirk Granite in the direction of the Granite Tor Granite (Leaman and Richardson, 1992). Most of the known mineral deposits in the Zeehan area occur within this zone and are considered to be related to the granite intrusion. The deposits include the dominantly carbonate-replacement tin deposits at Renison and Zeehan, and the Pb-Zn-Ag deposits in the mines near Zeehan. Host rocks for these deposits are the Precambrian Oonah Formation, the Eocambrian Success Creek Group, and the Crimson Creek Formation.

The original source for the tin in the mineralising fluid is clearly the Devonian granite, but the Pb-Zn-Ag mineralisation related to the granite in the Zeehan area appears to be a result of scavenging of these elements from the rocks through which the hydrothermal fluids from the granite passed. The Gordon Limestone, which is host to Pb-Zn-Ag exhalitive mineralisation (Taylor, 1989), and the Eocambrian Crimson Creek Formation are possible sources for these elements, and the presence of these units closely above postulated subsurface extensions of the granite may enhance the prospectivity of an area. As faults provide a conduit for the hydrothermal fluids from the granite, areas close to faults, even where the granite is considered to be at greater than two kilometres depths, may be prospective. The revision of the Zeehan map sheet has produced more detailed subdivision and distribution of these rock units and the location of faults, which will be of assistance in identifying exploration targets.

PERMIAN TILLITE (RHF)

STRUCTURE

Goscombe (1991) has demonstrated that there exists a cleavage of a 'diamond' pattern in beds of the Permian tillite which are exposed in the Montana Mine region and in the Reece Dam area. The cleavage is formed by a dominant surface following a northwesterly trend, together with a less dominant surface along a NNW trend. This cleavage is not the bedding-parallel cleavage described by Blissett (1962). Goscombe (1991) argued that the tillite has been folded about the northwest-trending cleavage, and that the outcrop pattern of the tillite in the Montana Mine region resembles a northwest-trending synformal basin. The cleavage is, "...apparently defined by aligned platy minerals in hand specimen, and has given rise to a finely spaced (<1 mm) foliation in many outcrops. In outcrop the cleavage is most easily discerned as very obvious cleavage planes spaced at 1–8 mm and accentuated in definition by recent weathering" (Goscombe, 1992, p. 4). E. Williams (pers. comm., 1992) has indicated that such seamed cleavages require a minimum shortening of 20%. Therefore, this first report (Goscombe, 1991) in the Zeehan area of post-Permian cleavage formation is of considerable importance in regional structural analysis.

In this context it should also be noted that Blissett (1962) cites the report of Campana and King (1958) that, in the now-flooded Montana Mine, the Oonah formation has been reverse-faulted over the Permian tillite by a northeast-dipping structure (Blissett, 1962, fig. 12), and that they regard the Oonah Formation in the Tasmanian Mine (southeast of the Tenth Legion Mine) as thrust over the pre-Permian surface. This later structure is presumably the

9/13

Tenth Legion Thrust, which in the Tasmanian Mine area Blissett and Gulline (1962) mapped as truncating beds of Permian tillite. Brown (pers. comm., 1992) has indicated that no beds of Permain age or characteristics have been found at these localities; rather the beds in question are interbedded siltstone and chert-granule conglomerate of probable Cambrian age. However, there does remain the possibility of re-activation of parts of the Tenth Legion Thrust during post-Permian faulting.

Finally, cleaved Permian tillite occupies the deeply incised valley of Stringers Rivulet in the region due north of the abandoned HEC camp east of the Reece Dam. To the north of these outcrops, the Oonah Formation occupies the high ground; however, the contact between the two formations has not yet been examined.

PERMIAN AND YOUNGER SUCCESSIONS (AVB)

Generally, revision of the Permian and younger successions was not carried out in detail, as where these faulted sequences were observed the work of Blissett and Gulline (1962) was confirmed.

GEOLOGICAL ATLAS 1:50 000 SERIES — TROWUTTA (JLE,DBS,AVB)

INTRODUCTION

This project, in the Arthur River–Rapid River area of North West Tasmania, involves detailed mapping of major rock units in the southeastern part of the Smithton Basin, the Rocky Cape Group, and the Arthur Metamorphic Complex. When completed, the work will complement the existing published Smithton and Woolnorth 1:50 000 map sheets to provide a modern geological map coverage of most of the northern half of the Rocky Cape Region of North West Tasmania. Some of the main contributions of the work in this region are given below.

SMITHTON BASIN

STRATIGRAPHY

Knowledge of the stratigraphy and basement-cover relationships of the Late Precambrian to Middle Cambrian Smithton Basin has been greatly improved. This includes confirmation of the existence, in the basin, of two separate carbonate (and chert after carbonate) sequences, and the identification, associated with the lowermost of these two sequences, of volumetrically significant but irregularly developed (?discontinuous) coarse mixtite units containing a polymict assemblage of rock fragments including basalt, chert, and stromatolitic carbonate. One of the mixtite units, underlying the lowermost tholeiitic basalt flow in the Trowutta area, contains acid volcanic detritus which consists of dacitic to rhyolitic lava and welded tuff fragments. The new data are providing a considerably enhanced geological basis for resource assessment and regional and interstate correlations, and sample control for recent stable isotope research on the carbonate sequences. The latter promises to provide important age control on previously poorly constrained Tasmanian ?Late Precambrian–?Early Cambrian rock sequences, and in the Smithton Basin in particular, may confirm the existence of a long-suspected major time break somewhere in the vicinity of the contact between the upper carbonate unit (the Smithton Dolomite) and the overlying fossiliferous late Middle Cambrian to early Late Cambrian clastic sedimentary sequence.

Reconnaissance mapping in the northwestern sector of the Magnet Quadrangle, to the south of Trowutta Quadrangle, has revealed an outlier of Smithton Basin rocks, including Black River Dolomite, chert and basalt, occupying a narrow, 5 km long, east-west trending structural basin in the Leigh River area.

BASALTIC ROCKS

Studies of the petrography and geochemistry of the basaltic rocks of the Smithton Basin have shown that at least four distinct groups are present, each characterised by a distinct range of TiO_2 values. The stratigraphically oldest are low TiO_2 (0.6–0.7 wt.%), MgO-rich basalts with altered phenocrysts of former olivine. These are followed by two younger suites with 1.0–1.1 wt.% and 1.6–1.7 wt.% TiO_2 respectively, containing phenocrysts of plagioclase and/or augite in an altered, fine-grained groundmass. The fourth and possibly youngest suite, with 2.1–2.4 wt.% TiO_2, is restricted to the Montagu area in the Woolnorth Quadrangle (Seymour and Baillie, 1992). Following a preliminary study by Brown (1989, pp. 70–77), the four suites are interpreted as the result of four batches of partial melting, each progressively enriched in TiO_2, Zr and other incompatible elements, and depleted in MgO, Ni and Cr, relative to the previous batch. Each of the four batches has subsequently been modified by crystal fractionation of olivine, or augite and plagioclase, following a tholeiitic differentiation trend. Trace element and rare-earth element data confirm that the latter two augite-plagioclase-phyric suites are correlates of the tholeiitic basalts within the Crimson Creek Formation of the Zeehan area. Most samples are highly magnetic, and their regional distribution is obvious on contoured aeromagnetic maps.

DOLERITE DYKES WITHIN THE PRECAMBRIAN ROCKY CAPE GROUP

The dolerite dyke swarm within the Rocky Cape Group, which extends from the Norfolk Range, east of Balfour and through the Rapid River area to the north coast, is being mapped and studied petrologically. Although at an early stage of assessment, geochemical data suggest that at least two of the five types of dyke identified by Brown (1989) on the north coast are present in the Trowutta Quadrangle. These are his "massive tholeiitic" and andesitic "calc-alkaline" types. However, the data do not support Brown's suggestion that the former may be feeders for the Eocambrian basalts of the Smithton Basin.

ARTHUR METAMORPHIC COMPLEX

Further progress has been made on the determination of the internal structure and lithological subdivision of the northern part of the economically important Arthur Metamorphic Complex. This hosts the Savage River iron ore deposit and also contains cupriferous sulphide deposits, magnesite deposits, gold-bearing quartz veins and associated alluvial gold, and silicified dolomite units from which have formed residual silica deposits. To date three subdivisions of the Precambrian rocks of this Complex have been recognised in the Keith River–Arthur River–Lyons River area. The westernmost unit comprises a relatively thin belt of phyllite and foliated quartzite, showing both structural and metamorphic transitions westward into the relatively unmetamorphosed Rocky Cape Group (see also Gee, 1977;

Turner, 1990). The central unit comprises commonly chlorite-rich and/or carbonate-rich greenschist-facies schist and subordinate amphibolite, and near its eastern boundary includes magnesite deposits and chalcopyrite-bearing pyrite-magnetite lodes (see also Turner, 1988; 1990). The easternmost unit comprises quartz-muscovite rich schist, phyllite and foliated micaceous quartzite which appear to show gradual metamorphic and structural transitions into relatively unmetamorphosed clastic sedimentary rocks probably equivalent to the eastern sedimentary association of the Rocky Cape Region (the Burnie Formation and equivalents).

STRUCTURAL PROFILES

A detailed composite structural profile is being progressively constructed from the northwest coast near Marrawah, through the Smithton Basin, Rocky Cape Group and the northern part of the Arthur Metamorphic Complex. The structural profile should provide invaluable control on tectonic interpretations (including those based on geophysics) of the various major rock units it crosses. In particular, the profile should enhance understanding of the three-dimensional geometric and structural relationships of the Arthur Metamorphic Complex to the less metamorphosed Precambrian sequences adjoining it to the east and west. It will also provide a basis for comparison with the recently published work on the southern part of the Complex and adjoining sequences in the Corinna area (Turner *et al.*, 1991), and with the proposed northern Tasmania deep seismic profile by the BMR.

GEOLOGICAL ATLAS 1:50 000 SERIES — ALBERTON (JLE,MPM,RHF)

INTRODUCTION

Field work for the Alberton geological map sheet, which also includes the Mathinna, West Pyengana, Upper Blessington and Mt Maurice areas, was completed in December 1991. The publication of this map will complete the first edition 1:50 000 scale Geological Atlas coverage of northeastern Tasmania.

The geology of the quadrangle consists broadly of a lower Palaeozoic turbidite sequence which has been folded and intruded by granitoids in the Devonian, unconformably overlain by Permian sedimentary rocks which have been intruded by Jurassic dolerite, and locally covered by Tertiary basalt flows and Cainozoic sediments.

PALAEOZOIC MATHINNA BEDS AND ENCLOSED AURIFEROUS QUARTZ VEINS

The oldest rocks in the area belong to a quartzwacke/slate turbidite sequence, the Mathinna Beds, which have been folded along NNW-trending axes and have undergone low-grade regional metamorphism in the Early to Middle Devonian in an event correlated with the Tabberabberan Orogeny of eastern Australia. A more detailed discussion of the structures in the Mathinna Beds is given by Goscombe and Findlay (1989).

The Mathinna Beds consist of interbedded sandstone, siltstone and mudstone, and individual units are generally not regionally mappable. However, in the southwest of the quadrangle a lutite-dominated sequence occurs which appears to be a strike extension of similar sequences in the Lebrina–Myrtle Bank and Lefroy–Bangor areas, where these sequences contain Early Ordovician graptolites and are quarried for slate. The main part of the Mathinna Beds in the east of the quadrangle is dominantly a mixed arenite/lutite sequence, although in some areas individual units of mudstone and quartzite can be mapped. This tract, which may belong to the sequence in which Silurian graptolites have been described (G. J. Davidson, pers. comm., 1992; Rickards *et al.*, in prep.), hosts significant and historically important gold mineralisation in a more-or-less linear belt extending from Mangana, through Mathinna and along the Dans Rivulet and Alberton valleys.

Structural studies of the Mathinna Beds, together with reconnaissance fluid inclusion studies by J. Taheri, point to fault control of the auriferous quartz veins which have originated by metamorphic processes unrelated to granitoid intrusion (Taheri and Findlay, 1992). Indeed, it is possible that these quartz veins post-date granitoid intrusion. In addition, structural studies have identified:

- large, generally northwest-trending chevron folds with low to high axial plunges;
- subsequent mega-kinking (Goscombe and Findlay, 1989) across generally northeast kink planes;
- multiple quartz veining; and
- later faulting.

Although the fault relationships are still being analysed, Findlay (in Taheri and Findlay, ibid), based on reconnaissance analysis of striated small faults, has offered the idea that strike-slip faulting is important. This has led to the, as yet unproven, idea that the gold mineralisation along the Mangana–Alberton lineament occurs mainly in veins localised principally at east-stepping, *en echelon* jogs within a broadly northwest-striking dextral strike-slip system.

DEVONIAN GRANITOID MASSES

SCOTTSDALE BATHOLITH

The Scottsdale Batholith is the westernmost of the three major granitoid batholiths in northeastern Tasmania, stretching south from Bridport to the northern flanks of Ben Lomond, where it disappears beneath Permian and Jurassic dolerite cover. In the Bridport–Scottsdale area it is mainly covered by thin Tertiary sediments and basalt, and the best exposures are generally to the south in the Alberton Quadrangle.

The granitoids have intruded the Mathinna Beds, producing narrow contact metamorphic aureoles with assemblages containing biotite and locally cordierite and/or andalusite. Individual plutons are generally steep-sided and elongated north-south in the regional fold trend. Intrusion took place shortly after regional folding. K/Ar biotite dating has given ages of 370–395 Ma and suggests two phases of igneous activity of slightly different age.

Regional geological mapping, aided by petrography and geochemistry, has shown that the Scottsdale Batholith can be subdivided into a number of discrete plutons, which can be grouped into two main geochemical suites; the Diddleum Suite and the Russells Road Suite.

The Diddleum Suite is meta-aluminous, with a few weakly per-aluminous samples, and consists of three granodiorite

bodies. The Diddleum and Porcupine Creek plutons in the western part of the batholith are very similar bodies of equigranular, medium-grained to coarse-grained biotite-hornblende granodiorite, separated by a 2 km-wide screen of hornfelsed Mathinna Beds. Rare augite, surrounded by or closely associated with amphibole (hornblende to actinolite), occurs within some samples from the Diddleum pluton. The Tulendeena pluton, composed of similar biotite-hornblende granodiorite, occurs on the eastern margin of the batholith, east of Scottsdale, and does not extend south to the Alberton Quadrangle. Field relations, such as chilling of other plutons near contacts, indicate that the granodiorites are the oldest components of the batholith.

The Russells Road Suite is weakly per-aluminous and more heterogeneous, ranging in composition from granodiorite to alkali-feldspar granite. The suite consists of four plutons. The most mafic is the Upper Blessington pluton, an irregular body of equigranular to seriate, coarse-grained to very-coarse grained biotite-hornblende granodiorite on the southwestern margin of the batholith, apparently plunging shallowly south beneath the Ben Lomond plateau. Sparse augite also occurs in this granitoid body. To its northeast is the Russells Road pluton, consisting of equigranular, coarse-grained to very coarse-grained, white to pink biotite ± hornblende granodiorite/adamellite, which forms an almost complete rim around the younger, similar but less coarse-grained Hogarth Road pluton. Both the Russells Road and the Hogarth Road plutons become more mafic (granodioritic) to the south, where they contain hornblende, and where the Hogarth Road pluton is characterised by very abundant quartz diorite xenoliths. The youngest major component of the batholith, the Tombstone Creek pluton, forms an elongate body in the centre of the Hogarth Road pluton, and tapers northward and becomes finer grained in the Upper Maurice River area. The pluton consists of sparsely porphyritic, fine-grained to coarse-grained biotite granite/adamellite, with a more leucocratic, equigranular marginal zone of alkali-feldspar granite, characterised by pink K-feldspar and iron-rich biotite (annite). This is attributed to autometasomatism by hydrothermal fluids released by crystallisation of the rest of the body. The pink granite variant of the Russells Road pluton, in the Kamona–Mt Stronach area east of Scottsdale, is very similar and probably formed in the same way.

Thus the Scottsdale Batholith exhibits a roughly zonal arrangement of its constituent plutons, with the older granodiorite plutons near its margins, and the younger granite/adamellite plutons in its core.

In contrast to the abundant tin mineralisation within the Blue Tier Batholith, known mineralisation within the Scottsdale Batholith is confined to a few Sn-Cu-Mo-Bi veins near Mt Maurice, and disseminated Mo at Mt Stronach near Scottsdale, although little exploration has been done. A possible explanation for this apparent paucity of mineralisation may lie in the petrology of the batholith. The presence of hornblende, pyroxene, and accessory minerals such as sphene and allanite, suggest that the granitoids of the Scottsdale Batholith are I-types (i.e. derived from partial melting of igneous source rocks) on the restite model of Chappell and White (1974), whilst most granitoids associated with tin mineralisation in Tasmania and elsewhere are S-types (i.e. derived from partial melting of sedimentary source rocks). Possibly Cu-Mo stockwork or disseminated mineralisation would represent a more appropriate target in this I-type batholith, although results to date have been disappointing (e.g. Ellis, 1984).

The Ben Lomond/Royal George Granite, lying south of the Ben Lomond plateau, has certain geochemical similarities with the Tombstone Creek Granite, and may represent an extreme fractionated phase (Findlay *et al.*, in prep.). However other evidence, such as abundant Sn-W mineralisation, accessory minerals and the lack of associated granodiorite, does not support its assignment to the Scottsdale Batholith.

The Tombstone Creek pluton, its marginal zone, and the chilled margin of the Russells Road pluton are currently all being quarried for building stone (trade names "Martich", "Jaydon" and "Tequila" respectively). The granodiorite plutons are also considered to have high to medium prospectivity for this commodity (Sharples, 1990).

BLUE TIER BATHOLITH

Part of the Blue Tier Batholith, lying in the northeastern part of the Alberton Quadrangle, has also been divided into constituent plutons. The Pyengana pluton consists of equigranular hornblende-biotite granodiorite, and is usually strongly magnetic. Marked local variations in susceptibility, and some large areas of relatively non-magnetic granodiorite, are attributed to fluctuations in oxygen fugacity during crystallisation of the magma, resulting in a variable abundance of magnetite, rather than separate intrusions. As noted in an earlier regional study by Gee and Groves (1971), this pluton is divided by an apparently dilational, dyke-like arm of the Poimena pluton (biotite ± muscovite granite/adamellite), in the vicinity of which the granodiorite is foliated, sometimes intensely so. However the southern portion of Groves' Poimena pluton is a slightly more melanocratic biotite adamellite with occasional hornblende, and represents the separate Haleys New Country pluton. It is separated from the Pyengana granodiorite by a wedge of Mathinna Beds, and is truncated by the arm of the Poimena pluton, also with local development of grain foliation near the contact. Mineralogical and geochemical data indicates that both the Pyengana and Haleys New Country plutons are I-type granitoids, with the later Poimena pluton having an ambiguous signature.

This part of the Blue Tier Batholith has little known mineralisation. However the Mt Paris pluton (associated with Sn mineralisation), which crops out just to the north of the map sheet, dips shallowly and irregularly beneath the northern part of the Rattler Range, making this area prospective for Sn-W mineralisation.

PARMEENER SUPERGROUP

The flat-lying Parmeener Supergroup, which unconformably overlies the basement rocks, is restricted in this area to a generally thin cover in highland areas. The unconformity on Mathinna Beds is usually nearly planar, and at Mathinna Plains and elsewhere corresponds to a striking physiographic surface at about 800 m elevation, representing an exhumed Carboniferous peneplain. On granitoid basement the base of the Supergroup is generally topographically more irregular. Regionally the rocks of the Supergroup dip at a few degrees to the south, and are disrupted by numerous, often NE-SW or NW-SE trending normal faults with small throws, which are often difficult to trace far into the basement rocks. The rocks of the Parmeener Supergroup are marine and non-marine sandstone, siltstone, mudstone, minor carbonaceous shale and basal conglomerate, wholly of Early to Middle Permian age. Correlates of the Castle Carey Formation (upper glaciomarine sequence), Aberfoyle

Formation (lower freshwater sequence), and Strickland Gorge Formation (lower glaciomarine sequence) have been mapped. In the eastern part of the quadrangle, the latter contains a stratigraphically lower, massive quartz sandstone facies which probably represents freshwater sedimentation during an earlier period of emergence, before deposition of the Aberfoyle Formation. No indication of coal or oil shale is known, and, except for a remote possibility of fossil placer deposits in basal freshwater units, these rocks are probably of no direct economic significance.

JURASSIC DOLERITE

Jurassic dolerite is confined to residuals capping Ben Nevis, Mt Saddleback, Mt Victoria, Mt Albert, Mt Blackboy and Mt Young. All contacts with the underlying Parmeener Supergroup are obscured by extensive scree and talus deposits, but it is probable that these mountains represent remnants of an extensive dolerite sheet, intruding at the stratigraphic level of upper Permian rocks, and once extending across northeast Tasmania. Feeders have not been recognised within the region. Areas of dolerite in lowland areas, occurring within basement, are shown as occurring within basement on some earlier maps, but these have been re-interpreted as probably older (Tertiary?) talus or lag deposits. Some of these deposits are also associated with similar boulder deposits composed of basal Permian conglomerate.

TERTIARY BASALT

The generally limited flows of Tertiary basalt in the area range in composition from alkali-olivine basalt to olivine nephelinite. Drilling of a small intense magnetic anomaly near Upper Esk has revealed a basaltic pyroclastic vent within the Mathinna Beds, concealed by river alluvium. South of Ringarooma, Olivers Hill represents the probable source of extensive Miocene(?) olivine-nephelinite basalt flows extending northward. The Eocene alkali-olivine basalt and pyroclastic rocks of the Weldborough Pass area extend to West Pyengana, and have been prospected for heavy minerals (Morrison, 1988), notably sapphire and zircon which also have been reworked into local gravels. These and other minerals, such as spinel, garnet and the rare earth phosphate florenceite, represent fragments of high-pressure origin brought to the surface by the basalt.

QUATERNARY ALLUVIUM

Extensive tracts of Quaternary alluvium are present in the Dorset and New River valleys, where they have been worked for gold, and in the South Esk valley near Mathinna, where they have been unsuccessfully prospected for gold (Mellor, 1982).

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The Mt Read Volcanics: An explorer's perspective

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There has been much comment about the mineral recession in Tasmania during the last few years. The level of exploration is a good indicator of pending changes in fortune for the minerals industry. Expenditure during the last 3–4 years has slumped to the lowest level in real terms since 1978 and is currently less than $10 million per annum. The area held under exploration licences has been reduced even more dramatically in this same period.

This paper is presented at a Symposium which is promoting the positive aspects of the minerals industry in Tasmania, in particular the potential for major new mineral developments. Despite the gloom felt by many in Tasmania, there are a number of positive aspects for those explorers in the industry with foresight and conviction. This paper focuses on some of those aspects, in relation to an explorer's perspective of the most productive belt of geology in Tasmania, the Cambrian Mt Read Volcanics.

Availability of coherent parcels of this belt, especially the "most prospective" ground between Hellyer and Mt Lyell, has been very restricted during the last 30 years. When fragments of the belt became available through mandatory relinquishment they were vigorously tendered for, with competition such that in some instances quite small blocks attracted unrealistically high bids. However, during the recent recession significant tracts of highly prospective ground, including parts of the "productive" Mt Read Volcanics became vacant on the mineral tenement maps. Other blocks were held by companies who were actively seeking to farm-out their interest as part of their strategic retreat from the State.

This opportunity has enabled much of the highly sought land to be pieced together to form geologically coherent blocks, without the artificial barriers to exploration imposed by tenement boundaries. Strong tenement holdings enable comprehensive regional exploration utilising all the latest developments in remote sensing, geochemistry and geological models. New exploration plays can be more readily developed and specific target areas discerned from these large, consistent data bases. The Government funded Mt Read Volcanics Project has provided explorers in Tasmania with an outstanding set of regional data, unsurpassed by data from any other comparable area in Australasia. The current geological and metallogenic maps, stratigraphic drilling information, air-borne and ground geophysical data and geochemical studies form a strong framework onto which explorers may build their own results. Whilst this valuable project has recently been terminated, just short of completing the original target of 1:25 000 map sheet coverage, it should be noted that much of the project data is not static. For example, company aeromagnetic and gravity surveys are incorporated into the regional data sets which are available to all explorers, once they become an open file.

The establishment of the Key Centre for Ore Deposit and Exploration Studies (CODES) at the University of Tasmania in 1989 has provided the industry with another source of relevant and current geological information. The CODES staff have formed a strong team of dynamic researchers and lecturers who are to the forefront in many areas of economic geological studies, especially for volcanic-hosted massive sulphide deposits. Explorers are able and encouraged to tap into this expertise through: collaborative research assistance; support for Honours and post-graduate students, supervised by CODES staff, to work on Company projects; attendance at pertinent short courses and by direct consulting work on specific projects.

A recent trip to some of famous volcanic-hosted massive sulphide camps in North America has highlighted the comparative prospectivity of the Mt Read Volcanics. The minerals industry here appears quite buoyant in comparison to the depression overshadowing many of the well known base metal districts in Canada with many mines closed or facing imminent closure and a dramatic down-turn in exploration expenditure. Whilst the Canadian mines have been prolific producers of base metals, they are generally much smaller and lower grade and are often developed on clusters of separate bodies. Many of these deposits have been economically viable only because of high metal prices, lower mining costs and the existence of good infrastructure. This contrasts markedly with the average deposit in Western Tasmania, which is larger and much higher grade and can withstand the mineral price recession, especially when productivity gains are made in mining and processing at older mines, such as Rosebery.

Knowledge from the current wave of study and analysis of the geology of Tasmania is contributing significantly to the understanding of the critical relationships of that geology to mineralisation, as addressed by many papers at this Symposium. Recent encouraging results from exploration indicate that the potential to discover and develop economic deposits in the Mt Read Volcanics is still high. However, these new discoveries will only be made through the major and sustained efforts of serious explorers utilising the best available geological information in a multi-disciplinary program and with a strong commitment to drilling.

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Stable isotopes and geochemistry as exploration indicators

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ABSTRACT

The footwall volcanic sequences to massive sulphide mineralisation at the Hellyer and Hercules mines show an increase in whole-rock $\delta^{18}O$ values from <7 to 10‰ in the alteration pipe, to values of up to 13.8 and 15.7‰ respectively in more distal rocks. These data are consistent with alteration by a fluid with a $\delta^{18}O$ value close to the seawater value of 0‰ with a decline in temperature away from the focus of mineralisation. At Hellyer a similar zonation of increasing $\delta^{18}O$ values away from ore and upward through the section appears to persist in the post-ore basalts. At Hercules the situation is more complex, with decreasing $\delta^{18}O$ values, increasing Mn contents of chlorite, and enrichment of whole-rock K, Rb, S and base metals, together with Na, Ca and Sr depletion occurring progressively up section towards the old East Hercules copper prospect, 300 m east of the mine. These geochemical signatures are similar to those associated with the focus of alteration in the footwall, and may indicate that the hangingwall rocks are prospective for Hercules-style mineralisation. In areas relatively unaffected by Devonian granite-related hydrothermal overprinting, the higher $\delta^{18}O$ values require the interaction of the rocks with considerable quantities of seawater at low temperatures (<150°C), and indicate that sub-sea floor hydrothermal alteration has taken place.

Areas of relatively low $\delta^{18}O$ rocks warrant more intensive exploration, but other techniques are required for more detailed prospect definition. A distinctive style of alteration of plagioclase phenocrysts to carbonate ± K-feldspar is developed adjacent to footwall alteration pipes at both mines, and has also been reported at Rosebery (Green et al., 1981) and Que River (McGoldrick and Large, 1992). Chlorite geothermometry offers promise as a target indicator in the relatively undeformed Que–Hellyer Volcanics, but the compositions of chlorites at Hercules have been reset during deformation. The oxygen isotope compositions of hydrothermal carbonates also offer promise, particularly where the fluid $\delta^{18}O$ value can be constrained independently by fluid inclusion geothermometry.

Many barren pyritic alteration zones can be distinguished on the basis of relatively low (<5‰) $\delta^{34}S$ values.

A combination of careful petrography, fluid inclusion work, and oxygen and sulphur isotope data has confirmed the dominantly Devonian magmatic association of Au-Sn-Cu-As mineralisation in the Lakeside–Sterling Valley area.

INTRODUCTION

Western Tasmania provides a unique opportunity to study a variety of styles of volcanic-associated mineralisation with differing degrees of deformation, metamorphic grade (prehnite-pumpellyite to lower greenschist), overprinting by later magmatic-related alteration, and wall rocks (felsic to mafic composition; lavas and volcaniclastic rocks). However this geological spectrum presents a challenge to the explorer wishing to develop the most effective exploration strategy. Although EM was responsible for the discovery of the Que River and Hellyer orebodies, some ores (zinc-rich and pyrite-poor), with certain geometries (fragmented) and alteration styles (silicification), may not give an EM response (Bishop and Lewis, 1992).

The approach of the Isotope and Alteration Studies component of the Mount Read Volcanics Project has been to provide an integrated approach to the study of rock alteration around massive sulphide deposits, involving petrography, mineralogy, stable isotope and whole-rock geochemistry, and fluid inclusions, with the dual aims of:

1. Defining the extent of alteration haloes around massive sulphide deposits and developing techniques to map palaeotemperatures within the volcanics, and;
2. Developing criteria to enable the distinction between rock alteration associated with polymetallic massive sulphide ore and barren pyritic mineralisation.

This work has relied on the input of a number of people. We would like to express our appreciation to Michael Power, Richie Woolley and Gerritt Kuipers for isotope analyses, Ann Bamford, James Nye and John-Paul van Moort for field and general assistance, Janine Triffett and Jane Mackey for lapidary, and to the drafting, editorial and secretarial staff of the Department of Mines. We also wish to thank Rod Hargreaves for initiating the project and to Dave Duncan for continual support, and to numerous company geologists for discussion, advice and logistical support.

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TECHNIQUES: APPLICABILTY AND LIMITATIONS

OXYGEN ISOTOPES

For recent detailed reviews of the literature on stable isotopes and applications to ore deposits and petrology the interested reader is referred to the Mineralogical Society of America volume *Reviews in Mineralogy* (Volume 16, 1986) and the Mineralogical Association of Canada *Short Course Handbook* (Volume 13, 1987).

Stable isotope analyses are expressed as the permil (parts per thousand) difference of the ratio of the heavier to lighter isotope in a sample from that in a standard. For oxygen isotopes this is written as:

$$\delta^{18}O_{sample} = [(^{18}O/^{16}O)_{sample}/(^{18}O/^{16}O)_{standard} - 1] * 1000‰) \quad (1)$$

where the standard is V-SMOW seawater.

Similar definitions apply to other elements, e.g. C, S, H, N, B etc.

Mineral Applications

The oxygen isotope compositions of minerals can be used as geothermometers in situations where co-existing minerals formed in mutual equilibrium and have not subsequently undergone isotopic exchange, *or* in cases where the oxygen isotope composition of a hydrothermal fluid from which a mineral formed can be determined independently, or be reasonably inferred.

The temperature dependence of oxygen isotope fractionation between two minerals, or a mineral and water can be frequently expressed by:

$$1000\ ln\ \alpha_{X\text{-}Y} = A*10^6 / T^2 + B \quad (2)$$

where $\alpha_{X\text{-}Y}$ is the ratio $(^{18}O/^{16}O)_X/(^{18}O/^{16}O)_Y$,
A and B are constants,
temperature T is in °K.

Because fractionation factors are usually close to unity:

$$1000\ ln\ \alpha_{X\text{-}Y} \approx \Delta_{X\text{-}Y} = \delta^{18}O_X - \delta^{18}O_Y \quad (3)$$

The $\delta^{18}O$ value of fluids in the Earth's crust varies substantially: seawater has a value of 0‰, magmatic fluids have values generally in the range +5 to +8‰, and meteoric waters mostly range from -15 to 0‰ depending on geographic location, the lower values typifying high latitude or high altitude areas. Over the past twenty years, oxygen and hydrogen isotope studies have been used extensively in the identification of the nature of fluids responsible for hydrothermal mineralisation, and have contributed substantially to a revolution in concepts of ore genesis.

Numerous studies of volcanogenic massive sulphide deposits have shown that the $\delta^{18}O$ value of fluids which formed deposits, ranging in age from Archaean to Tertiary, is generally close to the seawater value of 0‰. Fluids precipitating calcite in chimneys and mounds in a sulphide-forming submarine geothermal system on a sedimented spreading rift, the Guaymas Basin, Gulf of California, have $\delta^{18}O$ values ranging from -0.8 to 4‰ (Peter and Shanks, 1992).

In the case of samples from the Mount Read Volcanics, $\delta^{13}C$ and $\delta^{18}O$ values of Cambrian hydrothermal vesicle- and vein-forming calcites can be used as a semi-quantitative geothermometer, assuming a fluid $\delta^{18}O$ value of 0‰ using the equation:

$$\delta^{18}O_{calcite} - \delta^{18}O_{water} = 2.78 * 10^6/T^2 - 2.89 \quad (4)$$

where T is in °K.

Similar equations have been calibrated for other carbonate minerals. More confidence in the method can be obtained in cases where the fluid $\delta^{18}O$ value has been established by determining the temperature of formation of one or a few members of a suite of samples by an independent technique (e.g. chlorite geothermometry or fluid inclusions). Extreme care must be taken in the selection of samples, firstly in the identification of Cambrian hydrothermal assemblages and secondly in avoiding samples where recrystallisation of carbonate minerals in the presence of a fluid phase may have resulted in resetting of the $\delta^{18}O$ value. A rough check on the validity of results may be obtained by calculating the $\delta^{13}C$ value of the H_2CO_3 in the fluid by the equation:

$$\delta^{13}C_{H2CO3} = \delta^{13}C_{calcite} + 8.914 * 10^8 / T^3 - 8.557 * 10^6 / T^2 + 18110 / T - 8.27 \quad (5)$$

In submarine basaltic hydrothermal systems the fluid $\delta^{13}C$ value is generally close to 0‰ (Muehlenbachs, 1986). In the Guaymas Basin calcite $\delta^{13}C$ values are much lower, consistent with deposition from a fluid with a value of about -11‰, reflecting roughly equal carbon inputs from seawater (0‰) and oxidised organic matter from the sediments (-21‰) (Peter and Shanks, 1992). An additional contribution from magmatic CO_2 (-7‰) cannot be ruled out either from these data. Carbonates from Tasmanian VMS deposits appear to have carbon derived from a mixed seawater-magmatic source ($\delta^{13}C$ = -5 to +0.6‰; Khin Zaw and Large, 1990).

Whole-Rock Applications

For a rock undergoing isothermal alteration in a closed system, in which there is negligible transfer of water between the fluid phase and the rock, the $\delta^{18}O$ value of a rock after water–rock interaction can be expressed as (Taylor, 1979):

$$\delta^{18}O_r^f = \frac{\delta^{18}O_r^i + (\delta^{18}O_w^i + \Delta_w^r)\, w/r}{1 + w/r} \quad (6)$$

where the superscripts i and f refer to the initial and final conditions respectively, and the subscripts r and w refer to the rock and water respectively. w/r is the atomic ratio of oxygen in the fluid phase to that in the rock, which is approximately equal to twice the water/rock mass ratio.

Δ_w^r, which closely approximates the oxygen isotope fractionation factor between rock and water (Equation 3), is

a function of temperature and the mineralogical composition of the rock, and is given by the expression:

$$\Delta_w{}^r \approx \delta^{18}O_r - \delta^{18}O_w \qquad (7)$$

Equation (7) can be recast in terms of the water/rock ratio:

$$\frac{w}{r} = \frac{\delta^{18}O_r{}^f - \delta^{18}O_r{}^i}{\delta^{18}O_w{}^i - (\delta^{18}O_r{}^f - \Delta_w{}^r)} \qquad (8)$$

Under open system conditions, in which each aliquot of water makes a single pass through the system and does not have the opportunity to further interact with the rock, the above expression becomes:

$$\frac{w}{r} = \ln\left\{\frac{\delta^{18}O_w{}^i + \Delta_w{}^r - \delta^{18}O_r{}^i}{\delta^{18}O_w{}^i - (\delta^{18}O_r{}^f - \Delta_w{}^r)}\right\} \qquad (9)$$

For VMS systems where a considerable proportion of the water is discharged into the ocean, open system conditions (Equation 9) might prevail. Under conditions of burial diagenesis in which the fluid may have been in prolonged contact with the rock and recycled several times, the closed system case (Equation 8) might provide a better approximation. The assumption of isothermal water/rock interaction involved in the models is clearly somewhat naive, but it should be realised that whole-rock oxygen isotope data reflect the *integrated history* of interaction, and as such provide broad constraints on temperature of alteration and amounts of fluid involved.

Where the water/rock ratio is very large, such as in the hydrothermal feeder zone below a VMS deposit, Equation 6 and the corresponding statement for an open system reduce to:

$$\delta^{18}O_r{}^f \approx \delta^{18}O_w{}^i + \Delta_w{}^r \qquad (10)$$

In this case the final $\delta^{18}O$ value of the rock is a function only of the isotopic composition of the water, the mineralogy of the rock, and the temperature of alteration, and is independent of the original isotopic composition of the rock.

For most felsic rocks $\Delta_w{}^r$ can be approximated by the fractionation for alkali feldspar-water (O'Neil and Taylor, 1967), but in rocks rich in minerals with fractionation factors very different from the feldspars (e.g. chlorite or magnetite), the fractionation factors should be calculated individually. Spreadsheet programs have been developed to do this from quantitative X-ray diffraction analyses. For studies with the aim of detecting the outer subtle alteration haloes around VMS deposits, areas of strong overprinting alteration (e.g. that associated with Devonian granite-related mineralisation, rocks with later veining etc.) should be avoided. Experiments on the kinetics of oxygen isotope exchange and studies of geothermal systems (e.g. Cole and Ohmoto, 1986; O'Neil, 1987) show that most minerals (e.g. feldspars, micas, chlorite) re-equilibrate readily under hydrothermal conditions, but that quartz generally preserves its original $\delta^{18}O$ values and carbonate minerals may exchange oxygen isotopes if they undergo recrystallisation in the presence of a fluid phase. Because of this recalcitrance of quartz to isotopic exchange, a correction to raw $\delta^{18}O$ data is required for rocks with significant proportions of pre-hydrothermal quartz (e.g. phenocrysts).

In the Hokoroku district of northern Honshu, Japan, the area of the most important cluster of Kuroko deposits, the effectiveness of the oxygen isotope technique was demonstrated. The Fukazawa deposit consists of a cluster of three major and several small massive sulphide lenses, totalling about 6 million tonnes of ore in an area of 1.5×0.5 kilometres. The ore zones are surrounded by distinctive mineralogical alteration zones: a central sericite-chlorite zone extending up to 0.5 km away from ore in footwall rocks, flanked progressively by a montmorillonite zone, 1–3 km wide, and a zeolite zone. Each of the zones is characterised by a unique range in whole-rock oxygen isotope values: 16.9 ± 2.7 ‰ (1σ) for the zeolite zone, 11.1 ± 2.5‰ for the montmorillonite zone, and 6.7 ± 1.3‰ for the sericite-chlorite zone (Green *et al.*, 1983). Somewhat surprisingly there is no major break in either the clay-zeolite or oxygen isotope zonation at the ore horizon (although whole rock Na_2O depletion is restricted to footwall rocks near ore) and low $\delta^{18}O$ values extend at least 300 m above the ore horizon in the centre of the sericite-chlorite zone. The data were interpreted to reflect both a longevity of hydrothermal discharge in the ore zone and alteration by fluids with a $\delta^{18}O$ value of 0‰ at temperatures varying from 25° to 120°C in the zeolite zone, to 200° to 300°C in the sericite-chlorite zone. The significance of these results to greenschist facies metavolcanic terranes, such as the Mount Read Volcanics, is that the clay-zeolite mineralogical zonation would be destroyed, but provided that metamorphism took place under low water-rock ratio conditions the whole-rock oxygen isotope zonation would be preserved.

CHLORITE GEOTHERMOMETRY

Two types of thermometers exist:

(a) Empirical thermometers

(b) Thermodynamically calculated thermometers.

Empirical thermometers

The chemical formula for chlorite can be expressed as:

$$[Mg, Fe^{+2}, Mn, Al]_{12}\,[(Si, Al, Fe^{+3})_8O_{20}]\,[OH]_{16}$$

where the first group of cations are octahedrally co-ordinated in the structure and the second group are tetrahedrally co-ordinated by oxygen.

Based on studies of active geothermal fields in the Los Azufres area, Mexico and the Salton Sea area, California, Cathelineau and Nieva (1985) and Cathelineau (1988) noted an excellent correlation between the content of tetrahedrally co-ordinated aluminium of hydrothermal chlorites and temperature, with a regression co-efficient of 0.97 over the temperature range 130° to 325°C. Cathelineau (1988) noted that his thermometer applied in a general way to chlorites formed at temperatures as high as 350°C at Larderello, Italy and diagenetic chlorites formed at temperatures as low as 100° to 140°C in Colorado and the North Sea.

However his geothermometer is calibrated most precisely between 200° and 300°C, and only one data point exists below 170°C. Cathelineau also assumes that all iron is

present in the divalent state. This is likely to lead to over-estimation of the amount of tetrahedrally co-ordinated Al, and consequently of temperature, particularly of chlorites formed at temperatures of less than 200°C.

Thermodynamically calculated thermometers

Walshe (1986) developed a geothermometer based on the consideration of chlorite as a solid solution of six components, the thermodynamic properties of which were either known or could be reasonably estimated. His model specifically calculates the ferric iron and water contents of chlorite from electron microprobe analyses from the following equilibria, and from a formulation of the Gibbs-Duhem equation:

$$2Mg_5Al_2Si_3O_{10}(OH)_8 + 14/3\ SiO_2 + 8/3\ H_2O_{(l)} \rightarrow$$
component 2

$$Al_4Si_4O_{10}(OH)_8 + 10/6\ Mg_6Si_4O_{10}(OH)_8$$
component 5 component 1

and: $$Mg_5Al_2Si_3O_{10}(OH)_8 + 5/7\ Fe^{+2}{}_5Fe^{+3}{}_2Si_3O_{10}(OH)_8$$
component 2 component 4

$$3/7\ Fe^{+2}{}_5Al_2Si_3O_{10}(OH)_8 + 25/21\ SiO_2 \rightarrow$$
component 3

$$10/7\ Fe^{+2}{}_4Fe^{+3}Al_2Si_3O_{11}(OH)_7 + 10/6\ Mg_6Si_4O_{10}(OH)_8$$
component 6 component 1

$$+ 8/3\ H_2O_{(l)}$$

The technique involves solution of non-linear equations and is computer intensive but, apart from the estimation of thermodynamic data for the six components, the model rests on only one assumption: *co-existence in equilibrium of chlorite and quartz*. General experience of the chlorite model is that there is very good agreement between temperatures derived from it and other methods of temperature estimation, particularly in reduced hydrothermal systems at T >250°C, and under these conditions there is also usually good agreement with the Cathelineau and Nieva (1985) Al (IV) method. Under lower temperature, more-oxidised conditions, the Walshe model is preferred because it is more rigorous.

Care must be exercised with both methods in metamorphic terrains particularly where chlorite has an oppportunity to re-equilibrate (i.e. exchange silica) with quartz during prograde or retrograde metamorphism. In addition, reliable results are usually only achievable with hydrothermal chlorites. The rocks from the Mt Cattley–Hellyer area are unusual in the Tasmanian context in that undeformed vesicle chlorites enable these conditions to be met.

FLUID INCLUSIONS

During processes of crystal growth, recrystallisation or fracture healing, small proportions of the fluid medium may be trapped as fluid inclusions. Fluids may be trapped either during crystal growth in growth irregularities to form primary fluid inclusions, or at some later time by processes of recrystallisation or fracture filling to form secondary fluid inclusions. Pseudosecondary fluid inclusions are those formed along fractures during the growth of a crystal. Most fluid inclusions range in size from 3 to 20 μm.

Compositions of fluid inclusions vary widely. The major solvents are H_2O and less commonly CO_2 and the major solute ions include Na, K, Ca, Mg, Cl, SO_4 and HCO_3 with Li, B, Al, Fe, F, Mn, and Si being minor solute ions. Major constituents in inclusions with organic liquid or gas include H_2,CH_4 and C_2H_6, as well as a variety of high molecule weight compounds.

Fluid inclusions normally have a vapour or gas bubble which may move constantly under the effect of a thermal gradient or of gravity. The volume coefficients of thermal expansion for minerals are less than the water by up to 3 times. Therefore upon cooling, a fluid inclusion which has been formed as homogeneous fluid at elevated temperatures will shrink more than the host mineral, and when the total vapour pressure of the fluid is more than the pressure in the inclusion a bubble will nucleate and grow. The process can be reversed simply by heating the fluid inclusion to the temperature at which the bubble disappears (i.e. homogenisation temperature).

The salinity of fluid inclusions (wt.% NaCl equivalent) can be estimated by freezing the fluid inclusions and measuring the depression of the freezing points of the inclusions. This is just an estimate, as other solute ions such as Mg and Ca, which may also be present in the fluid, can affect the freezing point significantly. There are many methods (non-destructive and destructive) to determine the compositions of the fluid inclusions, and these have been explained in detail by many workers (e.g. Roedder, 1984).

In general, fluid inclusions can be utilised to define the possible environment of ore formation (e.g. epithermal, mesothermal), and in studies of physicochemical conditions of ore-forming fluids. They can also be used in igneous and metamorphic terrains, in oil exploration, in active geothermal systems, and in many other fields.

RESULTS

HELLYER

Prior to mining, the Hellyer massive sulphide orebody contained some 15.6 million tonnes of massive sulphide ore grading 0.3% copper, 6.8% lead, 13.0% zinc, 160 g/t silver and 2.2 g/t gold (Aberfoyle Ltd Annual Reports 1990, 1991). The ore is hosted by the Que–Hellyer Volcanics, a unit of predominantly andesitic to basaltic composition with subordinate dacite which includes lavas, hyaloclastites, shallow intrusives and minor epiclastic rocks (Corbett and Komyshan, 1989; Corbett, 1992; Waters and Wallace, 1992). In the mine area (McArthur and Dronseika, 1990), the orebody is underlain by plagioclase-phyric andesite lava and epiclastics. The ore horizon is marked by a unit of polymict breccia, sandstone and shale up to 10 m thick, the hangingwall volcaniclastic sequence, which laps onto the massive ore. Succeeding basaltic pillow lavas, peperites and minor chert are about 220 m thick and are overlain by 100 m of black pyritic shale and siltstone of the Que River Shale. The ore is cut by a vertical fault with horizontal displacement of 130 metres.

A well-developed footwall alteration zone extends for at least 550 m below the ore and consists of a central stringer zone, comprising from the centre outward: a siliceous core, chlorite, chlorite-sericite and sericite facies surrounded by the sericite-quartz dominated stringer envelope zone (Gemmell and Large, 1992). Alteration extends through the

hangingwall basalt in the form of a fuchsite-carbonate±barite zone which broadens somewhat immediately below the Que River Shale (Jack, 1989). Ductile deformation is locally intense in the orebody and in the stringer envelope zone and the stringer zone outside the siliceous core, but elsewhere deformation is of a semi-brittle nature and is generally minor. This minimal deformation and the low-grade prehnite-pumpellyite facies metamorphism (Offler and Whitford, 1992) make Hellyer an ideal case study.

Whole-rock oxygen isotope analyses of some 64 samples of drill core selected for a parallel study of geochemical variation (Jack, 1989), together with analyses of samples of footwall rocks supplied by J. B. Gemmell from exploration drill holes up to 2300 m from the deposit, show a number of parallels with the zonation around the Kuroko deposits. Within 200 m laterally of the orebody there is a total variation in whole rock $\delta^{18}O$ values from 6.2 to 16.7‰. The data are consistent with alteration by a seawater-dominated hydrothermal fluid with a $\delta^{18}O$ value close to 0‰. The footwall andesites have $\delta^{18}O$ values of 11.28 ± 0.92‰ (one standard deviation, number of samples n = 20), with progressively lower values reported from the stringer envelope zone of 9.81 ± 1.76 ‰ (n = 8) and the stringer zone 8.28 ± 1.25‰ (n = 10). In the hangingwall basalt there is a similar distinction between samples from the fuchsite-carbonate zone ($\delta^{18}O = 10.57 \pm 1.16$‰, n = 12) and other basalts ($\delta^{18}O = 11.8 \pm 2.18$‰, n = 9). There is no marked increase in $\delta^{18}O$ values across the ore horizon in any of the holes sampled.

Two samples from the Que River Shale 250 m laterally from ore have values of 15.4 and 15.6‰, similar to values from unaltered sedimentary rocks. This may indicate that the commencement of deposition of the shale marked the end of activity in the Hellyer hydrothermal system, but more analyses from rocks closer to ore would be needed to confirm this. Some supporting evidence for this postulate is that the highest $\delta^{18}O$ values from the hangingwall basalt occur at the top of the unit, consistent with a decline in temperature of alteration. Regionally the highest $\delta^{18}O$ values in footwall volcanics are recorded in rocks 1400 to 2300 m from the Hellyer orebody ($\delta^{18}O$ range of 12.0 to 13.8‰, mean = 13.09‰, standard deviation = 0.53, n = 10). These data indicate the regional extent of alteration; to produce such high $\delta^{18}O$ values from normal basaltic to andesitic rocks with initial values in the order of 6 to 7.5‰ requires considerable input of low temperature fluid with a seawater isotopic composition.

The results indicate the potential utility of the use of oxygen isotope data in screening areas worthy of more detailed exploration. However, because of the relatively small gradients in $\delta^{18}O$ values in more distal areas other techniques are needed for detailed targetting. Possible techniques include chlorite geothermometry and isotopic studies of carbonates, the latter providing relatively precise temperatures in the range 25° to 350°C. Assuming a fluid $\delta^{18}O$ value of 0‰, early (pre-cleavage) vein and amygdule carbonates show a general temperature increase from about 120°C at the top of the hangingwall basalt to around 160° to 200°C towards the base of the fuchsite-carbonate zone and near the margins of the stringer zone. Vesicle-filling hydrothermal chlorites in the Que–Hellyer Volcanics display a distinctive fanning habit and grey-blue interference colours. Similar chlorite also occurs in pyroxene pseudomorphs. Such chlorites generally give temperatures in good agreement with the carbonate data at liquid-vapour pressure using the program of Walshe (1986). Chlorite occurring in the cleavage has green or brown interference colours. These chlorites give consistent temperatures of 280° to 310°C at 1 kilobar pressure. A combination of the two techniques has considerable promise in the mapping of palaeotemperatures of alteration in these relatively undeformed rocks.

A further useful exploration criterion, indicating proximity to a footwall stringer system, is the presence of K-feldspar carbonate replacements of plagioclase phenocrysts, which in drill hole HL14 extend up to 50 m laterally from the stringer envelope zone. McGoldrick and Large (1992) have recorded similar, but more extensive alteration in the footwall at the Que River Mine, where it is associated with anomalous gold, barium and antimony values. However this alteration style is apparently not always present. Within the K-feldspar-carbonate zone and extending beyond it in HL14 are pyrites with anomalously high $\delta^{34}S$ values of +12.7 to +32.0‰ (analysed by R. N. Woolley for this study and reported in Jack, 1989 and Gemmell and Large, 1992).

HERCULES

The Hercules Mine produced 3.12 million tonnes of ore grading 5.7 % lead, 17.8% zinc, 0.47% copper, 180 g/t silver and 2.94 g/t Au from discovery in 1891 to closure in 1986. The ore occurs in a number of lenses extending along strike for some 800 m, straddling the contact between thick plagioclase-phyric pumiceous mass-flow deposits in the footwall and overlying black slate (Allen and Hunns, 1990). Quartz-feldspar bearing breccia and sandstone overlie the slate and are succeeded by pumiceous mass-flow units with feldspar phenocrysts identical to those in the footwall. This stratigraphic arrangement is similar to that at Rosebery. Tabular felsic intrusive bodies are common and appear to occupy significant fault zones. In contrast to Hellyer, the ore lenses are aligned parallel to subvertical cleavage, and are sharply discordant to open to tightly folded bedding. In addition to massive sulphides much of the ore-grade mineralisation is disseminated. The rocks hosting and surrounding the ore are commonly altered to chlorite and a variety of carbonate minerals, with textures ranging from disseminated oolites, through colloform types to large (to about 300 mm) spheroids which predate cleavage development. These bodies appear to be of syn-diagenetic origin (Fitzgerald, 1974) and the disseminated sulphides may, at least in part, represent replacement of this carbonate, or of feldspar, as suggested by Khin Zaw and Large (1992). The origin of the mineralisation is however controversial: recent interpretations range from a replacement origin during Devonian deformation (D. G. A. M. Aerden, pers. comm.), through sub-sea floor replacement during diagenesis, to structurally remobilised lenses of originally massive exhalative massive sulphide (Lees and Howarth, 1989).

The footwall alteration is strongly zoned: beneath a silicified zone closely associated with ore is an alteration pipe cored by quartz-chlorite-pyrite±chalcopyrite which passes outward to quartz-sericite-pyrite±sphalerite±galena with a halo of quartz-sericite rich rocks containing K-feldspar±carbonate replacements of plagioclase, texturally identical to those at Hellyer (Green, 1990; Eastoe *et al.*, 1987). Alteration in the hangingwall rocks is more poorly defined. There are a number of old copper and lead-zinc prospects associated with quartz-sericite or chloritic alteration. Some of these appear to be associated with the margin of the porphyries.

Whole-rock oxygen isotope data show a similar range to that at Hellyer from 6.8 to 15‰, with the lowest $\delta^{18}O$ values of 6.8 to 10.0‰ in rocks from the alteration pipe, through 11.2‰ 750 m NE of the mine, to 14.0 to 15.5‰ 100 to 250 m further north. In footwall rocks within 100 m of the pipe margin 600 m west and 350 m vertically below the orebody heavy values of 15 and 15.6‰ are present. Surprisingly a trend of decreasing $\delta^{18}O$ values from 12.8 to 6.8‰ upward through the sequence over a horizontal distance of 250 m was noted in hangingwall rocks east of the Hercules orebody. This trend correlates with an increase in alteration towards the old East Hercules copper prospect, and is also marked by an increase in Na, Ca and Sr depletion and enrichment in K, Rb, S and base metals, although the oxygen isotopes provide the broadest halo. The Mn content of chlorites increases progressively from 0.9 to 1.3% over the same interval. The alteration affects all rock types, including the porphyry intrusives.

Eastoe *et al.* (1987) regarded this mineralisation as Devonian in age, but samples of pyritic chlorite-rich rocks from the dumps show evidence of a pre-deformational age (e.g. pressure shadows adjacent to pyrite). Eastoe *et al.* (1987) carried out systematic analyses of chlorite in the footwall rocks. Chlorite is manganese-rich, and there are a variety of Mg/Mg + Fe ratios from 0.3 to 0.75, with relatively iron-rich chlorite (0.35) in the centre of the pipe and an increase in Mn towards ore. Further chlorite analyses were carried out in this study in an attempt at geothermometry. A restricted range of temperatures of 300° to 320°C, calculated at a pressure of one kilobar, reflects metamorphic conditions. Apart from chlorite in late quartz tension veins which gives lower temperatures, all of the chlorite is aligned in the cleavage.

Furthermore the sulphur isotope composition of samples from this hangingwall alteration zone (11 to 19‰) is indistinguishable from that in the Hercules orebody and footwall. This similarity of geochemical characteristics led Green (1986) to postulate that the East Hercules mineralisation might represent a product of Cambrian hydrothermal remobilisation from a buried massive sulphide at depth. An equally probable explanation, permissible if porphyry intrusion closely followed deposition of the enclosing rocks, is that hydrothermal activity in the Hercules area was a protracted process, thus providing indirect evidence for the diagenetic replacement model of mineralisation. Either way, the area of prospectivity is enhanced by these data.

BOCO

In the Boco Siding area 13 km northeast of Rosebery, a moderately pyritic, pre-cleavage sericite-quartz alteration zone extending along strike for about one kilometre occurs in a sequence of felsic lavas and pyroclastic rocks with a very minor component of epiclastic rocks, which locally contain small amounts of probable exhalative pyrite. No significant base or precious metal mineralisation has been discovered in the area.

The rocks display some of the geochemical features typical of a footwall alteration zone associated with massive sulphide mineralisation, such as strong depletion in Na, Ca and Sr, and moderate enrichment in S and Mg. In contrast to the situation at Hellyer and Hercules there is little difference in the $\delta^{18}O$ values of altered and unaltered rocks, with a total range of 9.7 to 11.8‰. The sulphur isotope values are distinctly lower than those at Hercules, with a range of pyrite $\delta^{34}S$ values of -1.2 to 4.7‰. This is similar to the values for some other apparently barren pyritic deposits in the Mount Read Volcanics such as Basin Lake, Chester and the Cattley Range prospect (Collins, 1981; Green, 1986; Solomon *et al.*, 1988; Green, unpublished data). In the latter occurrence, the lead isotope values are consistent with a Cambrian age for the mineralisation (Carr, 1990), suggesting that while lead isotopes provide a useful guide to the age of alteration, they do not necessarily indicate mineralisation of an economic grade.

The data are compatible with alteration by a fluid of seawater origin but at lower temperatures (<200°C) than those required to inorganically reduce seawater sulphate or to transport sufficient base metals together with H_2S to form an orebody. This would account for the low $\delta^{34}S$ values in the deposit, in that the sulphur was probably leached from the surrounding volcanic rocks.

LAKESIDE

The discovery of gold mineralisation at the Henty Prospect prompted intensive exploration along the Henty Fault Zone. Our investigation of the Lakeside Prospect (Taheri and Green, 1990) was undertaken because of a possible volcanogenic component of the mineralisation in the area (Polya *et al.*, 1986), and to study the metallogenically rare gold-tin-copper-arsenic association. Several small to medium sized Pb-Ag to polymetallic Sn-Au bearing deposits occur adjacent to the fault in the Mt Farrell area, where the fault separates the Mt Black Volcanics to the west from the Farrell Slates and the Murchison Volcanics to the east (McNeill and Corbett, 1992). The rocks to the west of the Henty Fault are predominantly chloritised feldspar-phyric andesite and dacite, and are silicified near the fault. The Farrell Slates mainly consist of grey to black slate, shale, greywacke and volcaniclastic arenite. The rocks are commonly deformed and are brecciated.

The mineralisation associated with the Henty Fault Zone in the Mt Farrell area post-dates Devonian cleavage development and may be divided into two broad categories:

1. Pb-Ag dominated deposits hosted by the Farrell Slates. The deposits occur as sub-parallel lenticular fissure lodes and veins in shears striking from NNW to NNE (e.g. New North Mt Farrell Mine).

2. Polymetallic Sn-Au bearing mineralisation which occurs as disseminations, fissure fillings and stringers adjacent to the Henty Fault in the Farrell Slates (e.g. Lakeside Prospect) or in the Mt Black Volcanics (Sterling Valley Sn-As prospect).

The mineralisation appears to be directly associated with the intrusion of the Granite Tor Granite at a shallow depth in the Devonian. A WSW-trending granite ridge extends from the Granite Tor Granite to the Pine Hill Granite, and possibly as far west as the Heemskirk Granite (Leaman and Richardson, 1989). A number of tin and tourmaline-bearing deposits, as well as Pb-Zn-Ag vein deposits, occur within the zone of the granite ridge. Based on recent interpretations of gravity data by Leaman and Richardson (1989) and Archer (1989), the Sn-Au mineralisation occurs above the crest of the ridge where the granite lies at a depth of about 1 km, whereas Pb-Ag dominated deposits occur where the granite surface is at a greater depth. High-angle reverse movement of the Henty Fault synchronous with the intrusion of the granite (Berry, 1989) probably created permeable ore channels in the area.

Mineralisation at the Lakeside Prospect may be divided into four different stages.

Stage 1: pyrite + pyrrhotite + arsenopyrite.

Stage 2: the mineralisation is divided into two substages:

2a: arsenopyrite + cassiterite + chlorite,

2b: chalcopyrite + stannite + gold

with quartz, tourmaline and fluorite being the common gangue minerals for the both substages.

Stage 3: galena + sphalerite, and

Stage 4: chlorite + carbonates + pyrite.

The mineral contents and/or proportion of the different ore minerals changes with increase in depth. Pyrite, galena, sphalerite, stannite and chalcopyrite contents decrease at depth, whereas cassiterite and pyrrhotite contents increase. The main mineralising events appear to have resulted from boiling of a CO_2-bearing fluid at a temperature of around 340°C, although only dilute CO_2-rich fluid inclusions interpreted to be the vapour condensate of a fluid which had undergone phase separation. The $\delta^{18}O$ values of quartz, together with the fluid inclusion data, constrain the water $\delta^{18}O$ values for the early stages of mineralisation at 7.2 to 9.1‰, indicative of Devonian magmatic fluids. The reduced character of the fluid and high temperature of the mineralisation particularly favoured tin transport through Cl complexes. The temperature may have been sufficiently high for Cl complexes to have played a major role in Au transport, although the neutral complex $HAu(HS)_2$ is at least equally probable (Hayashi and Ohmoto, 1991). Boiling would have been an effective depositional mechanism from either of these species under these conditions, and the concentration of gold was probably optimised at the Lakeside Prospect.

The Sterling Valley Sn-As mineralisation in the Mt Black Volcanics has characteristics indicative of its being a deeper analogue of the mineralisation at the Lakeside Prospect. The gold content is lower and pyrrhotite is a more common mineral. Topaz, closely associated with fluorite, is present. A recent preliminary fluid inclusion investigation by J. Taheri shows that at least four separate generations of fluids, with homogenisation temperatures up to 390°C and salinities of up to 15 wt.% NaCl equivalent, were involved in the mineralisation. Berry's (1989) structural synthesis of syn-mineralisation reverse faulting followed by sinistral strike-slip faulting is consistent with the two deposits being displaced units of an original single-sheeted vein system developed on both sides of the Henty Fault. If so, the extent of the left lateral displacement on the fault can be constrained at about 1100 metres.

Sulphur isotope studies (e.g. Solomon *et al.*, 1969) and the zonation of hydrothermal alteration assemblages in the Murchison Volcanics east of the fault (Polya *et al.*, 1986) have been interpreted to indicate a syn-volcanic Cambrian origin for the mineralisation. Sulphur isotope compositions reflect the gross mineralogical zonation of the area. $\delta^{34}S$ values of +11.9 to +16.5‰ in the Ag-Pb deposits flanking the granite ridge are similar to those in the Rosebery and Hercules volcanic-associated deposits. Hence the Pb-Ag deposits could contain recycled Cambrian sulphur. However $\delta^{34}S$ values of +5.2 to +12.0‰ (80% of values between +7 to +10 ‰) for the Sn-Au deposits above the ridge crest suggest a substantial component of magmatic sulphur for these deposits.

The lead isotope compositions from the vein deposits along the Henty Fault Zone in the Mt Farrell area (Gulson and Porritt, 1987; Carr, 1988) have higher $^{206}Pb/^{204}Pb$ than Cambrian VMS deposits, and plot either within the field of the Devonian mineralisation or between the Cambrian and the Devonian fields of Gulson and Porritt (1987). The values from the Lakeside Deposit are the most radiogenic and are consistent with a Devonian magmatic source.

In summary, the mineral zoning, petrographic observations, fluid inclusion, sulphur, oxygen and lead isotope data indicate that the mineralisation along the Henty Fault zone in the Mt Farrell area is related to the intrusion of the Granite Tor Granite, although a country rock input for S and possibly some of the Pb and Au might be important.

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1/1

Hematite/barite alteration in the Owen Conglomerate at North Lyell

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The intense hematite/barite alteration associated with bornite-rich ore at North Lyell transgresses the volcanics / conglomerate contact (the Great Lyell Fault), suggesting that ore deposition and the related alteration occurred after deposition of the Owen Conglomerate (i.e. post Late Cambrian–Early Ordovician). Many authors have accepted a Devonian hydrothermal event coincident with the Tabberabberan Orogeny, remobilising pre-existing Cambrian chalcopyrite mineralisation and forming zones of bornite enrichment in areas where the acidic, reduced volcanic(?) fluids reacted with the oxidised connate waters from the overlying Owen Conglomerate. This appears to have occurred where major conduits (such as the intersection between the Great Lyell Fault and North Lyell Fault) were available to focus the upwelling fluids to this redox front.

The timing of the alteration and mineralisation should be reflected in the extent and type of alteration observed within the overlying siliciclastic Owen Conglomerate and Gordon Limestone Group. Total hematisation of the Owen has occurred in areas adjacent to the Great Lyell Fault (GLF) near North Lyell and Lyell Tharsis, and a progression through to slightly hematitic, relatively unaltered conglomerate may be observed away from the main zone of alteration. Barite occurs within the intensely-altered conglomerate, with whole rock compositions of up to 15% barite which decreases quickly away from the main alteration zone.

Geochemical analysis of samples from the alteration zone shows that there are three main assemblages which define a geochemical signature for the alteration fluids. These include a sericitic dominated assemblage ($Al_2O_3 + K_2O + Cr + Rb$), a phosphate / hematite dominated assemblage ($Fe_2O_3 + P_2O_5 + La$), and a barite dominated assemblage ($Ba + Sr$). These assemblages may be found within the Upper Owen (Pioneer Beds) and are suspected within the overlying highly-weathered Gordon Limestone. The mineralisation within the Owen, moving away from the GLF, reflects the evolution of the alteration fluids, showing the trend from the volcanic rocks, which exhibit a low–medium pH, low fO_2, sulphide-dominated environment, to the low pH, high fO_2, oxide-dominated red bed environment of the conglomerate.

Chlorite microprobe analyses broadly define a declining temperature of formation away from the volcanic-conglomerate contact, with the high iron content of the rocks (and alteration fluids) being reflected in the chlorite composition. Minor aluminium and iron phosphates have been found replacing euhedral pyrites within the more highly altered Owen Conglomerate. This is thought to represent a modification of the circulating fluids to a more acidic-oxidised mix, rich in hematite and phosphate near the GLF, grading to a more sericitic / hematitic mix away from the fault.

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1/3

Laser ablation sulphur isotope analysis at the University of Tasmania — preliminary results from a new technique with research and exploration applications

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INTRODUCTION

Over the past five to ten years, lasers have been used to sample geological materials at microscopic scales for isotopic and compositional analysis. Development of laser sampling techniques has proceeded in parallel with advances in instrumentation which allow the analysis of much smaller amounts of material. In particular, the development of micro-inlets on stable isotope mass spectrometers has decreased the sample size required for analysis by several orders of magnitude. Isotope labs at the University of Wisconsin (Crowe *et al.*, 1990) and the Scottish Universities Research and Reactor Centre (Kelley and Fallick, 1990; Fallick *et al.*, 1992) have demonstrated the application of laser ablation microprobes to sulphur isotope analysis. Spatial resolution of 100–200 μm with a precision (0.15–0.43 ‰) comparable to conventional analyses has been demonstrated by Crowe *et al.* (1990). Smalley *et al.* (1989; 1992) demonstrated an analogous method for carbon-oxygen isotope analysis of carbonate minerals at the Institute for Energy Technology in Norway.

In June 1991 a Nd:YAG laser and ancillary facilities (fig. 1) for laser ablation extraction of SO_2 gas from sulphide minerals was installed in the Central Science Laboratory at the University of Tasmania. After initial experiments off-line, the laser ablation facility was connected on-line to a VG SIRA Series II mass spectrometer to analyse the SO_2 gas. A VG Isogas automatic clean-up system attached to the mass spectrometer has been used for sample purification; in mid-May 1992 SO clean-up and analysis was automated. This contribution reports the design of this system and some preliminary calibrations of fractionation factors involved in the analysis.

SYSTEM DESIGN AND ANALYTICAL PROCEDURES

Figure 1 illustrates the University of Tasmania laser ablation system. The system consists of four components:

(1) an 18 watt Quantronix model 117 Nd:YAG laser and Geolase designed beam delivery system;

(2) an optical viewing system including an Olympus SMC zoom microscope, video camera and monitor;

(3) a heated sample chamber with facilities to introduce O_2 gas and for evacuation; and

(4) the automatic clean-up system and mass spectrometer.

Sample chips 150 μm thick, which were polished on one side, were cleaned in acetone and dried overnight at 110°C before being placed on a glass pedestal in the sample chamber. Prior to analysis of the first spot on each sample, the sample chamber was evacuated for at least 30 minutes. This extended evacuation was not required for subsequent spots on the same sample chip. For each analysis 10–50 torr of O_2 were introduced into the sample chamber to facilitate the oxidation of sulphide minerals to form SO_2.

The chosen spot on the sample chip was then ablated for 1–3 seconds using a laser power level such that an even burn was just initiated. The produced SO_2 and any excess O_2 were then let into the automatic clean-up system where the water and SO_2 were frozen down in traps at -100°C and -190°C, respectively, for 7.5 minutes. After the freeze-down period, O_2 and other non-condensibles were pumped away above the traps. SO_2 was then transferred cryogenically to the cold finger in the mass spectrometer from whence it was analysed. The trapping and analysis of the gaseous samples was carried out automatically. The entire process, from ablation to analysis, requires 30–40 minutes, of which the operator only has to be present for the first five minutes.

RESULTS

Ablation of the samples resulted in holes which penetrated through the chip and which varied in diameter from 70 to 500 μm. Holes in chalcopyrite and sphalerite tended to have a relatively constant size of 150–250 μm, whereas hole sizes in pyrite, pyrrhotite and galena tend to be more variable. Ablation of sphalerite and galena produced white (ZnO) and brown (PbO?) powders which coated the sample chip. The power required for ablation varied with mineral, as follows: pyrite > sphalerite > pyrrhotite > chalcopyrite > galena. The power required also varied with the quality of the polish, with polished surfaces requiring higher power for ablation than rough surfaces.

Table 1 summarises the results of experiments undertaken from 13 May 1992, when automatic sample purification and analysis was initiated, to 8 July 1992. During this period over 180 analyses were undertaken to establish correction factors and uncertainties associated with ablation. Experiments were undertaken on monomineralic chips that were inferred to be homogeneous from conventional analyses. From these and earlier experiments the following observations were made:

HUSTON, D. L; POWER, M.; LARGE, R. R. 1992. Laser ablation sulphur isotope analysis at the University of Tasmania — preliminary results from a new technique with research and exploration application. *Bull. geol. Surv. Tasm.* 70:93–95.

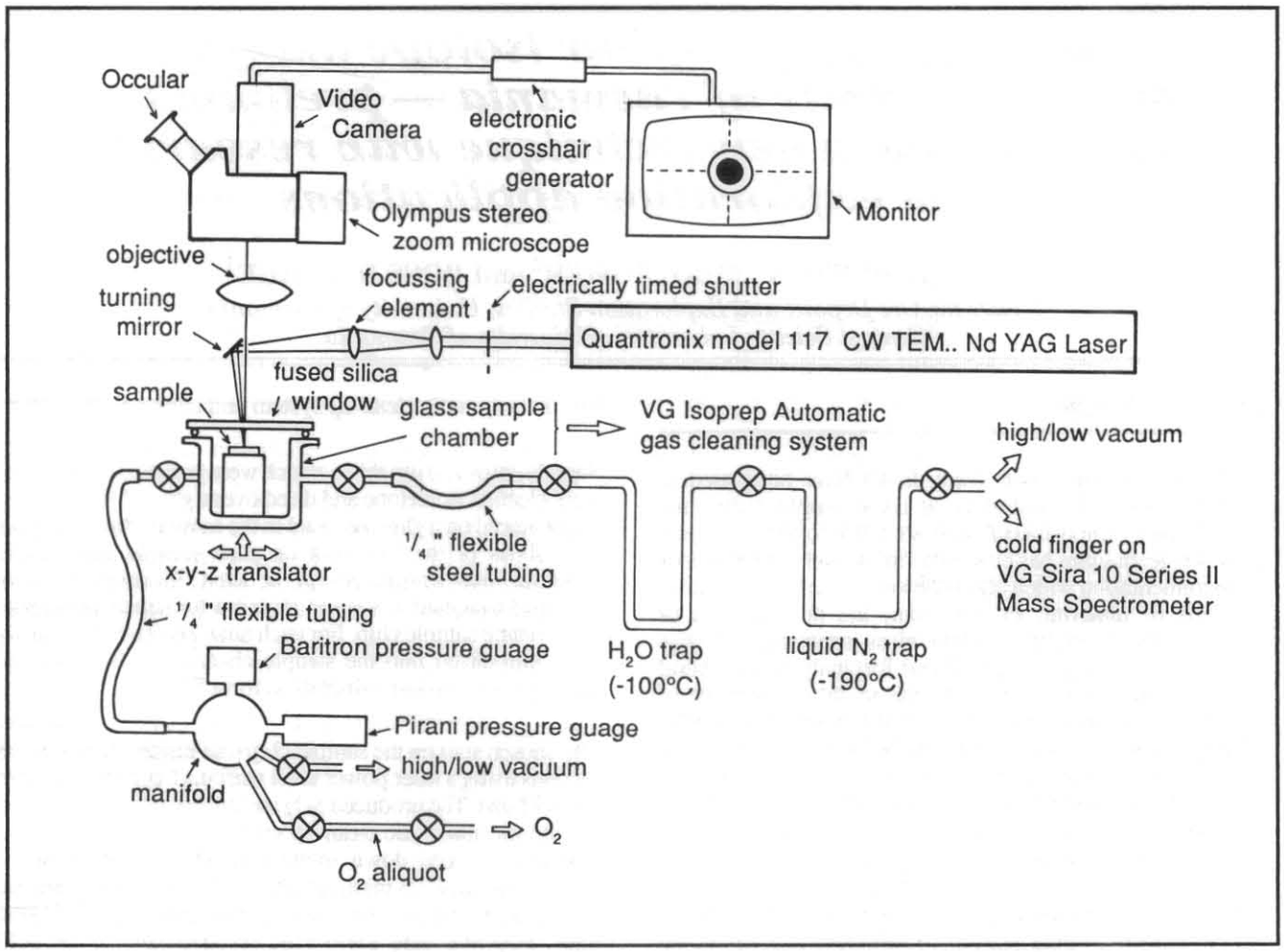


Figure 1

(1) Heating of the sample chamber and transfer lines is required to facilitate sample transfer.

(2) Varying the O_2 pressure between 10 and 50 torr did not effect the ablation or fractionation factors significantly.

(3) Varying the ablation time from 1 to 3 seconds also had no significant effect.

(4) The present method of SO_2 collection only retains 60% of the SO_2 produced. Use of lower O_2 pressures (<10 torr) improves SO_2 collection. Increasing the collection time also improves SO_2 collection. Improved SO collection decreases fractionation factors.

(5) Ablation of rough surfaces resulted in larger fractionation factors than ablation of polished surfaces.

(6) Analyses of larger holes (>250 μm) yielded larger fractionation factors and poorer precisions than analyses of smaller holes (150–250 μm).

(7) One 150–250 μm hole provide sufficient SO_2 gas for analysis for pyrite, sphalerite, pyrrhotite and chalcopyrite. Two or three holes are required for galena analysis, as galena contains proportionately less sulphur.

If an O_2 pressure of 25 torr is used with a 2 second ablation time on polished surfaces, the one sigma precision for 150–250 μm holes is generally between 0.3 and 0.4 ‰. For pyrite a precision of 0.15 ‰ was obtained, but the lack of a large number of analyses suggests that this may be an underestimate. This precision compares with precisions reported by Crowe *et al.* (1990) and Kelley and Fallick (1990) based on substantially fewer analyses. The precision of laser ablation is roughly twice that of conventional sulphur isotope analysis (0.2 ‰ at the University of Tasmania), but it is two to three times better than that of the SHRIMP ion microprobe at the Australian National University (C. S. Eldridge, pers. comm., 1992), which has a better spatial resolution.

Calculated fractionation factors vary from 0.19 ‰ for sphalerite to 6.75 ‰ for pyrite. Ablation of rough surfaces increases these values by up to 2.58 ‰. Precision also deteriorates. Fractionation factors and precisions also deteriorate for holes larger than 250 μm.

GEOLOGICAL APPLICATIONS

Sulphur isotope analysis has been an integral part of the study of mineral deposits over the past three decades. Sulphur isotopes can provide information about the source of sulphur, the importance of redox reactions during sulphide deposition, and the temperature of mineral deposition. Conventional analysis has given a great deal of information about the former two factors, but less information about geothermometry. The difficulty of obtaining geothermometric data relates to both disequilibrium sulphur isotope fractionation during mineral precipitation and also

3/3

Table 1

Fractionation factors and precision (one sigma) for laser ablation sulphur isotope analysis at the University of Tasmania (150–250 μm holes).

	Fractionation factor (‰)	Precision (‰)	n	Fractionation factor (‰)	Precision (‰)	n
Pyrite	6.75	0.15	4			
Chalcopyrite	3.80	0.33	12	4.63	0.46	6
Sphalerite	0.19	0.41	20	2.77	0.66	12
Galena	3.90	0.40	6			
Pyrrhotite	2.92	0.38	8	4.82	0.50	7

the fine intergrowth of sulphide minerals, which makes mineral separation very difficult. Hence, one of the great promises of laser ablation sulphur isotope analysis is definitive geothermometry. Crowe and Shanks (pers. comm., 1991) have demonstrated this for volcanogenic massive sulphide mineralisation in Alaska.

Analysis of trace sulphide minerals in sedimentary, volcanic and magmatic rocks is possible using laser ablation techniques. This application has particular relevance to determining the potential sources of sulphur in ore-forming fluids. Laser ablation sulphur analysis is one technique that will be used to determine the source of metals and sulphur in Mt Read Volcanics volcanogenic massive sulphide deposits in studies currently being undertaken by Bruce Gemmell and Joe Stolz at CODES. With respect to exploration, Solomon *et al.* (1988) have suggested that sulphur isotopes may have some use in distinguishing barren from mineralised systems in the Mt Read Volcanics; barren systems tend to have sulphur isotope values lighter than those of mineralised systems. The use of laser ablation analysis may help refine these differences.

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1/1

Geology and genesis of silica flour and gold in the Corinna district, western Tasmania

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Silica flour deposits are located in the Corinna district of western Tasmania, where alluvial gold was recovered from 1877 to 1941 (Bottrill *et al.*, this volume). The silica flour deposits occur as pod-like residual bodies overlying Upper Proterozoic dolomite (Turner *et al.*, this volume). The silica flour contains 99.9% pure silica with minor aluminium, iron, calcium and titanium.

The dolomite is a silicified light grey to dark grey rock with a grainsize of 20 to 300 μm. It is cut by various sets of quartz ± carbonate vein networks. The veins consist of early thin veins of milky quartz ± dolomite (Type I), which were cross-cut by later thicker veins with or without pink carbonates (Type II). Quartz veins with lacy agate (crustiform) texture occur in the area and in places are found in contact with silicified grey dolomite. This veining has been followed by the extensive silicification of the dolomite and disaggregation of the silica flour.

Three major fluid inclusion types are present in quartz at Corinna:

(1) H_2O-dominated, two-phase, liquid and vapour inclusions which homogenise to liquid upon heating (Type I);

(2) CO_2-bearing inclusions (Type II); and

(3) Two-phase, liquid-rich inclusions with variable liquid and vapour ratios (Type III).

The Type I inclusions in quartz veins gave a homogenisation temperature range of 169° to 298°C, whereas the Type I inclusions in the quartz with lacy agate texture yielded homogenisation temperatures from 166° to 263°C. Type III secondary inclusions yielded filling temperatures in the range of 71° to 144°C.

Freezing point depression (Tm-ice) of the Type I inclusions gave salinities of 1 to 13 NaCl equiv. wt.%, whereas the Type II, CO_2-rich inclusions gave salinities from 0.2 to 17 NaCl equiv. wt.%. The Type III secondary inclusions gave salinities of 4 to 8 NaCl equiv. wt.%. Decomposition temperature of clathrates (T-clathration) yielded salinities of 10 to 13 NaCl equiv. wt.% for the Type I inclusions 11 NaCl equiv. wt.% for the Type II inclusions, and 5 to 13 NaCl equiv. wt.% for the Type III inclusions. Preliminary Laser Raman Spectroscopy analysis, using the DILOR MICRODIL-28® at the Bureau of Mineral Resources, Canberra, gave a significant proportion of CO_2 (~95 mole %) and minor amounts of CH_4 (~5 mole %) in the gases of the fluid inclusions.

CAMECA microprobe analyses indicate that fineness of gold grains ranges from 890 to 951. The morphology of the gold suggests that the gold grains from the vicinity of the silica flour deposits do not appear to have been transported too far away from their source. The lack of Ag-rich rim in the gold grains from the silica flour area adds support to this interpretation.

Fluid inclusion evidence suggests that the source of the fluids for the silicification was likely to be magmatic (e.g. post-orogenic Devonian granite), although fluids of metamorphic origin cannot be ruled out. The early vein formation is related to higher temperature fluids (~300°C) which passed through the dolomite; dolomite silicification followed at a cooler temperature around 250°C. The late-stage, silica flour formation (disaggregation of the silicified dolomite) relates to the late-stage, secondary inclusions (<150°C).

The close association of silica flour and gold grains in the Corinna area suggests a genetic link, and the gold may have been derived from the same silica flour-forming fluids. The high temperature fluid characteristics (~300°C) in the silica flour samples also suggest that the precious metal could have been transported in the fluids. Gold grains may have been derived from carbonate (dolomite)-hosted, Carlin-type deposits which are yet to be discovered in the area. The enrichment of volatiles (e.g. CO_2, CH_4) in the Carlin-type gold deposits (Pasteris *et al.*, 1986), and in the Corinna district, supports the potential discovery of Carlin-type deposits in the Arthur Mobile Belt.

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1/21

The geological and structural controls on mineralisation at the Renison tin mine

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ABSTRACT

The Renison tin mine in Western Tasmania is hosted by subareal to shallow-marine, Late Precambrian to Early Cambrian Success Creek (Corbett and Lees, 1987) and shallow marine Early Cambrian Crimson Creek Formations (Kitto, 1990) within the Early Palaeozoic Dundas Trough. The deposit occurs on the northeast limb of a broad SE-plunging monocline, which in turn constitutes a major horst block bounded to the northeast by the Federal-Bassett Fault (FBF), and to the southwest by the Argent Fault. The dominant brittle deformation structures at Renison, together with the FBF, include the Blow Fault, which occurs west of and sub-parallel to the FBF, and a series of east-west interconnecting Transverse Faults. The Transverse Faults bound a complex series of minor horst and grabens.

The carbonate replacement and vein styles of cassiterite mineralisation were structurally controlled by the complex nature of brittle faulting that focused the mineralising fluids into dilatent fault zones. A detailed study of kinematic indicators on the mineralised faults has determined the stress field during mineralisation (Kitto, 1990; Kitto and Berry, 1991). Four phases of brittle deformation (Devonian to Tertiary) were determined, based on style and relative ages of fault striations. The first generation fibre growths have a mineralogy consistent with host veins suggesting contemporaneous brittle deformation and mineralisation. No striations predating the mineralisation were observed. The initial brittle deformation (BD_1) at Renison produced a normal-dextral orientation of striations, grooves and undulations on fault surfaces, with modelled stress tensors predicting a near-vertical maximum compressive stress and near-horizontal minimum compressive stress trending 84°. This stress regime was unique to Renison and initiated the FBF along a pre-existing monocline as a principal graben boundary fault-couple linked by minor antithetic normal faults. The Argent, Blow and Transverse Faults were also initiated by this BD_1 event, together with the complex system of horst and grabens bounded by the Transverse Faults.

The syn-Devonian normal faulting at Renison contrasts with the NE-SW compressional structures related to the Tabberabberan Orogeny throughout the rest of western Tasmania. The major horst structure bounded by the Federal-Bassett and Argent Faults resulted from the modification of a Devonian monocline by the forceful emplacement of an asymmetrical northwest-trending Devonian granite ridge. The FBF was propagated as a double fault structure on the easternmost margin of the granite subparallel to the -500 m , -1000 m and -1500 m granite contours. The FBF offsets the monoclinal mine sequence by upwards of 700 m in the immediate mine area. The Blow Fault Complex was initiated subparallel to the FBF over an apothysis in the -500 m granite contour, and forms the westernmost boundary to economic cassiterite mineralisation at Renison.

Local uplift in the σ_2 direction and a 15% N-S extension of the mine horst occurred on the eastern margin of the intruding granite, and resulted in the production of the Transverse Faults subparallel to the EW-trending section of the -500 m and -1000 m granite contours. As the granite related stress field decayed, a regional Tabberabberan dextral wrench (BD_2) reactivated earlier BD_1 fault structures and produced a dilational jog in the FBF as a consequence of differential displacements on the Transverse Faults. The stress field associated with the BD_2 wrench may have facilitated the formation of the largest carbonate replacement orebodies within dilational areas adjacent to the convex flexures.

The listric extensional Transverse Faults acted as basal detachments to a system of linked synthetic and antithetic displacements which formed a complex series of N-S oriented horst and graben structures in a plane perpendicular to σ_3. These horsts and grabens show maximum extension (>20%) to the south, directly above an apophysis in the -500 m granite contour. These fault structures controlled carbonate replacement in the up-dip dolomite horizons distal to the FBF.

The intimate association of brittle deformation structures, granite topography (Leaman, 1991), and granite geochemistry (Bajwah et al.; in prep.) suggest that the forceful intrusion of a late-stage Sn-rich granite occurred immediately beneath Renison during the Devonian. The granite intrusion not only prepared the overlying carbonate-rich sediments structurally but also supplied the source of fluids responsible for carbonate replacement and vein styles of cassiterite mineralisation.

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2/21

INTRODUCTION

Australia's largest primary tin producer, Renison, is located on the West Coast of Tasmania (fig. 1) within the longitudinal Palaeozoic Dundas Trough, bounded by the Proterozoic Tyennan and Rocky Cape metasedimentary regions (Solomon, 1981). The carbonate horizons hosting replacement mineralisation lie within the subareal to shallow marine, Late Precambrian to Early Cambrian Success Creek Formation (Corbett and Lees, 1987) and shallow marine Early Cambrian Crimson Creek Formation (Kitto, 1990). Forceful emplacement of an asymmetrical granite ridge associated with the Devonian Pine Hill Granite (355 ± 4 Ma; Brooks, 1966) resulted in complex brittle deformation of the host rocks (Kitto, 1990; Kitto and Berry, 1991), providing a major focus for ascending hydrothermal fluids which resulted in carbonate replacement and vein styles of mineralisation.

An abundance of information has been documented on the Renison mine geology since the commencement of large-scale underground operations in the mid 1960s (interested readers are referred to the following authors: Patterson *et al.*, 1981; Morrison, 1982; Davies, 1985; Holyland, 1987; Kitto and Berry, 1991, 1992).

HISTORICAL PRODUCTION

The Renison orebodies were discovered in 1890 as alluvial and gossanous deposits. Hard-rock mining ceased in the 1920s when only untreatable massive iron sulphide remained. Technology in the 1930s overcame the difficulties of recovering tin from massive pyrrhotite, allowing small-scale open-cut and underground mining to resume. The large-scale underground mining operations commenced in 1967.

Renison, in 1991, had an annual production rate of approximately 550 000 tonnes at 1.2% Sn and an identified mineral resource totalling 11 million tonnes at 1.26% Sn. Since production figures have been recorded (1960), the total recovery of Sn has exceeded 115 000 tonnes.

STRATIGRAPHY*

The typical mine sequence is interpreted as two regressive and a partial transgressive cycle of subtidal-intertidal-supratidal and fluvial units (fig. 2; Morrison, 1982). The sequence is widely distributed to the north and west upon the Rocky Cape Block, but its depositional limits to the east and south are equivocal (Holyland, 1987). The stromatolitic-oolitic facies (i.e. No. 1, 2 and 3 carbonate horizons; see fig. 2 and 3) form an extensive supratidal platform continuous with the Smithton Dolomite which has undergone diagenetic or hydrothermal alteration of an originally clastic limestone (Morrison, 1982).

A summary of the major lithologies at the mine is provided in Figure 3. The basal unit to the mine sequence is the Dalcoath Member, which has identifiable upper sub-units beginning with the Dalcoath Contorted (up to 80 m). This consists of intensely contorted, laminated, black to grey shale and siltstone. Soft-sediment deformation is invoked, but Brown (1986) has also identified later tectonic overprinting. A lithologically equivalent, yet undisturbed carbonaceous and non-carbonaceous siltstone, overlies this sub-unit. This is in turn overlain by the Dalcoath Upper (10–15 m), a laminated shale-siltstone unit containing thin, folded, boudined and nodular dolomite beds.

The No. 3 Dolomite (up to 15 m) is the lowermost of the three carbonate units which host the known stratabound mineralisation. It is a massive, light to dark grey dolostone with relatively sharp lithological contacts.

Conformably overlying this zone are the three sub-units of the Renison Bell Member (RBM). The RBM Lower comprises 20–40 m of massive white to grey, fine-grained quartz sandstone with characteristic pebble beds. The RBM Middle (10–30 m) is a laminated micaceous black shale, with local thin siltstone and sandstone laminae distinguishing it from the RBM Upper (5–10 m) with its increasing carbonate fraction. The RBM Upper has a gradational contact with the No. 2 Dolomite, and also includes a minor yet significant dolostone, the 2.2 Horizon. The No. 2 Dolomite is similar to the No. 3 Horizon except for characteristic silty interbedding and impure gradational margins.

A very distinctive marker horizon, the Red Rock Member (25–35 m), overlies the No. 2 Dolomite and marks the top of the Success Creek Group. This horizon has a highly variable lithology characteristic of a fluvial environment, and is subdivided into three units; a siltstone and fragmental-tuffaceous group; a conglomerate, grit, sandstone, carbonate group; and a chert-iron formation, carbonate group (Morrison, 1982).

The No. 1 Dolomite (8–25 m) is conformable with the underlying Red Rock and is a chemically impure equivalent of the No. 2 and No. 3 Dolomites, having well-developed silt-mudstone interbeds up to four metres in thickness.

The Upper Contorted Dreadnought Hill Member represents the basal sequence of an overlying sequence of massive to thinly-bedded siltstone, shale and mafic volcaniclastic greywackes known as the Crimson Creek Formation (>1000 m). Evaporite horizons, scattered throughout the succession, have been interpreted as shallow water sabkha representatives (Kitto, 1990). Gabbroic sills and dykes? occur within the Crimson Creek Formation at Renison, and their geochemistries would indicate that these post-orogenic collisional tholeiites have been cannibalised to source the Crimson Creek sediments.

REGIONAL STRUCTURAL SETTING

In the Renison–Zeehan region, Brown (1986) isolated an east-west compressive event (D_1) which pre-dated the deposition of the early-Middle to Late Cambrian Dundas Group. D_1 produced shallow east to southeast-dipping thrust sheets associated with belts of sheared and disrupted allochthonous mafic and ultramafic complexes (Berry and Crawford, 1988). A NE-SW compressive event, D_2, coeval with the Tabberabberan Orogeny, was identified by Holyland (1987) to be responsible for moderately open regional northwest-trending folds. Leaman (1988) further recognised the close association regionally between the intersection of D_1 sutures, D_2 anticlines, granite emplacement and subsequent mineralisation. Marjoribanks (1990) postulated that the D_2 event initiated the brittle

* Editorial footnote: Much stratigraphic and structural terminology is local mine terminology only.

deformation associated with propagation of the master faults at Renison.

OVERVIEW OF THE STRUCTURAL GEOLOGY AT RENISON

A number of the regional fault structures around Renison were correlated by Lea (1991) to the tensional regime associated with emplacement of the steep-sided northwest-trending Pine Hill Granite ridge (fig. 4). The Federal-Bassett Fault (FBF) was inferred to project steeply upward from the northeast margin of the granite ridge into the overlying Success Creek and Crimson Creek sedimentary rocks. The less-steep, westerly-dipping Argent Fault has similarly been correlated with the westerly-dipping roof of the cupola. The Argent Fault, together with the FBF, defines the Renison mine horst.

The mine horst is approximately one kilometre wide and three kilometres long (fig. 5). The Renison mine sequence associated with the mine horst clearly defines a broad monoclinal fold which steepens its dip toward the FBF (fig. 6). The monoclinal fold is thought to occur on the northeast limb of a regionally southeast-plunging anticline (Patterson, 1979). The absence of an axial-surface cleavage, however, leaves conjecture as to the presence and exact location of this anticlinal structure.

On approach to the FBF from the west, the mine sequence steepens from near-horizontal 600 m away, to almost parallel adjacent to the FBF. Rotation of the mine sequence into the plane of the FBF occurred by simple shear, and emphasised the monoclinal nature of the sediments (fig. 6). Facies variation within the mine sequence, rather than ductile thinning, is sufficient to explain the minor thickness variations observed. McQuitty (1991), however, has evoked a ductile deformation component at depth, to the North Bassett region, together with a facies variation to explain variations in the dolomite thickness.

The dominant brittle deformation structures within the immediate mine area associated with the FBF are the Blow Fault Complex (BFC), 700 m southwest of and subparallel to the FBF, and a series of east-west interconnecting Transverse Faults (fig. 5). The Transverse Faults have acted as listric basal detachment faults, upon which a set of secondary normal faults have developed and resulted in a complex series of north-south oriented horst and graben structures (fig. 6).

A detailed study of kinematic indicators on the major faults at Renison by Kitto (1990) and Kitto and Berry (1991) determined the stress field during mineralisation. Four phases of brittle deformation, from Devonian to Tertiary in age, were identified, based on the style and relative age relationships of the fault striations. The first generation of mineral fibres had a mineralogy consistent with host veins, suggesting contemporaneous brittle deformation and mineralisation. No striations predating the mineralisation were observed.

The initial brittle deformation (BD_1) at Renison produced a normal-dextral orientation of striations, grooves and undulations on fault surfaces. The modelled stress tensors predicted a near-vertical maximum compressive stress (σ_1), and near-horizontal minimum compressive stress (σ_3) which trended 84° (fig. 7a, b). This stress regime was unique to Renison, and contrasts with the NE-SW compressional event suggested by Marjoribanks (1989) related to the Tabberabberan Orogeny. Kitto and Berry (1991) concluded that the dominant brittle deformation structures were initiated by the forceful emplacement of the Pine Hill Granite, and that the early stages of cassiterite mineralisation were coeval to this BD_1 event.

As the radial stress field associated with the granite intrusion decayed a regional Devonian Tabberabberan stress field remained. This caused a dextral wrench (BD_2) to reactivate the earlier brittle deformation structures because of a near-horizontal maximum compressive stress, σ_1, trending 172°, and a near-vertical intermediate compressive stress, σ_2 (fig. 7c, d). The latter stages of cassiterite mineralisation continued during this BD_2 event.

Two minor, post-Devonian, reactivations unrelated to mineralisation have also been recorded. The first, a reverse-sinistral displacement (BD_3) with less than a few tens of metres displacement, overprints the earlier fault striations. Modelled stress tensors indicate that the maximum compressive stress (σ_1) was near-horizontal, trending 88°, and the minimum compressive stress (σ_3) was vertical (fig. 7e, f). This reactivation may be associated with a suspected regional Carboniferous thrust (Brown, pers. comm.), or due to an elastic rebound of the rocks after normal-dextral faulting. Minor Tertiary normal-sinistral reactivation (BD_4) is the last recognised brittle deformation at Renison, and was formed by a near-vertical maximum compressive stress (σ_1) and a horizontal minimum compressive stress (σ_3) trending 158° (fig. 7g, h).

STRUCTURAL CONTROLS TO MINERALISATION

FIRST ORDER STRUCTURES

The primary control on mineralisation at Renison was the Federal-Bassett Fault (FBF), which provided the major focus for ascending hydrothermal fluids off the forcefully-emplaced asymmetrical Devonian granite ridge. Less important, but subparallel to the FBF, was the Blow Fault Complex (BFC), which forms the western boundary to economic tin mineralisation at Renison.

Federal-Bassett Fault (FBF)

The FBF has a strike length of several tens of kilometres (Lea, 1991) and dips to the northeast at approximately 70°, along the easternmost margin of the Renison Mine Horst. The FBF forms a double-fault structure, or fault couple, with up to 100 m of separation. In the mine area the fault couple can be divided into three distinct zones (fig. 5):

(i) Envelopes; the region south of the 'Shear L' – FBF intercept.

(ii) Federal; the region between the 'Shear L' and 'Shear P' intercepts with the FBF.

(iii) North Bassett; the region north of the 'Shear P' – FBF intercept.

NOTE: At Renison the term 'shear' is a historical term, and does not have a generic connotation.

The FBF in the North Bassett region, together with the monoclinal fold seen in the mine sequence, very closely

resemble structures described by Al Kadhi and Hancock (1980) in the Persian Gulf (fig. 8a, b). These structures show planar high-angle normal boundary faults intimately associated with subsidiary antithetic and synthetic normal faults. Such fault patterns typically characterise terrains that have experienced minor inhomogeneous extensions (Wernicke and Burchfiel, 1982). This is confirmed by cross-section reconstructions for the North Bassett region of the FBF at Renison, where extension in the vertical plane of the fault couple has varied from between 15% and 30% (fig. 9). The percentage of extension in the 'Envelope' and Federal regions is uncertain but thought to be of the same orders of magnitude.

The hangingwall to the FBF in the mine area is essentially continuous except for very minor late-stage fault offsets. The footwall structure, in comparison, is highly variable and responsible for initiating the Transverse Faults and other minor faults from flexures within the footwall structure (fig. 6).

Normal-dextral displacement of the hangingwall mine sequence relative to the footwall mine sequence by the BD_1 deformation event resulted in approximately 700 m of dip-slip movement on the FBF in the North Bassett region of the mine (McQuitty, 1991) (fig. 8b). Dip-slip movement on the FBF decreases northward to less than 400 m (Marjoribanks, 1990) but increases to the south where granite stoping of the hangingwall, at depth in the Federal area, prevents an accurate estimation of the fault offset.

Dextral-wrench displacement on the FBF during BD_2 was, at most, only a few tens of metres. It produced the dilational jog in the Federal region where right lateral reactivation of the FBF was partially transferred along the Transverse Shears, 'Shear P' and 'Shear L', resulting in a steep southeast-plunging dilational inflexion on the FBF. A similar estimate for dextral displacement on the FBF was determined by Holyland (1987) using an isodilate method for trend surface residuals on the FBF footwall and hangingwall. He suggested that an oblique normal-dextral slip movement of approximately three metres, plunging at 15° south, would explain the sulphur distribution observed within the FBF. The formation of the Melba Fracture Orebody was a probable consequence of this dextral-wrench reactivation. Previous workers have postulated several hundreds of metres of dextral wrench movement at Renison but this clearly has not occured on the FBF.

The FBF was the major focus for granite-related mineralising fluids at Renison. It provided an access for the hydrothermal fluids to adjacent dolostone horizons and to further second and third-order fault structures.

Blow Fault Complex (BFC)

The Blow Fault Complex has been interpreted as a near-continuous fault structure west of, and subparallel to, the FBF (fig. 5). Similar structures involving the Blow Fault have previously been termed the Western Boundary Fault (Davies, 1985) and the Footwall Fault (Marjoribanks, 1989). At its southern extension the BFC is interpreted to crop out approximately one kilometre west of the FBF and is terminated by the Argent Fault. The BFC strikes north-south and dips steeply east, approaching within 600 m of the FBF on the Murchison Highway in the Black Face Opencut. The BFC and FBF serve as boundary faults to the interconnecting Transverse Faults but neither is truncated by them. North of the study area the BFC is interpreted to either terminate against the FBF or change strike and parallel the FBF (Marjoribanks, 1990).

The BFC was initiated, along with the other major faults at Renison, by the BD_1 normal-dextral movements. Dip-slip displacement was of the order of a few tens of metres. Dextral wrenching (BD_2) on the BFC strongly overprints the earlier generation of normal-dextral fault striations in the Black Face Opencut and railway exposures. These features support Marjoribank's (1990) argument that some of the high strain on the FBF was transfered to the BFC during the BD_2 Tabberabberan reactivation. Only minor dextral-wrenching affected the southern extensions of the BFC as it is terminated by, but does not truncate, the Argent Fault.

The BFC was a minor conduit to mineralising fluids at Renison and did not undergo the same degrees of brittle deformation, displacement or dilation which characterise the FBF structure. The BFC was, however, important in providing access to fluids responsible for the formation of the up-dip carbonate replacement Argent and Ring orebodies (fig. 10).

SECOND-ORDER STRUCTURES

Transverse Faults

The Transverse Faults have, at Renison, been historically termed the Transverse Shears. They are a series of east-west trending, shallow to steeply northeast-dipping faults which interconnect but do not truncate the two first-order structures; the FBF and BFC. South to north in the study area, the Transverse Faults are called the Mercury Fault, 'Shear L', 'Shear P', 'Shear R', and 'Shear S' (fig. 5).

In cross-section (fig. 6), the Transverse Faults form a listric extensional fault system and act as basal detachment faults to third-order fault structures. The Transverse Faults were initiated as brittle deformation structures which splayed off convex-west flexures in the footwall of the FBF during the normal-dextral BD_1 event. Kitto (1990) has suggested that the Transverse Faults were initiated as secondary reverse faults relative to the FBF, when the FBF is oriented and viewed as a pure wrench structure during BD_1 (fig. 11). In short, normal-dextral brittle deformation on the FBF and BFC, initiated by granite emplacement, produced local uplift and north-south stretching of the uplifted block via the extensional Transverse Faults. The percentage of crustal extension experienced in the north-south direction during granite emplacement was approximately 15%, based on cross-section reconstructions.

In plan, the Transverse Faults exhibit a weak sigmoidal outline; a primary feature analogous to the helicoidal structures observed during the formation of an extensional negative flower structure commonly described in the petroleum industry (Harding, 1985; Woodcock and Fischer, 1986; Naylor *et al.*, 1986). Surface expressions of the Transverse Faults in the study area are poor, but 'Shear L' can be observed near the Federal Opencut on Stebbins Hill and 'Shear R' in the Black Face Opencut on the Murchison Highway. 'Shear R' at this location has been interpreted by previous workers as a low-angle thrust, but first and second generation fibres on fault surfaces are consistent with BD_1 and BD_2 deformations observed elsewhere at Renison, negating any suggestion of an earlier thrust event within the study area. Shears 'R' and 'S' experienced only minor displacements relative to the other Transverse Faults.

The dolomite horizons are highly dissected and exhibit fault gaps due to second and third-order fault structures when viewed from a footwall projection (fig. 10). Sulphide replacement of the dolomite horizons was greatest in the dilational areas adjacent to the convex regions of the sigmoidal second-order Transverse Faults (e.g. the Dreadnought and North Stebbins orebodies of the Number 2 Dolomite Horizon, and the Penzance and Colebrook orebodies of the Number 3 Dolomite Horizon).

The Melba Fracture orebody, an anastomosing sheeted-vein complex hosted by the Renison Bell Formation siltstone, is anticlinal in cross-section and located between Shear 'L' and 'P'. In plan, the 'Melba' splays from 'Shear P', close to the FBF, creating an orebody which resembles a huge tensional gash opening, possibly the product of differential dextral displacement on 'Shear L' and 'Shear P' during the BD_2 reactivation.

The western margin of 'Shear P' is interpreted, in this study, to be terminated against the BFC and to occupy the same site as the 'Polaris' carbonate-magnetite orebody. Cross-sectional interpretations for this area indicate that the 'Polaris' orebody is located within a dilational zone, where 'Shear L' has ramped upward into 'Shear P' (fig. 12).

'Polaris' is a bedding-subparallel shear zone that hosts an early carbonate-magnetite and a later replacement pyrrhotite (± pyrite) mineralisation (Simonsen, 1988). These two phases of mineralisation may be associated with the two phases of brittle deformation identified as BD_1 and BD_2. Previous investigators (Barber, 1990; Marjoribanks, 1990) have proposed a pre-Devonian low angle thrust to accommodate 'Polaris'-type mineralisation, but such mechanisms are not supported by field observations.

THIRD-ORDER STRUCTURES

The second-order listric extensional Transverse Faults have acted as basal detachments to a system of linked third-order listric faults which exhibit both synthetic and antithetic displacements. These third-order structures produced a series of minor horst and grabens which strike subparallel to the FBF in a direction normal to the minimum compressive stress (σ_3) associated with normal-dextral brittle deformation (BD_1) (fig. 5 and 6). These structures controlled the carbonate-replacement mineralisation within the up-dip dolomite horizons by providing access for sulphide-rich hydrothermal fluids.

Horst and grabens within the mine area developed east of the BFC. The BFC bounds a major horst block west of the study area. Each horst and graben pair, within the mine area, have centres which diverge toward the south and reflect maximum extension in the direction of minimum thickness over basal detachments, i.e. the Transverse Faults. Regularly spaced cross-section reconstructions for the study area indicate that east-west extension, due primarily to second and third-order structures, is approximately 20% (fig. 13). Extension north of 'Shear P', however, gradually decreases to only about 5%. This area is associated with 'Shear R' and 'Shear S', and reflects the small degree of deformation that accompanied these Transverse Faults.

In plan, the dolomite horizons at Renison show extensive brittle deformation due to third-order fault structures, particularly in the up-dip areas distal to the FBF (fig. 10). In these regions the third-order structures are particularly important for carbonate replacement styles of mineralisation by providing access for the hydrothermal fluids. The formation of the Ring, Sligo and Argent orebodies in the Number 3 Dolomite Horizon appears to be strongly dependant on these third-order structures distal to the FBF.

GRANITE TOPOGRAPHY

Lea (1991), based on a gravity model for the granite profile (Leaman, 1990), has proposed that the major FBF at Renison was initiated by the tensional regime associated with granite emplacement. The gravity response of the granite (average density 2.66 t/m^3) also suggests that a lower density granite phase (average density 2.64 t/m^3) occurs at two locations; one directly beneath the Renison Mine and the other at Pine Hill (D. E. Leaman, pers. comm., 1991). This observation strengthens the arguement proposed by Kwak (1987) that the primary source of deep magmatic solutions is related to a small granite cupola down-dip from the Federal section of the FBF, and not from the Pine Hill greisen some 400 m topographically above and three kilometres south of the Renison Mine.

Numerous researchers emphasise the effects of fluid overpressure within plutons due to crystallisation reactions in hydrous melts (Burnham, 1979; Heinrich, 1990). In such melts positive volume changes of several tens of percent cause the hydrostatic pressure to exceed the lithostatic load, and result in hydraulic fracturing. Failure of the country rocks in the direction of the minimum principal stress (σ_3) would therefore be expected at the points of highest curvature between the granite and host rock associated with the granite cupola where the stresses become concentrated. The first order FBF would therefore be expected to propagate as a normal-dextral fault along the steep asymmetrical eastern margin of the shallow northwest-plunging Pine Hill Granite ridge, subparallel to the -500 and -2000 m granite contours, in a zone of structural weakness associated with monoclinal sediments (fig. 14). During this brittle deformation event (BD_1) associated with forceful granite emplacement, the BFC and the Transverse Faults would also be initiated and developed over the eastern extension of the asymmetrical granite ridge.

In the study area, the BFC developed subparallel to the north-trending apophysis of the -500 m granite contour, confirming the close association between major faults and granite topography. This association ideally explains why the BFC may subparallel or terminate against the FBF north of the study area, and only have a few tens of metres displacement.

The second-order listric extensional Transverse Faults dissect the uplifted block bounded by the FBF and BFC and mimic the granite topography. The Transverse Faults near-parallel the east-west trend of the -500, -1000 and -1500 m granite contours and plunge to the north. The north-south extension of the uplifted block resulted from the forceful emplacement of the asymmetrical granite ridge beneath the mine area.

Third-order horst and grabens developed as a consequence of both synthetic and antithetic displacements upon the listric extensional Transverse Faults, normal to the BD_1 minimum compressive stress (σ_3). These third-order structures are the result of east-west extension along the eastern margin of the asymmetrical granite ridge where the -500 and -1000 m granite contours strike east-west. Extension in this region may have resulted from the emplacement of a late-stage granite phase directly beneath the mine area in the region of

6/21

the apophysis in the -500 m granite contour. This interpretation is somewhat supported by the geophysical data, as discussed, and the granite geochemistry of Bajwah *et al.* (in prep.). They define a hydrothermal alteration halo in the granite beneath the mine area from a tourmaline-rich inner core through a sericite zone to an outer albite halo. The Sn-rich hydrothermal fluids exolving from this late-stage granite phase would have gained access to the first-order FBF structure immediately above the granite and then focused along the second-order listric extensional Transverse Faults. These second-order structures acted as basal detachments to the third-order horst and grabens, allowing mineralising fluids access to the mine sequence dolomites distal to the FBF. In these regions carbonate replacement and vein styles of mineralisation were controlled by the third-order structures and resulted in the Updip Orebodies.

The first, second and third-order normal-dextral (BD_1) fault structures associated with forceful granite emplacement at Renison contrast with the compressional structures related to the Tabberabberan Orogeny throughout the rest of western Tasmania. The fault patterns associated with the underlying granite topography resulted from the radial stress field, related to granite emplacement, overlapping with the regional Tabberabberan stress field. The compounding effect of both stress fields was sufficient to initiate normal-dextral brittle deformation (BD_1). The early stages of cassiterite mineralisation were coeval to this BD_1 event. Ode (1957) has invoked a similar superposition of local and regional stress fields to explain the observed patterns of faults and dyke emplacements seen above a granite intrusion in the Spanish Peaks area, Colorado.

As the granite-associated stress field decayed, the earlier brittle deformation structures were overprinted by a dextral wrench, BD_2, consistent with the regional Tabberabberan pattern of faulting and reactivation. The latter stages of cassiterite mineralisation continued during this event. Dextral-wrench displacement on the FBF during BD_2 produced the dilational jog in the Federal region of the FBF, where right lateral reactivation of the FBF was partially transferred along the Transverse Shears 'P' and 'L', resulting in a steep southeast-plunging dilational inflexion on the FBF. The formation of the Melba Fracture Orebody was a possible consequence of this dextral-wrench reactivation, as was the formation of some of the largest carbonate replacement orebodies within the dilational pressure zones adjacent to the convex regions of the Transverse Faults during the associated stress field related to BD_2.

CONCLUSIONS

A detailed geological interpretation of the geology at the Renison tin mine, using cross-section interpretations and computer modelling, has demonstrated the close association between granite emplacement, brittle deformation structures, and cassiterite mineralisation.

Many of the structural complexities at Renison resulted from the forceful emplacement of an asymmetrical northwest-trending Devonian granite ridge. The brittle deformation event (BD_1) associated with emplacement initiated normal-dextral faults subparallel to the granite topography in the overlying late Precambrian Success Creek Formation and early Cambrian Crimson Creek Formation. The Federal-Bassett Fault (FBF) was propogated as a double fault structure on the easternmost margin of the granite, and offset the monoclinal mine sequence by upwards of 700 m in the immediate mine area. The FBF was the primary focus for hydrothermal fluids that were responsible for carbonate replacement and vein styles of mineralisation. The Blow Fault Complex (BFC) was initiated subparallel to the FBF over an apophysis in the granite contours, and forms the westernmost boundary to economic cassiterite mineralisation at Renison.

The Transverse Faults interconnect the FBF and BFC, subparallel to the east-west trend of the -500 and -1000 m granite contours. These second-order listric fault structures propogated from convex-west flexures in the footwall of the FBF and dissected the mine horst, resulting in approximately 15% north-south extension. A dextral-wrench reactivation (BD_2) overprinted the earlier BD_1 fault structures and produced a dilational jog in the Federal region of the FBF as a consequence of differential displacements on the Transverse Faults. The stress field associated with BD_2 may also have played a significant role in the formation of the largest carbonate replacement styles of mineralisation at Renison, which occur within dilational zones adjacent to the sigmoidal convex flexures on the Transverse Faults. The Melba Fracture Orebody also formed in a dilational zone, between 'Shear L' and 'Shear P', possibly as a consequence of BD_2 reactivation. Carbonate-magnetite mineralisation responsible for the Polaris Orebody occurs within the Transverse Fault, 'Shear P', close to its intersection with 'Shear L'.

Third-order, north-striking horst and graben structures developed as a consequence of both synthetic and antithetic faults above the listric extensional Transverse Faults. These-third order structures resulted in a 20% extension of the mine sequence in the direction of the minimum compressive stress for the BD_1 event above an apophysis in the -500 m granite contour. These third-order fault structures controlled the carbonate replacement styles of mineralisation in the up-dip dolomite horizons distal to the FBF.

At Renison, the intimate associations between brittle deformation structures, granite topography and its alteration geochemistry strongly suggest that a late-stage tin-rich granite forcefully intruded the sediments immediately beneath the mine during the Devonian. The granite intrusion not only prepared the overlying carbonate-rich sediments structurally but also supplied the source of fluids responsible for the carbonate replacement and the vein styles of cassiterite mineralisation.

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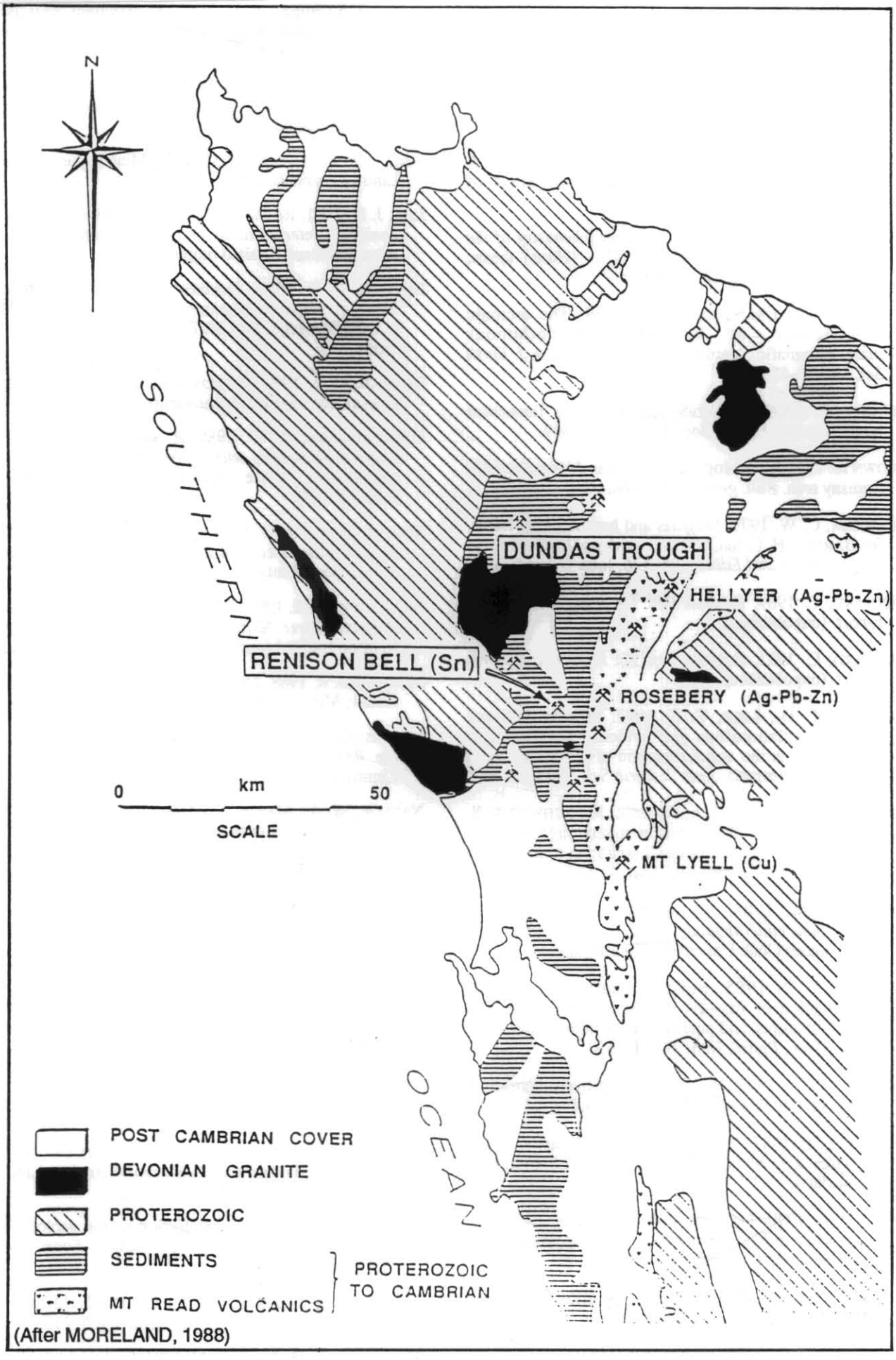


Figure 1. Regional geology, western Tasmania.

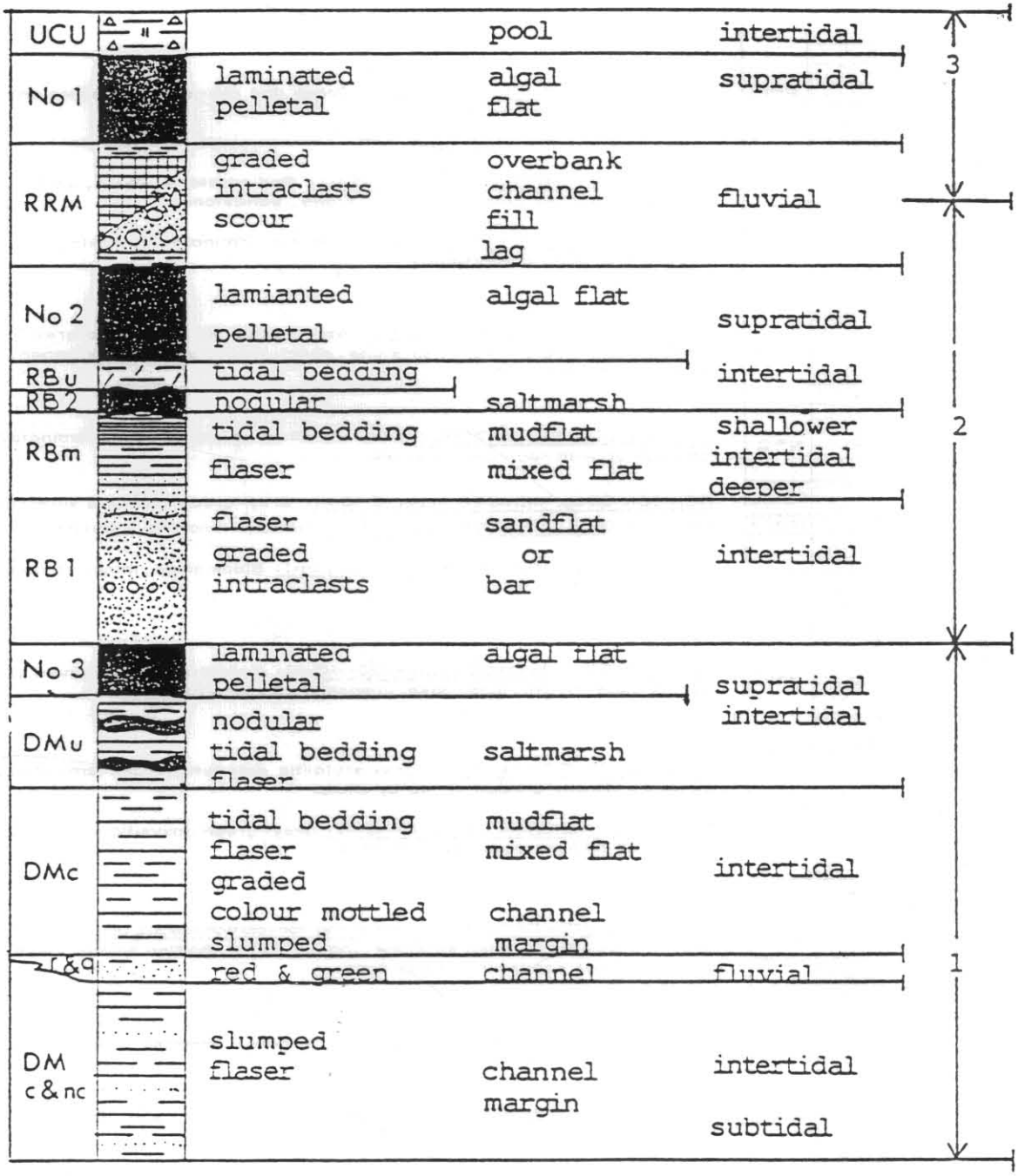


Figure 2

Sedimentary cycles in the Renison mine sequence, based on interpreted depositional environments. The lower two cycles are retrogressive, and the third cycle is partial but transgressive (from Morrison, 1992).

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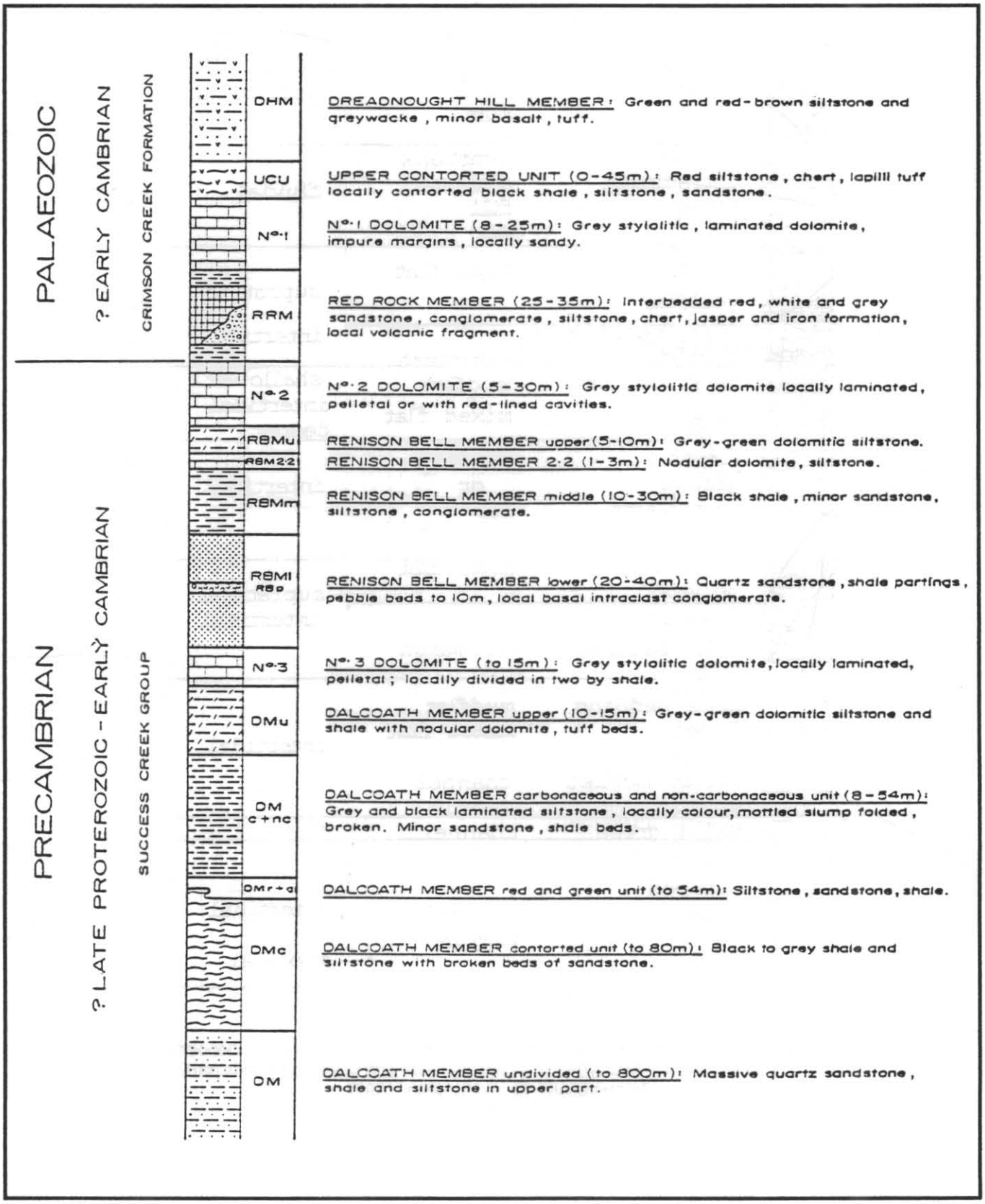
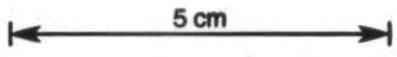


Figure 3

Stratigraphy of the Renison mine sequence (from Moreland, 1988).



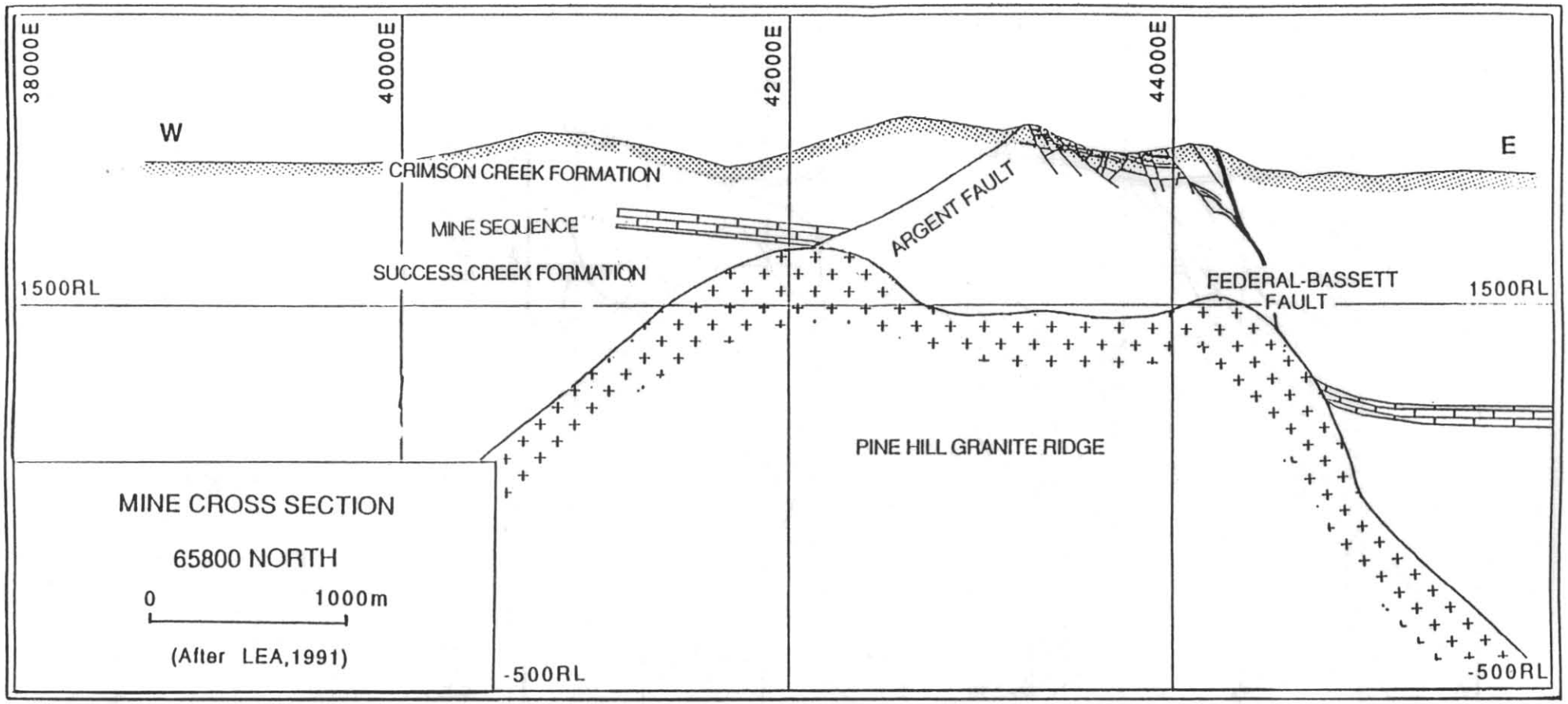

38000E
40000E
42000E
44000E
W
E
CRIMSON CREEK FORMATION
MINE SEQUENCE
SUCCESS CREEK FORMATION
ARGENT FAULT
FEDERAL-BASSETT
FAULT
1500RL
1500RL
PINE HILL GRANITE RIDGE
MINE CROSS SECTION
65800 NORTH
0
1000m
(After LEA,1991)
-500RL
-500RL

Figure 4

5 cm

12/21

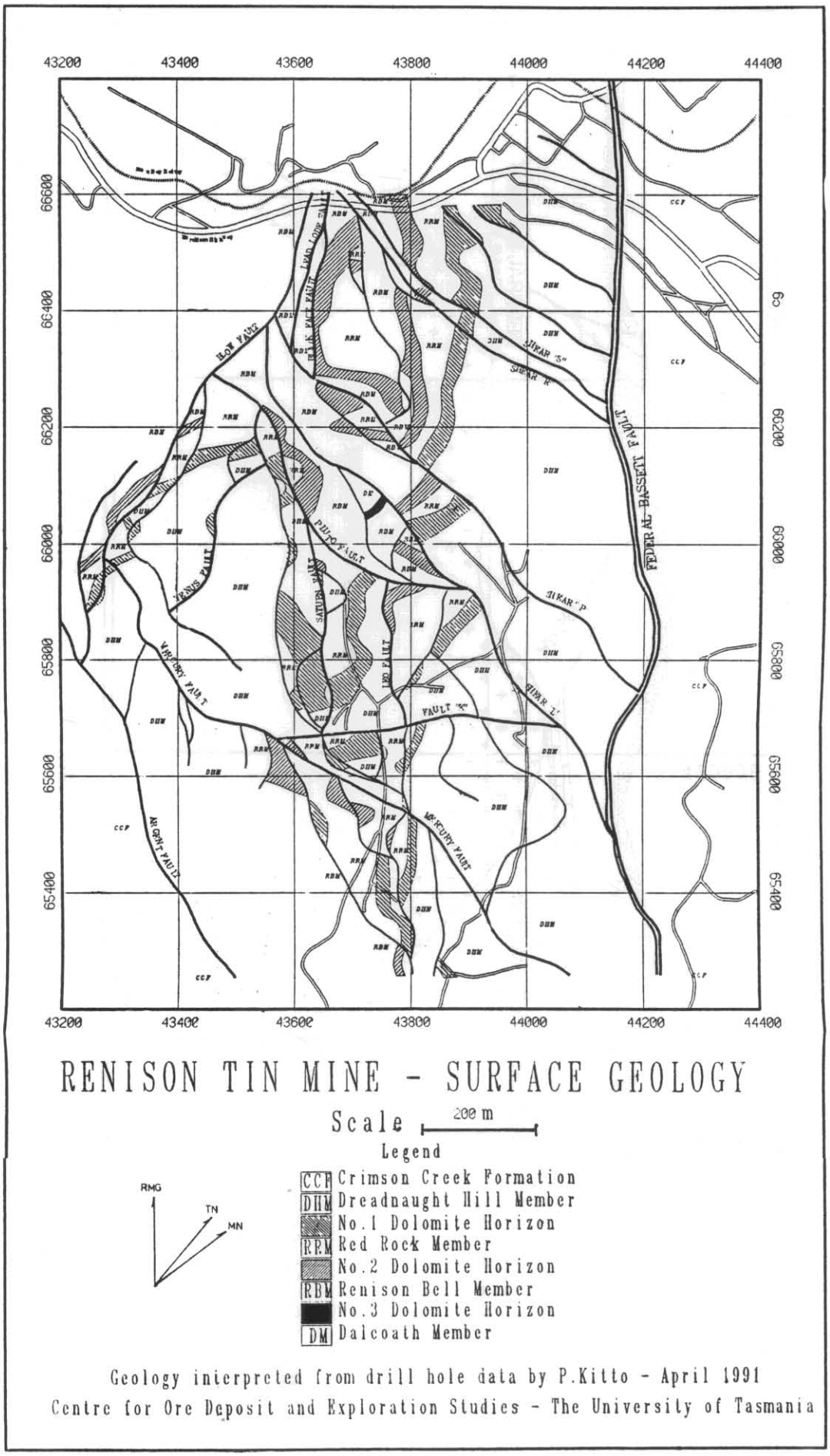


Figure 5

5 cm

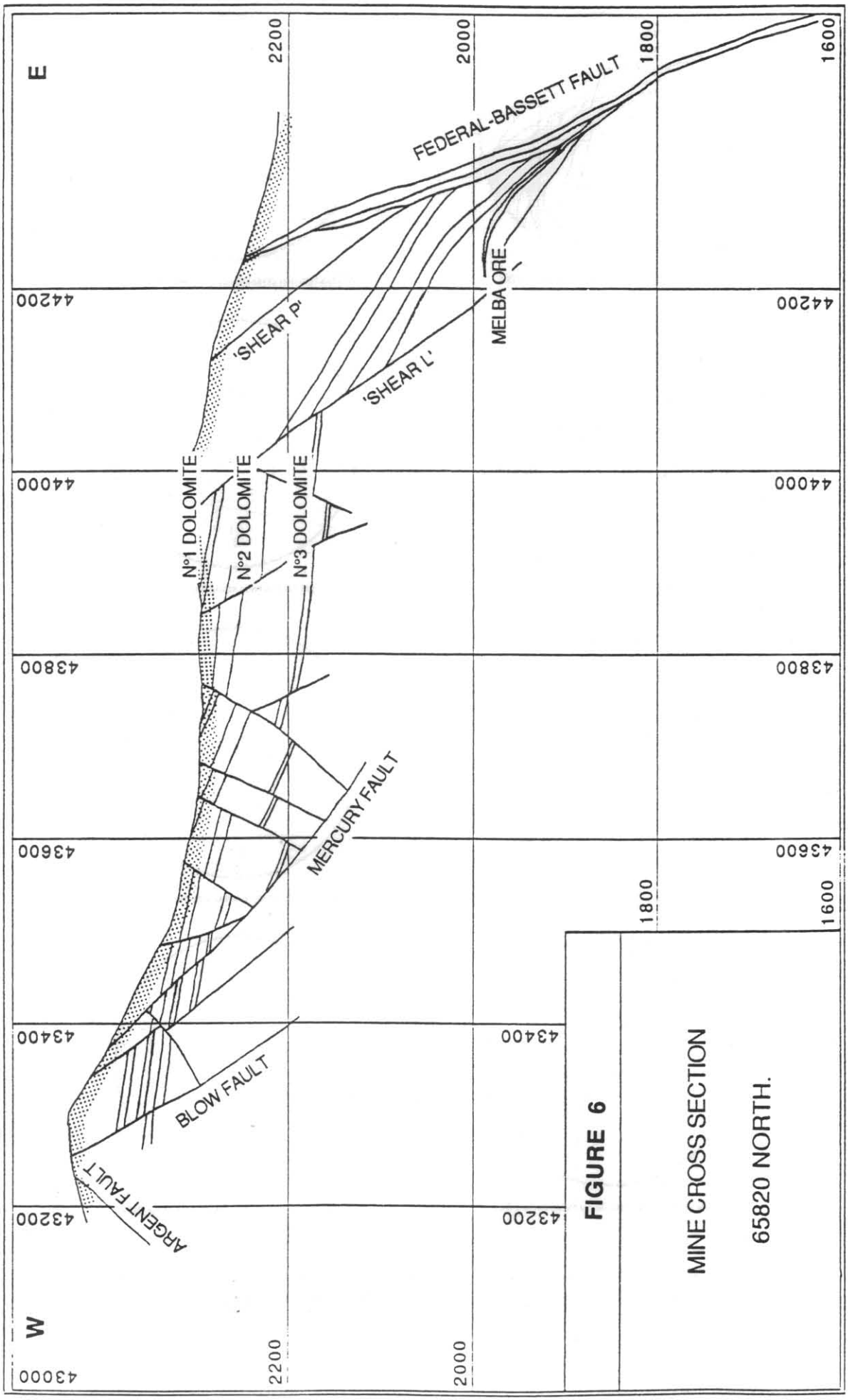
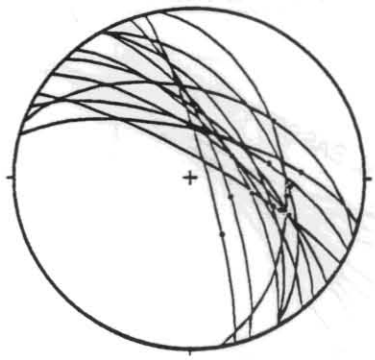


FIGURE 6

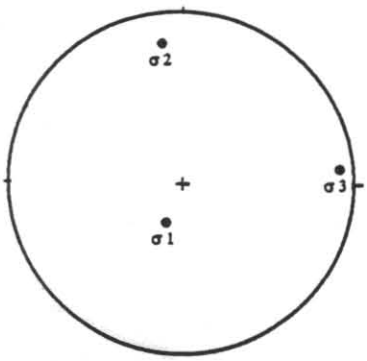
MINE CROSS SECTION

65820 NORTH.

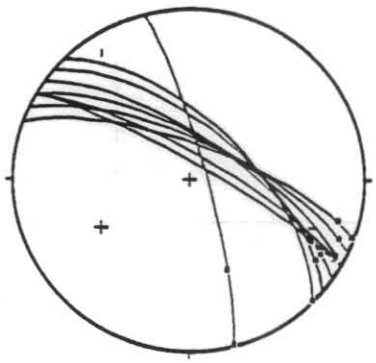
14/21



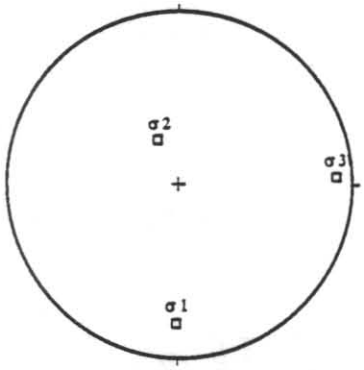
(a) BD1 - normal-dextral fault striatins for FBF.



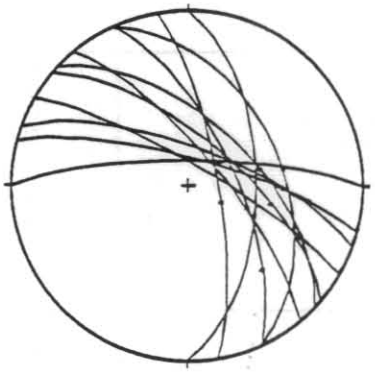
(b) Principal compressive stress directions for BD1.



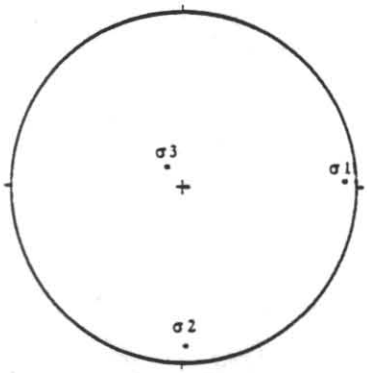
(c) BD2 - dextral wrench fault striations for FBF.



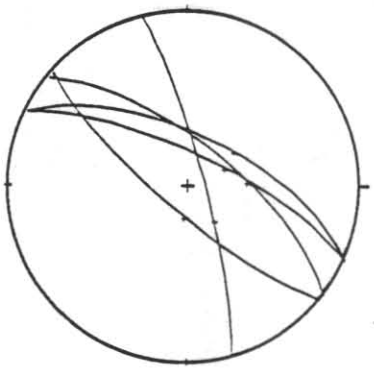
(d) Principal compressive stress directions for BD2.



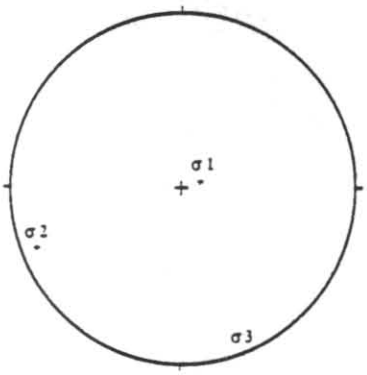
(e) BD3 - reverse sinistral fault striations for FBF.



(f) Principal compressive stress directions for BD3.



(g) BD4 - normal sinistral fault striations for FBF.



(h) Principal compressive stress directions for BD4.

Figure 7

Lower hemisphere equal area projections illustrating the brittle deformation history for the Renison tin mine, western Tasmania (from Kitto and Berry, 1991).

5 cm

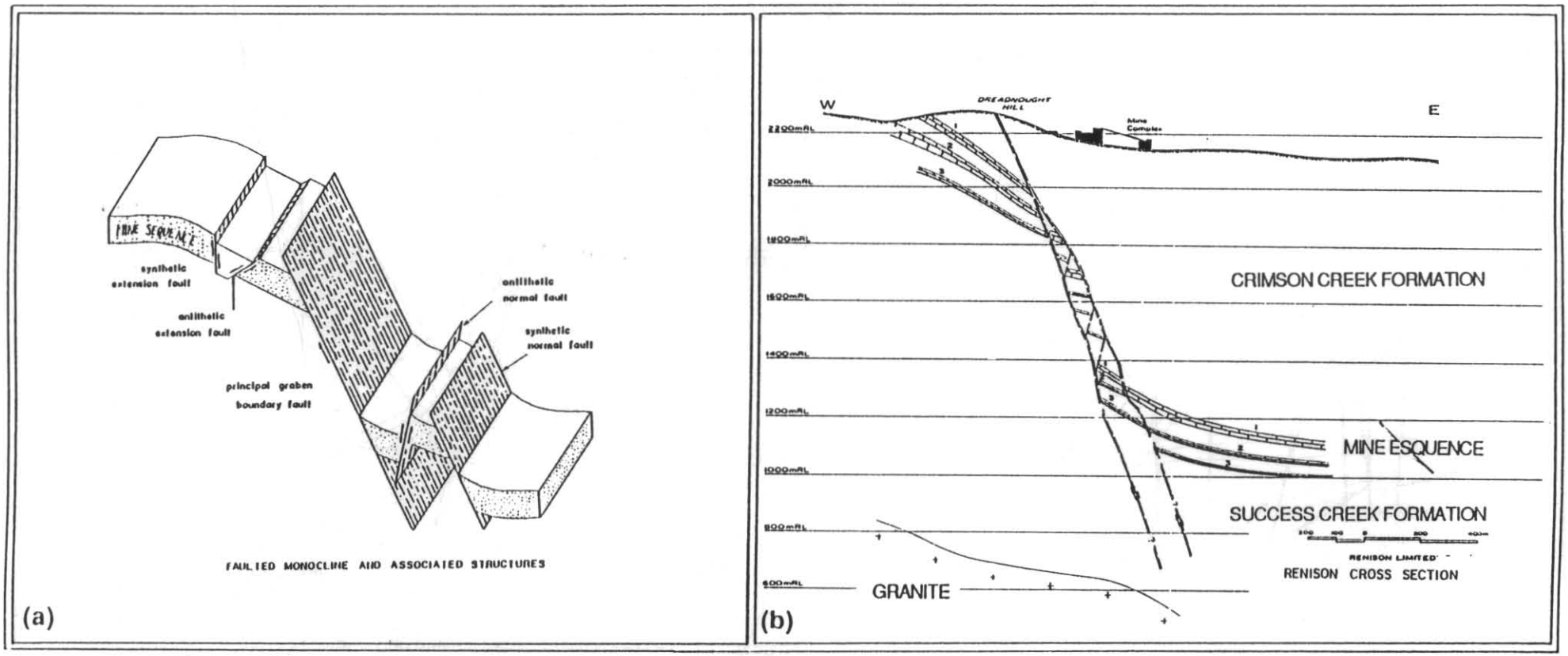


Figure 8a

Faulted monocline and associated structures (after Al Kadhi and Hancock, 1980).

Figure 8b

North Bassett cross-section, 67000 North (after McQuilty, 1991).

5 cm

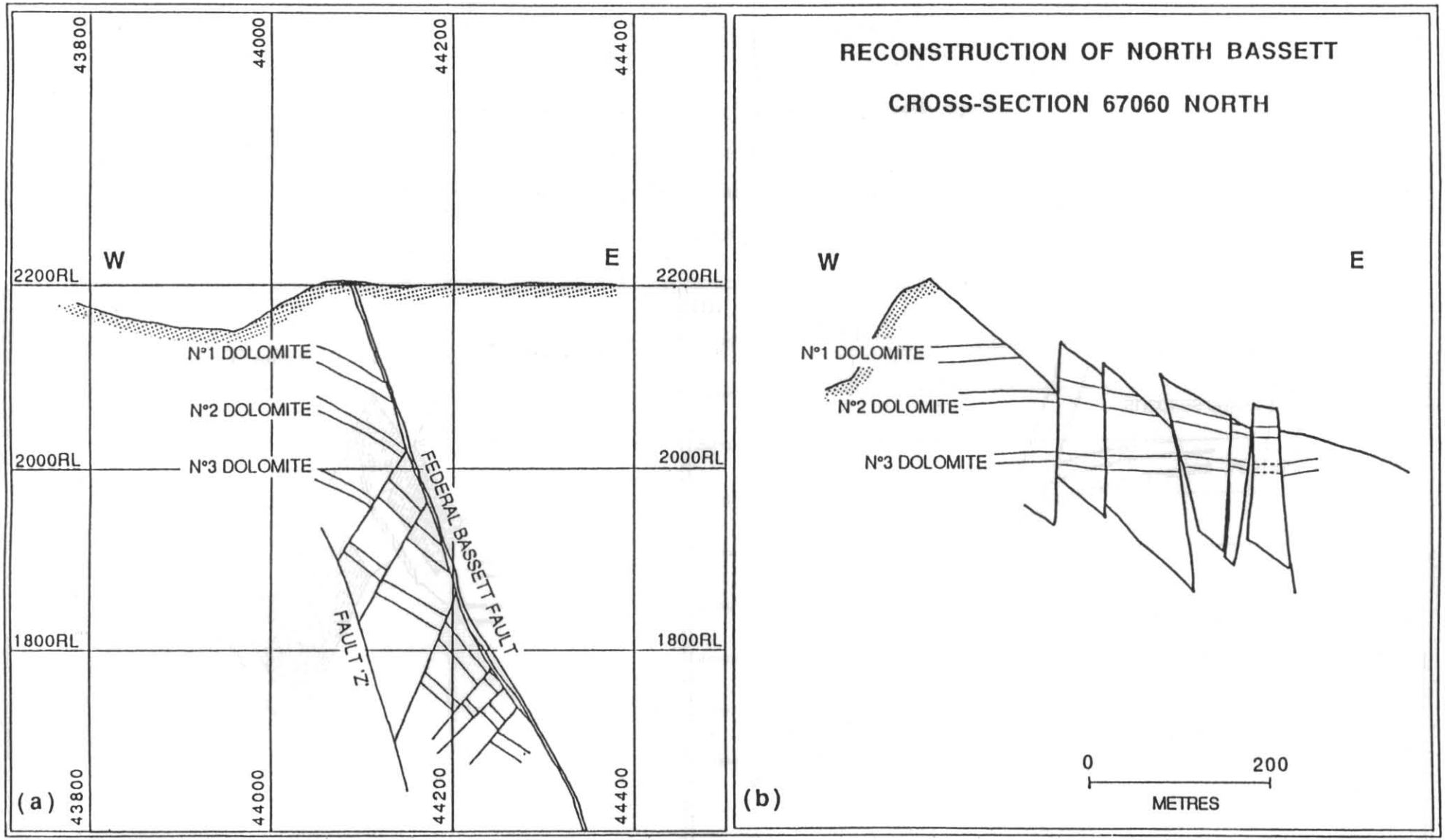


Figure 9a

North Bassett cross-section, 67060 North.

5 cm

Figure 9b

Reconstruction of North Bassett cross-section, 67060 North.

16/21

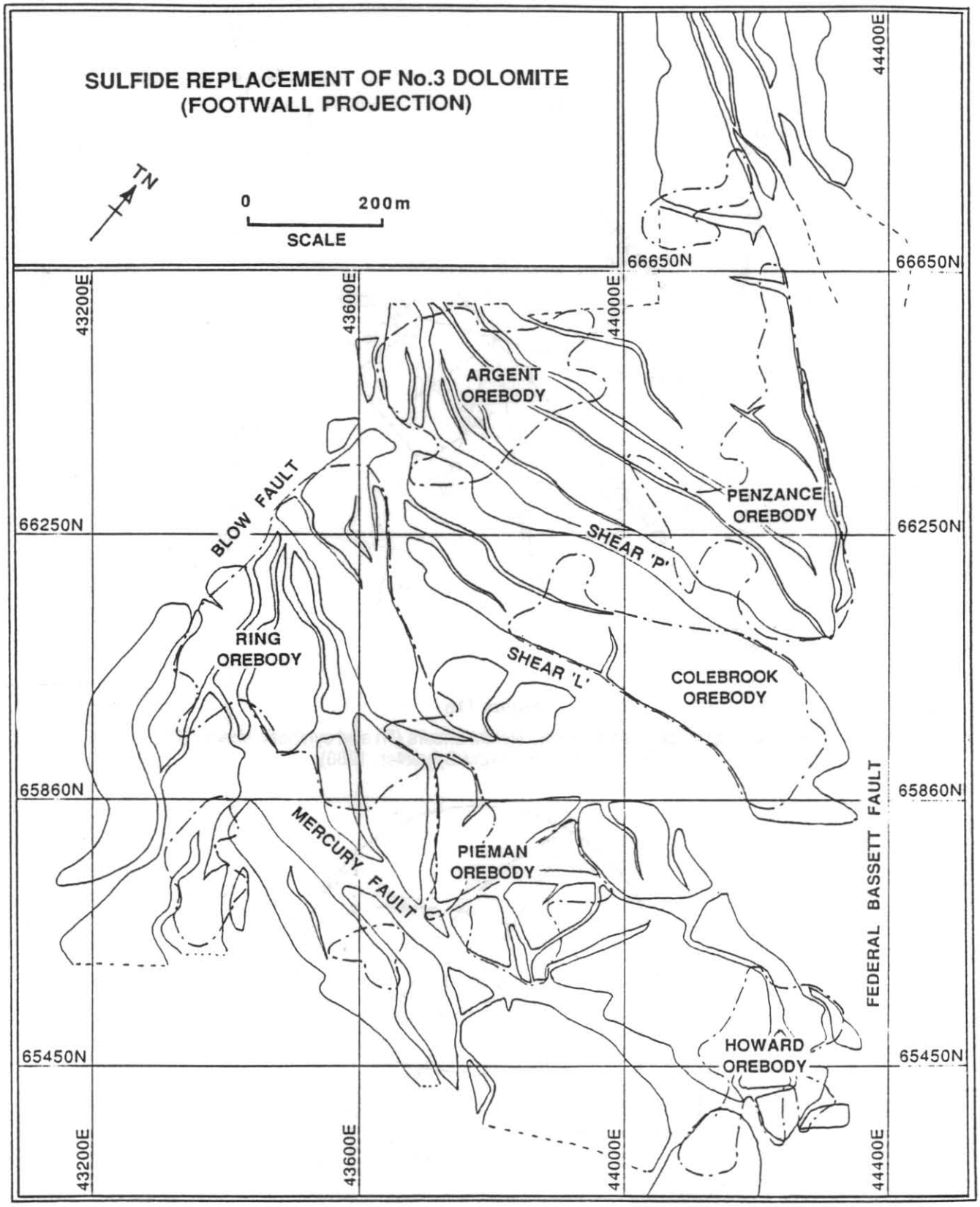


Figure 10

5 cm

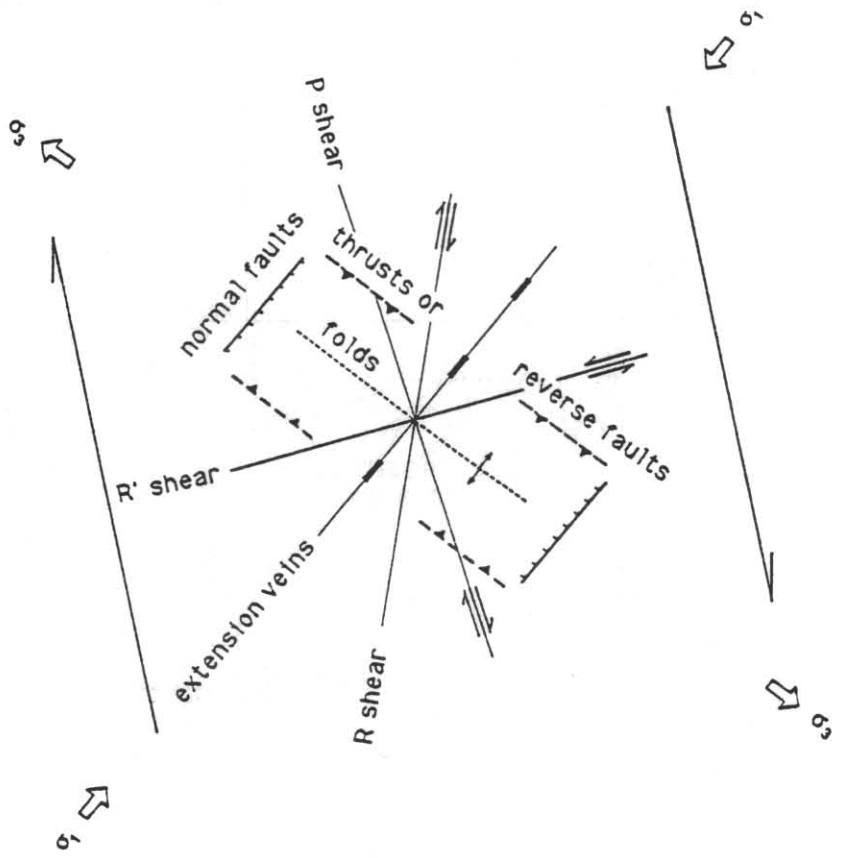
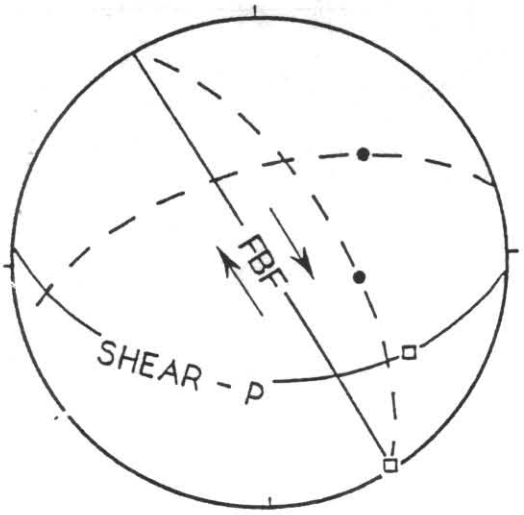
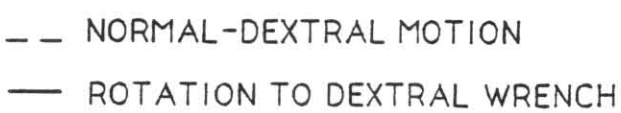


Figure 11a

Orientation of folds, reverse faults, Reidel shears (R) and synthetic shears (P) (after Harding, 1974 and Sylvester, 1988).





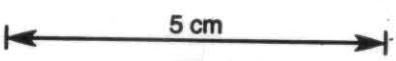


Figure 11b

Lower hemisphere equal area projection of the Federal-Bassett Fault and the secondary reverse fault 'Shear P'.

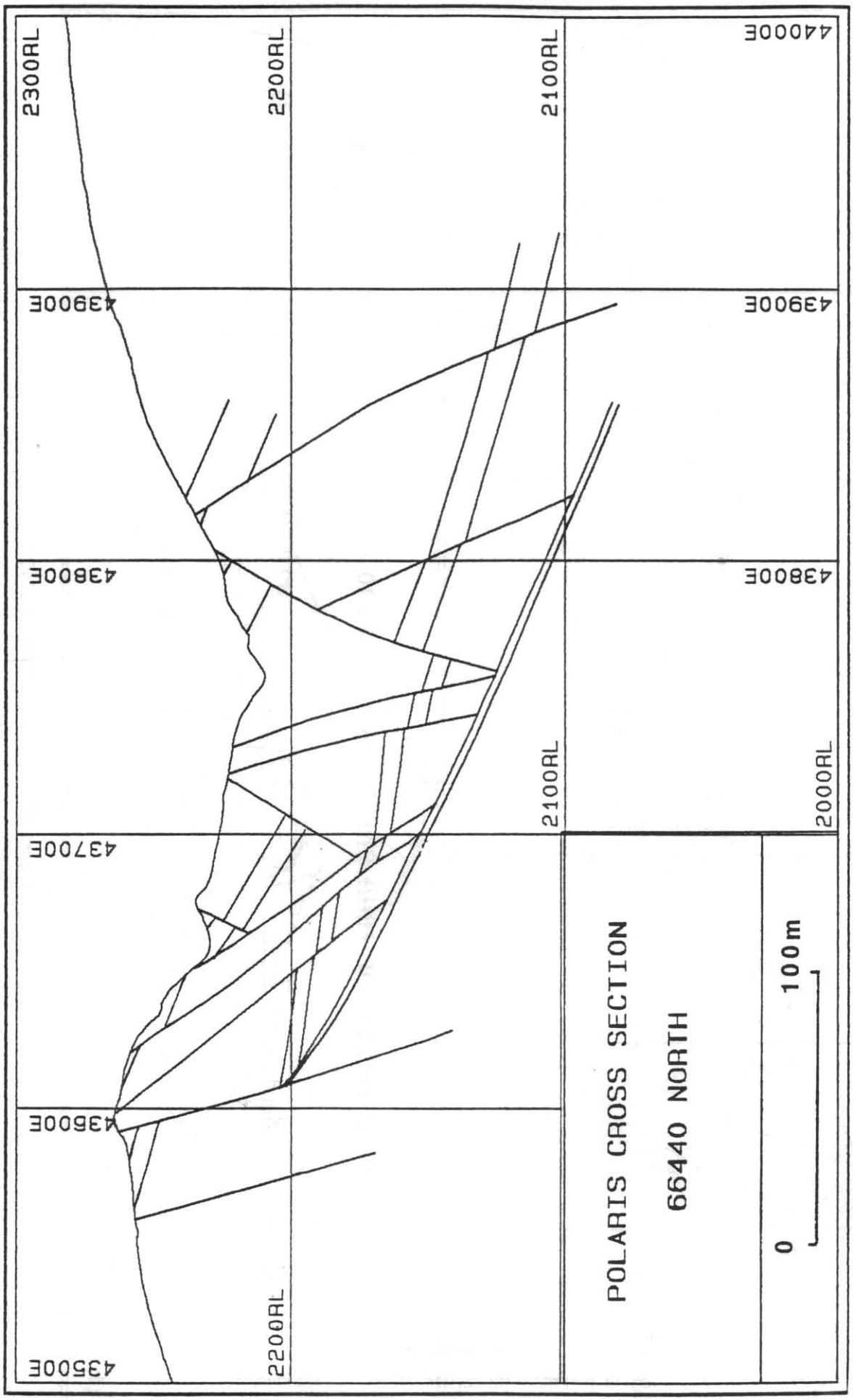

2300RL
2200RL
2100RL
44000E
43900E
43800E
43700E
43600E
43500E
2000RL
POLARIS CROSS SECTION
66440 NORTH
0
100m
5 cm

Figure 12

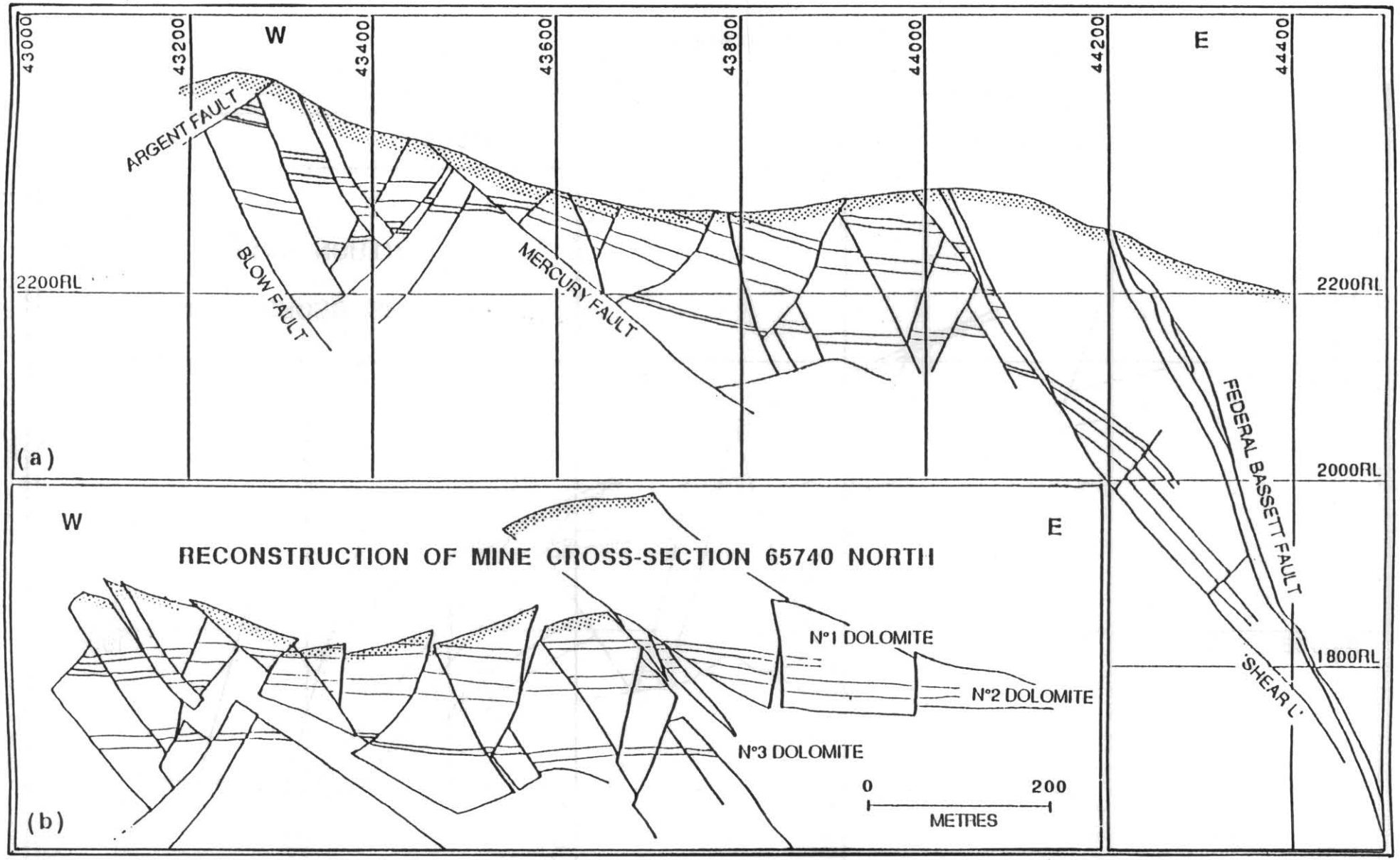
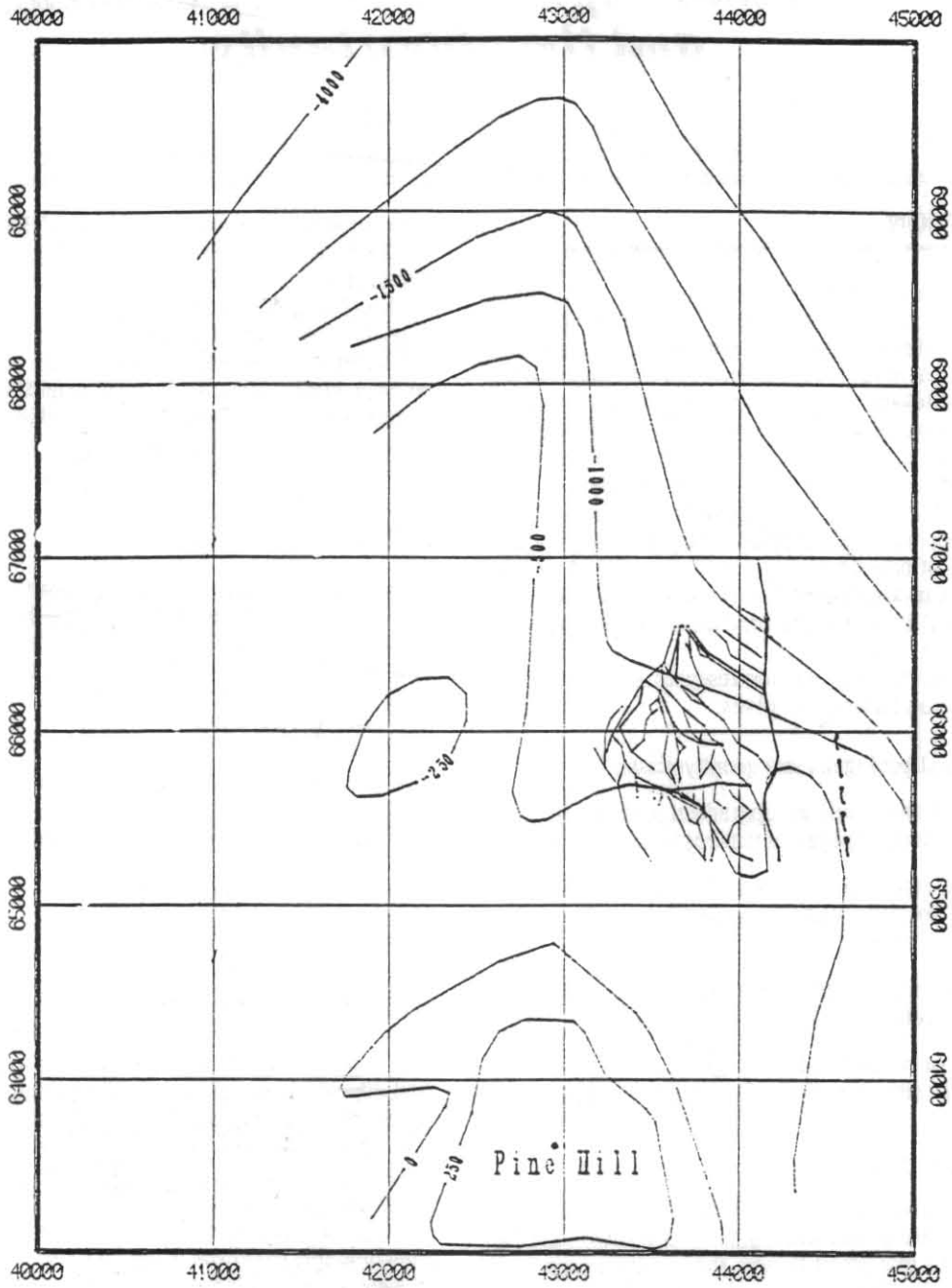


Figure 13a. Mine cross-section, 65740 North.

5 cm

Figure 13b. Reconstruction of Mine cross-section, 65740 North.



Location Diagram

FAULTS AND GRANITE CONTOURS

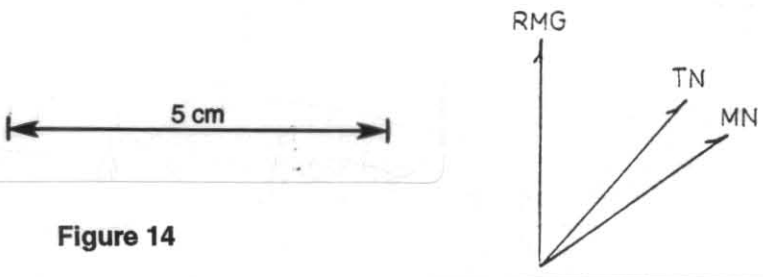


Figure 14

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1/9

Tasmanian exploration — the challenge and the opportunity

ROSS R. LARGE

Centre for Ore Deposit and Exploration Studies, University of Tasmania

INTRODUCTION

Tasmania is a mineral-rich province with an exciting diversity of geology and an array of mineral commodity types and ore deposit styles. Since the first significant discovery of tin at Mt Bischoff in 1871, twenty major mines have been established, giving rise to the growth of a strong and progressive mining industry over the past 120 years. Of these twenty major discoveries, nineteen were outcropping or subcropping deposits while only one (Hellyer) was a totally blind discovery. The potential for the presence of further blind deposits is considered to be excellent, however the application of best practice research and technology will be necessary for us to discover those hidden ore bodies which are necessary for the development of the mines of the future.

The development of best practice research and technology for the exploration industry involves:

- Highly trained geologists and geophysicists;
- Development and continual upgrading of the geological, geochemical and geophysical databases for the state;
- International standard research on the geological factors that control ore deposit location, and the criteria used to locate buried deposits;
- Cutting edge technology on the use of geochemical and geophysical techniques — both surface and down-hole;
- Application of computer technology to interpret large and complex data sets; especially Geographical Information Systems;
- Application of the best available drilling technology.

Tasmania is very well placed to achieve these best practice ideals, and because of the small area involved we have the capacity to focus this effort to gain the maximum result — major new ore discoveries. Currently we have a strong and active Department of Mines, a highly regarded National Key Centre at the University of Tasmania (CODES), and a technologically advanced (but small) exploration industry. Now is the time to build on our strategic advantages, and focus our attention to achieving excellence in mineral exploration — in terms of both practice and results.

THE EXCELLENT POTENTIAL FOR HIGH GRADE VHMS DEPOSITS

The grade advantage of Tasmanian deposits

In terms of tonnage and grade, the Tasmanian base metal massive sulphide deposits stand out as the best of their type in Australia, and rank amongst the best in the world (Large, 1992). A comparison of the average grade of Australian volcanic-hosted massive sulphides (VHMS) related to other lead-zinc types (Sedex and MVT) clearly indicates that their mean grade of 17.3% Pb + Zn is considerably better than Sedex (11.2% Pb + Zn) and MVT (8% Pb + Zn) mean grades (fig. 1). The comparison is even more favourable when the Tasmanian polymetallic deposits are shown to have an average grade of 21.1% Pb + Zn. In addition, the Tasmanian deposits are also significantly enriched in gold and silver, and form a pronounced high grade group when compared to all other Australian VHMS deposits (fig. 2).

Clusters of Deposits

World wide, massive sulphide deposits typically occur in clusters within a submarine volcanic belt. In the Mt Read Volcanics there are at least six clusters as listed below (passing north to south along the belt, fig. 3).

(1) Hellyer, Que River, Mt Charter

(2) Chester, Pinnacles, Browns Tunnel

(3) Rosebery, Koonya, Hercules, South Hercules

(4) Red Hills, Henty, CODES clasts

(5) Mt Lyell cluster — 11 separate deposits

(6) Wart Hill, Voyager 24

The clusters vary from two to seven kilometres in diameter and deposits may occur at one or a number of stratigraphic levels within each cluster. Only three of the six known clusters contain economic deposits, and each of these three clusters contains one large deposit and a number of smaller deposits. Based on the fact that each cluster represents a major submarine hydrothermal system, it is reasonable to conclude that excellent potential exists for the discovery of at least three further major deposits and a number of smaller deposits relating to the clusters. Based on the presence of a regular spacing to the clusters (e.g. Solomon, 1976), it is possible that a number of unidentified clusters occur elsewhere along the Mt Read Arc (e.g. Jukes–Darwin area, D'Aguilar Range, Cethana, Beulah).

Deep Exploration Potential for VHMS

The majority of exploration and discovery in the Mt Read Volcanics has occurred in the upper 300 metres. In the less well explored areas, such as Elliott Bay, D'Aguilar Range, and the far northern part of the belt, potential still remains for near surface (0–300 m) discoveries. In the central part of the belt (Hellyer to Mt Lyell) the next phase of exploration must target the deeper volcanic stratigraphy (300–1000 m) where excellent potential exists for new deposits. However, this phase of deep exploration will need to be guided by a better

LARGE, R. R. 1992. Tasmanian exploration — the challenge and the opportunity. *Bull. geol. Surv. Tasm.* 70:118–123.

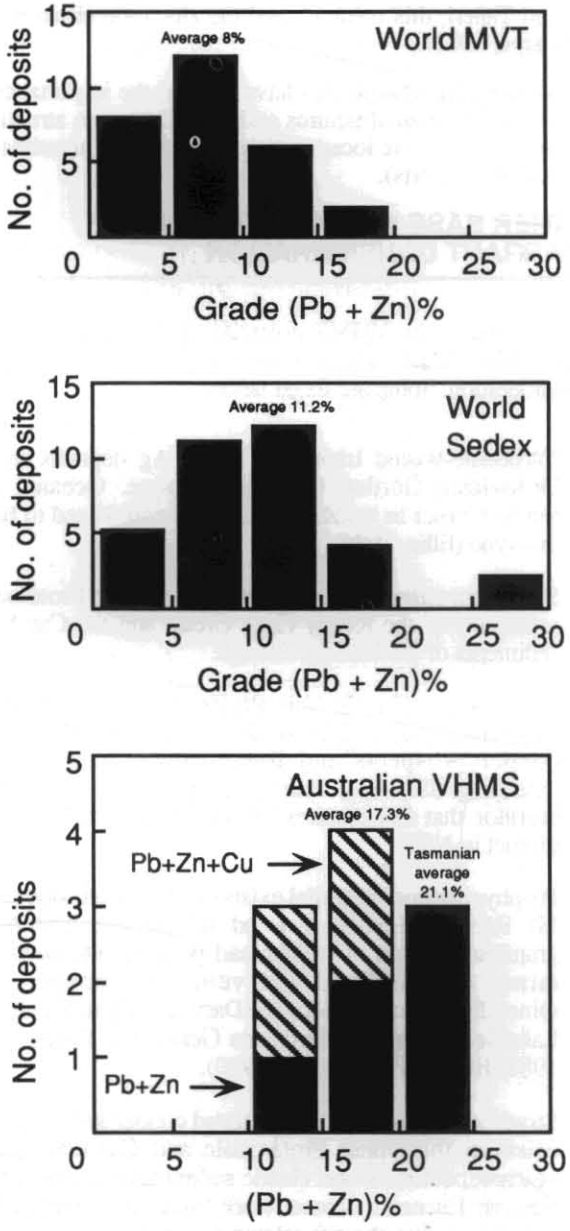


Figure 1

Comparison of grade histograms for Australian Pb-Zn VHMS deposits and world-wide MVT and Sedex deposits (data for MVT and Sedex deposits from Sangster, 1990). Note the high average grade of 21.1% for Tasmanian VHMS deposits.

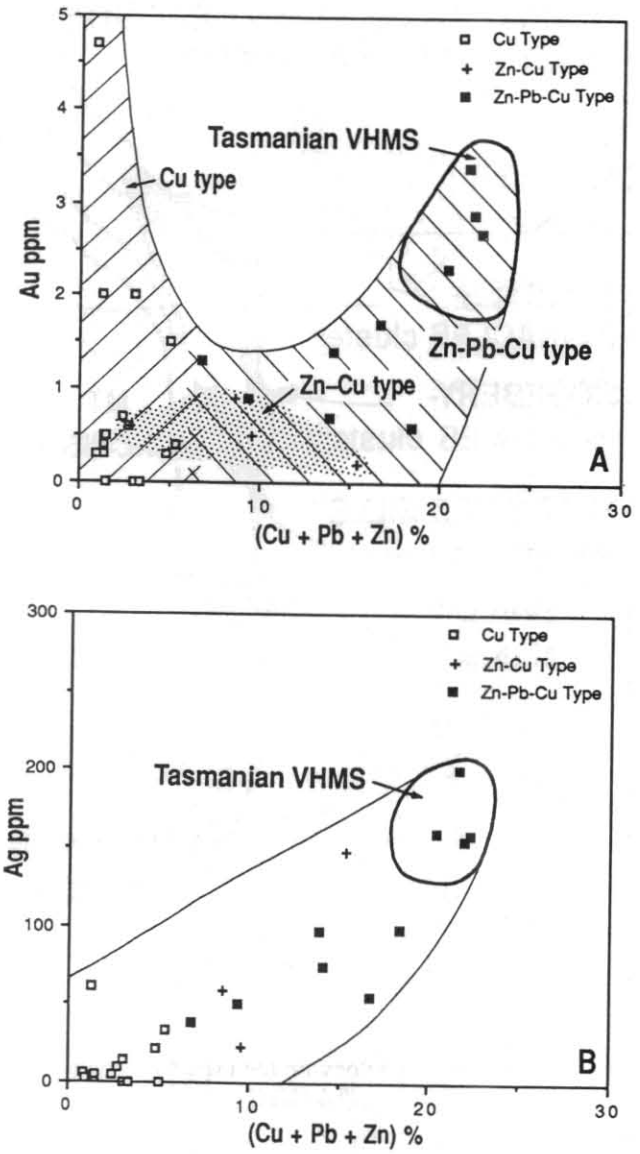


Figure 2

Variation in silver and gold with base metal (Cu+Pb+Zn) for Australian massive sulphide deposits. The Tasmanian polymetallic deposits are shown to have the best grade characteristics (modified from Large, 1992).

understanding of volcanic facies relationships, alteration geochemistry and down-hole geophysics. The integration of research with exploration, combining the experience and intellect of University, Department of Mines and company geoscientists will enhance the chances of discovery in this important phase.

Significance of recent research on exploration for VHMS

Research over the last five years into the volcanic rocks and deposits in western Tasmania has had a significant impact on the approach to mineral exploration. Much of this work has been published in a recent special issue of *Economic Geology* on Australian VHMS Deposits and their Volcanic Environment. Some of the important aspects of this and other research on the Tasmanian deposits are listed below.

- Completion of the Department of Mines mapping at 1:25 000 scale (Corbett, 1992) has revealed new stratigraphic relationships in the MRV.
- New theories have been developed on volcanic facies associations and correlations that relate to mineralisation (McPhie and Allen, 1992).
- Geochemical data on the volcanic rocks has enabled detailed grouping and correlations of different magma associations (Crawford *et al.*, 1992).
- A range of styles of VHMS mineralisation have been defined, which present different targets for exploration (e.g. Large, 1992; McGoldrick and Large, 1992, Khin Zaw and Large, 1992).
- Mineral zonation and alteration features of the Hellyer deposit have been detailed, which enables refinement of

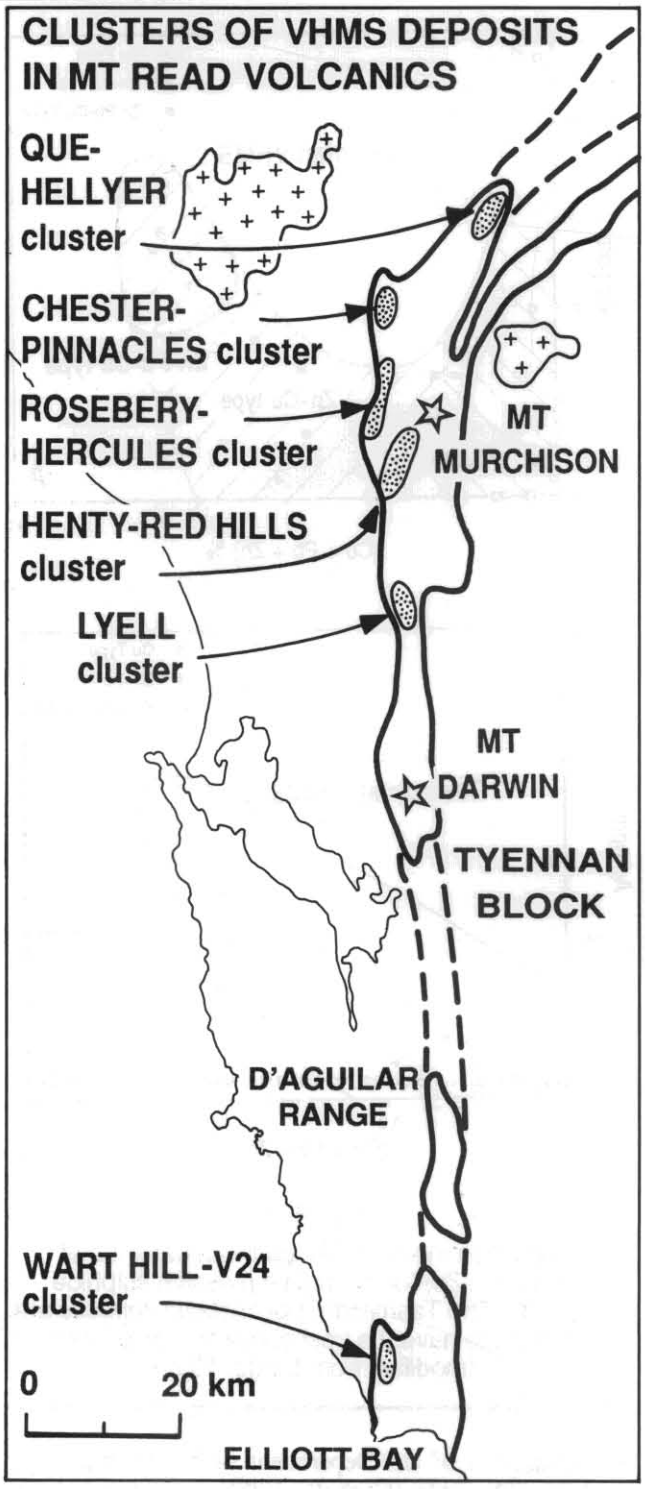


Figure 3

Known clusters of massive sulphide deposits in the Mount Read Volcanics.

exploration models (e.g. McArthur and Dronseika, 1990; Gemmell and Large, 1992).

- The relationship of gold and silver to base metals in VHMS deposits has been documented and related to deposit formation and zone refining (e.g. Huston *et al.*, 1992; Large *et al.*, 1989*b*).

- Geochemical and isotopic techniques have been applied to develop target selection criteria; e.g. Pb isotopes (Gulson *et al.*, 1987), oxygen and sulphur isotopes (Green and Taheri, this volume), and the zinc ratio (Huston and Large, 1987).

- Recent structural studies have defined the importance of early Cambrian structures and later Devonian structures in controlling ore location (Berry and Keele, unpublished AMIRA reports).

OTHER BASE METAL STYLES WHICH WARRANT CONSIDERATION

In addition to the VHMS potential of Tasmania there are other base metal styles which are worthy of serious consideration. Some are listed below;

- Carbonate-hosted Irish-style Pb-Zn-Ag deposits in the Ordovician Gordon Group Limestone. Oceania and Sunny Corner in the Zeehan area are considered to be of this type (Ellis, 1984).

- Stratiform sediment-hosted Pb-Zn-Ag within Proterozoic sediments of the Rocky Cape Group and the Cambrian sediments of the Dundas Trough.

- Cobar-style Cu-Au and Pb-Zn-Ag in the Norfolk structural corridor of the Rocky Cape Group. A series of copper prospects and linear magnetic anomalies extending SSE from Balfour occur within a structural corridor that has features of similarity with the Cobar district in NSW.

- Porphyry copper potential exists on the eastern side of the Mt Read Volcanics related to the late Cambrian granitoids. Areas of widespread potassic alteration and minor disseminated and vein style copper-gold mineralisation occur along the Darwin Ridge and between Lake Selina and the Murchison Gorge (e.g. Eastoe *et al.* 1987; Hunns, 1987; Doyle, 1990).

- Stratiform copper and shear-related copper-gold potential exists in the Upper Proterozoic and Cambrian mafic volcanic, dolomite and clastic sedimentary sequences of western Tasmania. Recent work (Stolz and Large, 1992) has shown that the rift-related tholeiitic volcanic rocks have anomalously high backgrounds in copper and gold, and therefore provide an excellent source for these metals. The carbonate and clastic sequences overlying these basalts (Smithton basalts, Crimson Creek basalts, Mainwaring Group basalts) hold potential for sediment-hosted stratiform copper deposits.

- Besshi-type copper deposits within the Arthur Mobile Belt associated with the amphibolite-schist sequence of the Bowry Formation (Turner *et al.*, this volume).

WORLD CLASS TIN AND TUNGSTEN DEPOSITS

Tasmania is the major tin-tungsten province of Australia with a range of deposit styles, including greisens, sheeted veins, skarns and massive sulphide stratabound replacements (fig. 4). Both the stratabound replacement tin deposits (e.g. Renison Bell, Mt Bischoff and Cleveland) and the tungsten skarns (King Island) are world class in terms of tonnes and grade. Although the commercial interest in tungsten deposits has declined drastically in the last ten years and the outlook remains bleak, there has been a recent surge in the tin price which indicates the need for a revaluation of the tin potential of the state.

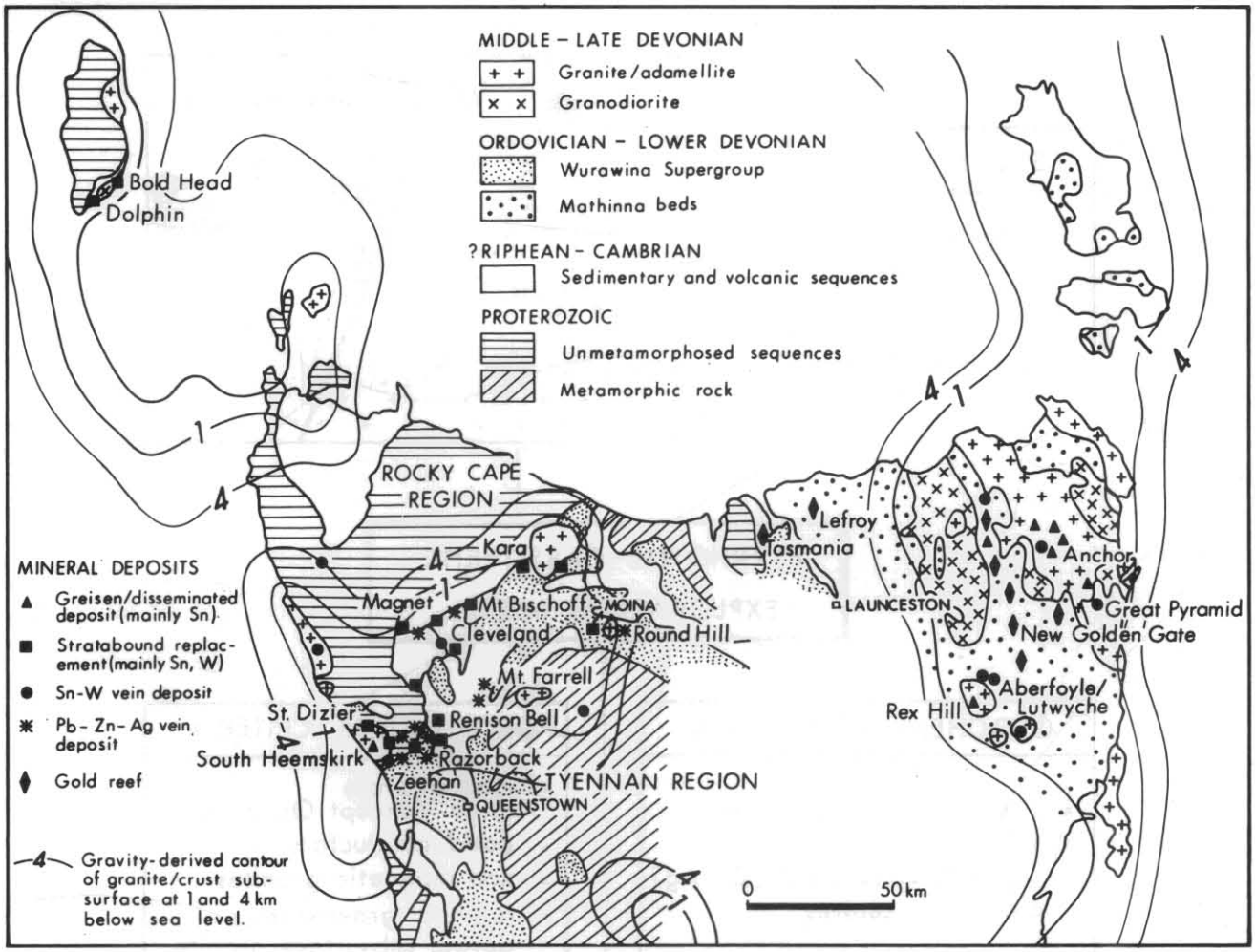


Figure 4

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

Potential for Stratabound Replacement Tin Deposits

Research into the massive pyrrhotite replacement deposits at Mt Bischoff, Cleveland and Renison Bell has shown that the deposits formed by the interaction of Devonian magmatic fluids with certain reactive carbonate horizons within the Dundas Trough sequences (Patterson *et al.*, 1981; Collins *et al.*, 1989; Kitto, this volume). Definition of the subsurface shape of the Devonian granite complex in western Tasmania and its relationship to the distribution of favourable carbonate stratigraphy are therefore key elements in the development of an exploration model (Large *et al.*, 1989*a* and fig. 5). Recent studies by Leaman and Richardson (1989) and Archer (1989) have used the comprehensive gravity database of western Tasmania to interpret the shape of the surface of the Devonian granite complex and relate this to the distribution of known tin deposits.

The incorporation of this gravity data on the granite surface, with structural studies to determine the magmatic fluid plumbing system, and stratigraphic studies to locate favourable host carbonate stratigraphy has recently led to the development of a very powerful exploration focus for this style of mineralisation. Because this data has gradually accumulated over the past decade during a period of little exploration activity for tin (compared with gold and base metals), the potential for new tin discoveries has reached a peak.

The best potential is considered to exist along the northeast-trending gravity low (i.e. subsurface granite ridge) extending from the Heemskirk Granite to Granite Tor. The major deposits at Renison and Queen Hill occur on this structure, along with many minor occurrences (fig. 6). Other target areas include:

- magnetic anomalies to the north of the Heemskirk Granite;
- along the NE-trending structure through Cleveland, Mt Bischoff and Kara;
- in the Dial Range Trough, where granite is interpreted at depth, and minor copper and tin prospects are known.

CONCLUSION

The future of the mining industry in Tasmania depends on the competitiveness of our current mines on the world market, coupled with our ability to discover new mines at the rate of about one every five years (Large, 1987). Given that the mineral potential of the State remains very high, other factors affecting the discovery of new mines are:

- the level of exploration activity by industry;
- the level of research into new exploration models and new exploration techniques;

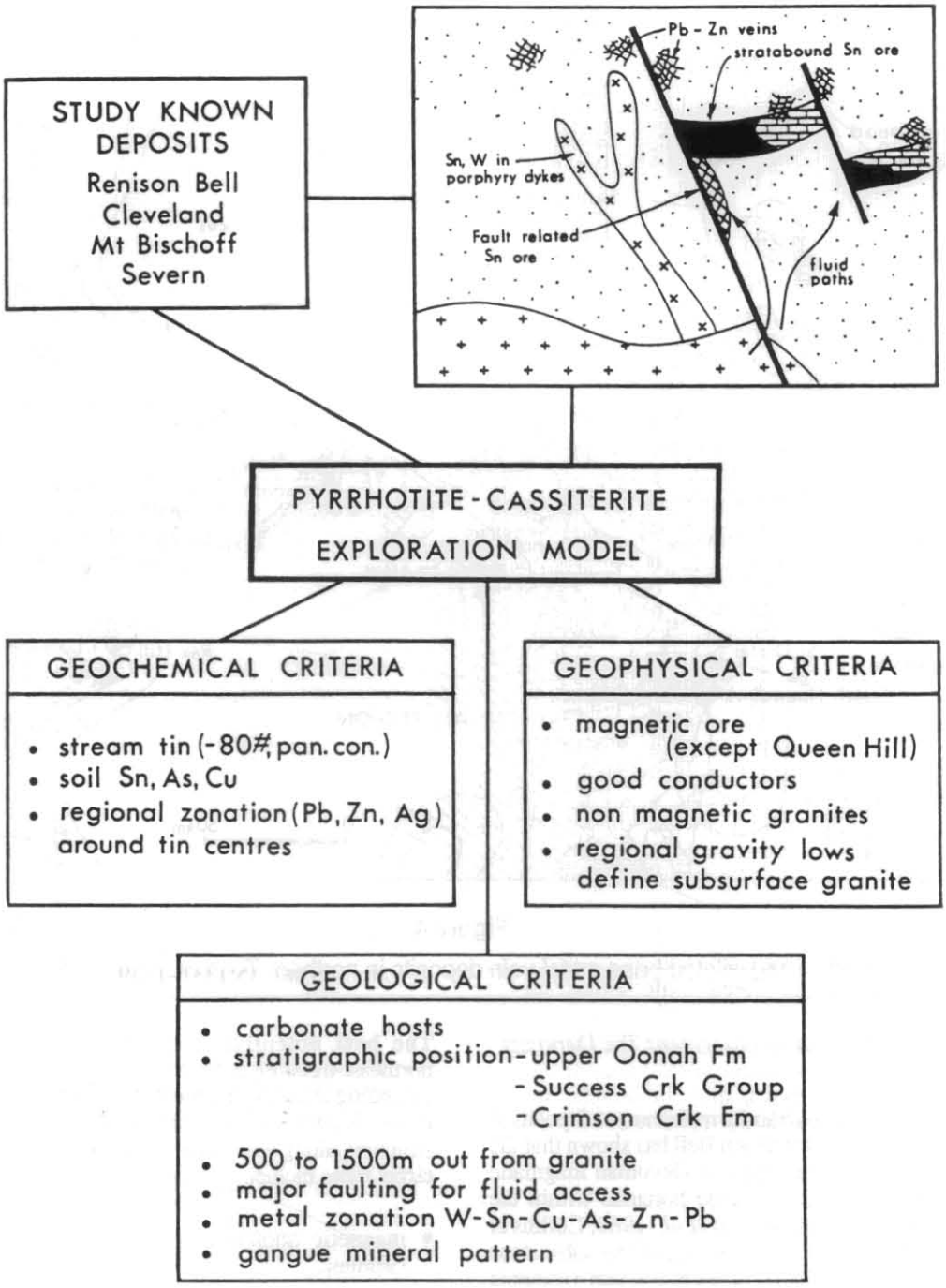
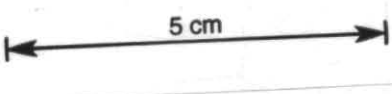


Figure 5

Exploration model for pyrrhotite-cassiterite replacement deposits, western Tasmania (from Large *et al.*, 1989).



NOTE: Figure 6 (a-c) is located in pocket at the rear of this Bulletin.

6/9

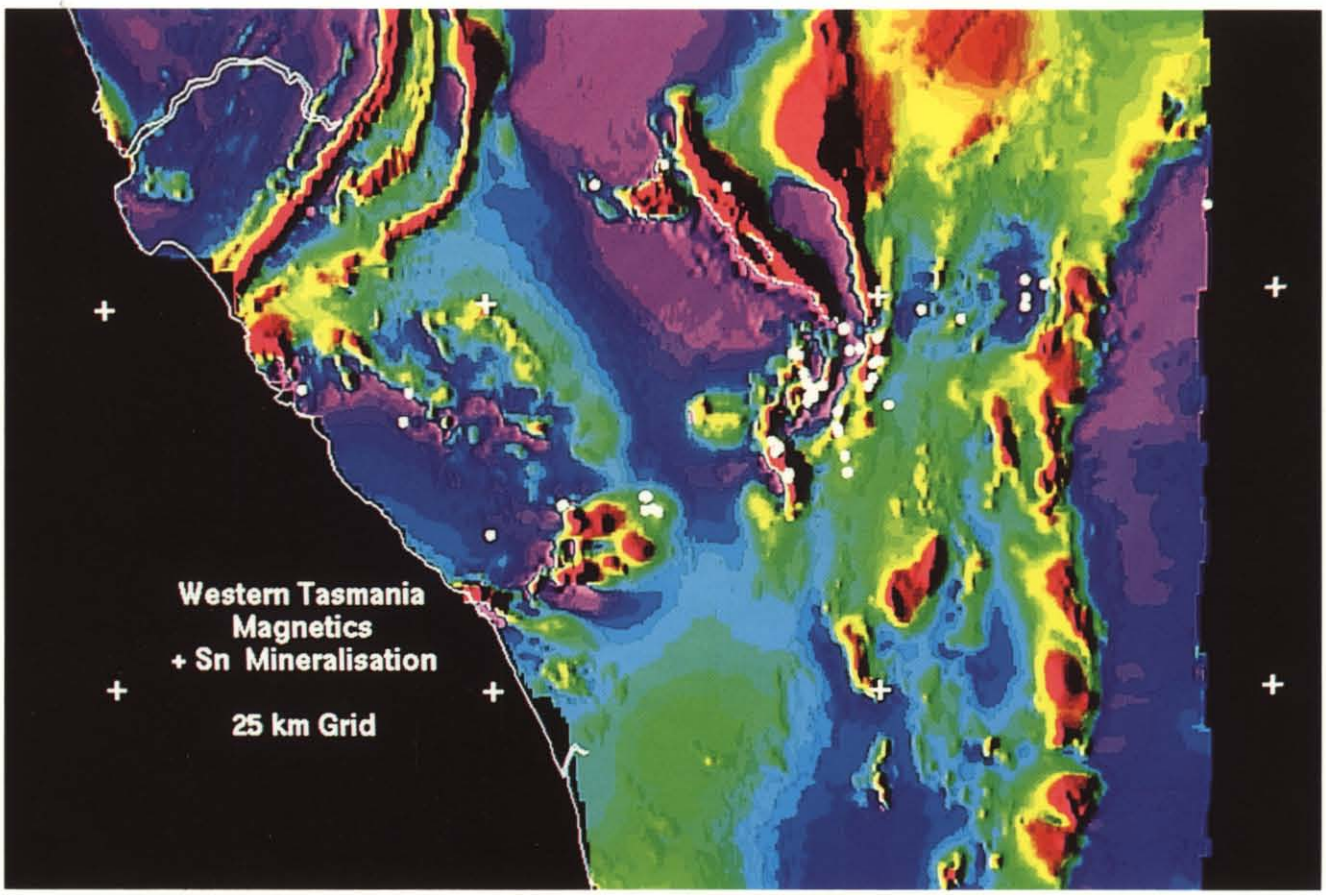


Figure 6*a*.

Western Tasmania — Magnetics and tin mineralisation

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Figure 6.
(R. R. LARGE — *Tasmanian exploration — the challenge and the opportunity*)

A comparison of magnetics, residual gravity, geology and tin deposit locations for central western Tasmania. Note the concentration of tin deposits across the gravity low feature (granite ridge) extending from Heemskirk Granite to Granite Tor. Processed magnetics is from the Department of Mines, 1981 survey. Processed gravity is from the Department of Mines Mt Read database. Tin deposits locations are from MIRLOCH. Refer to Large (this volume) for the discussion of tin potential in western Tasmania, relative to this figure.

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7/9

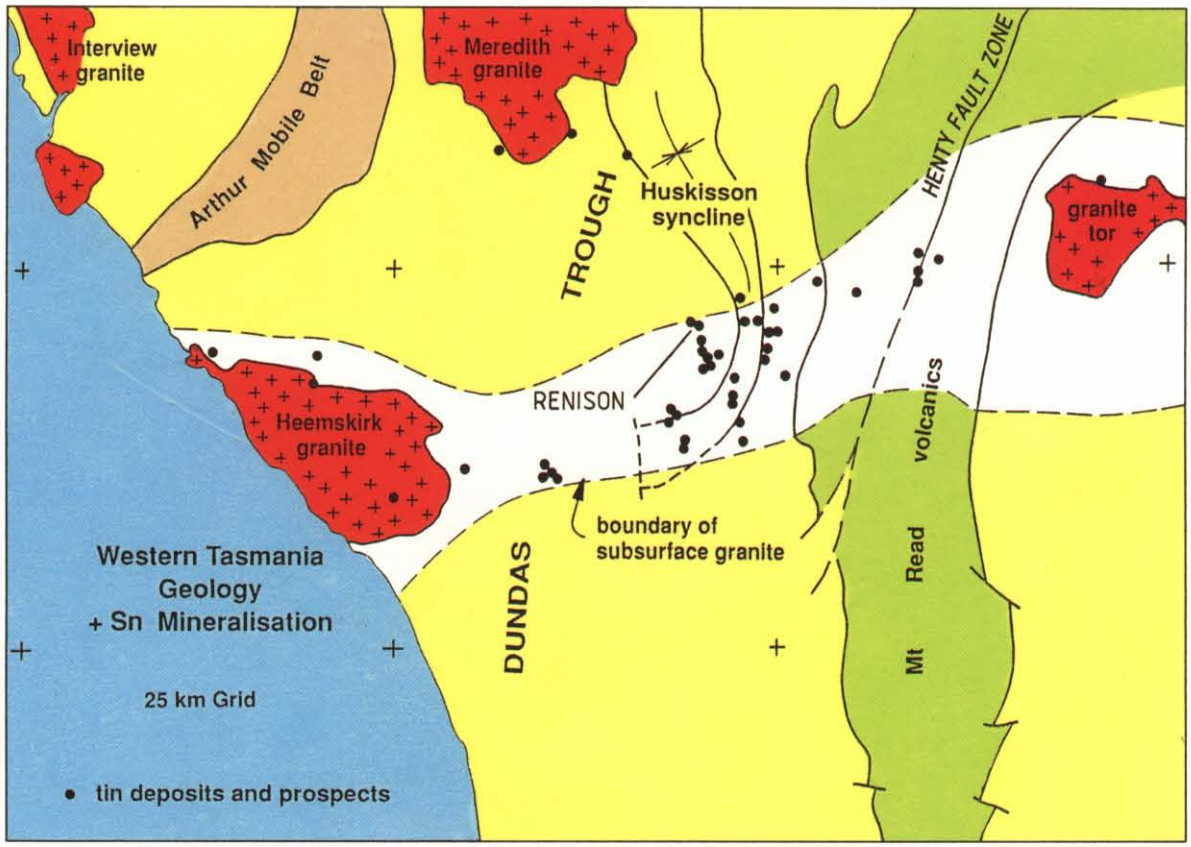


Figure 6*b*.

Western Tasmania — Geology and tin mineralisation

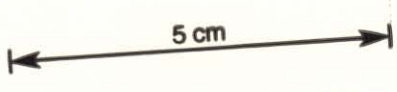


Figure 6.
(R. R. LARGE — *Tasmanian exploration — the challenge and the opportunity*)

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8/9

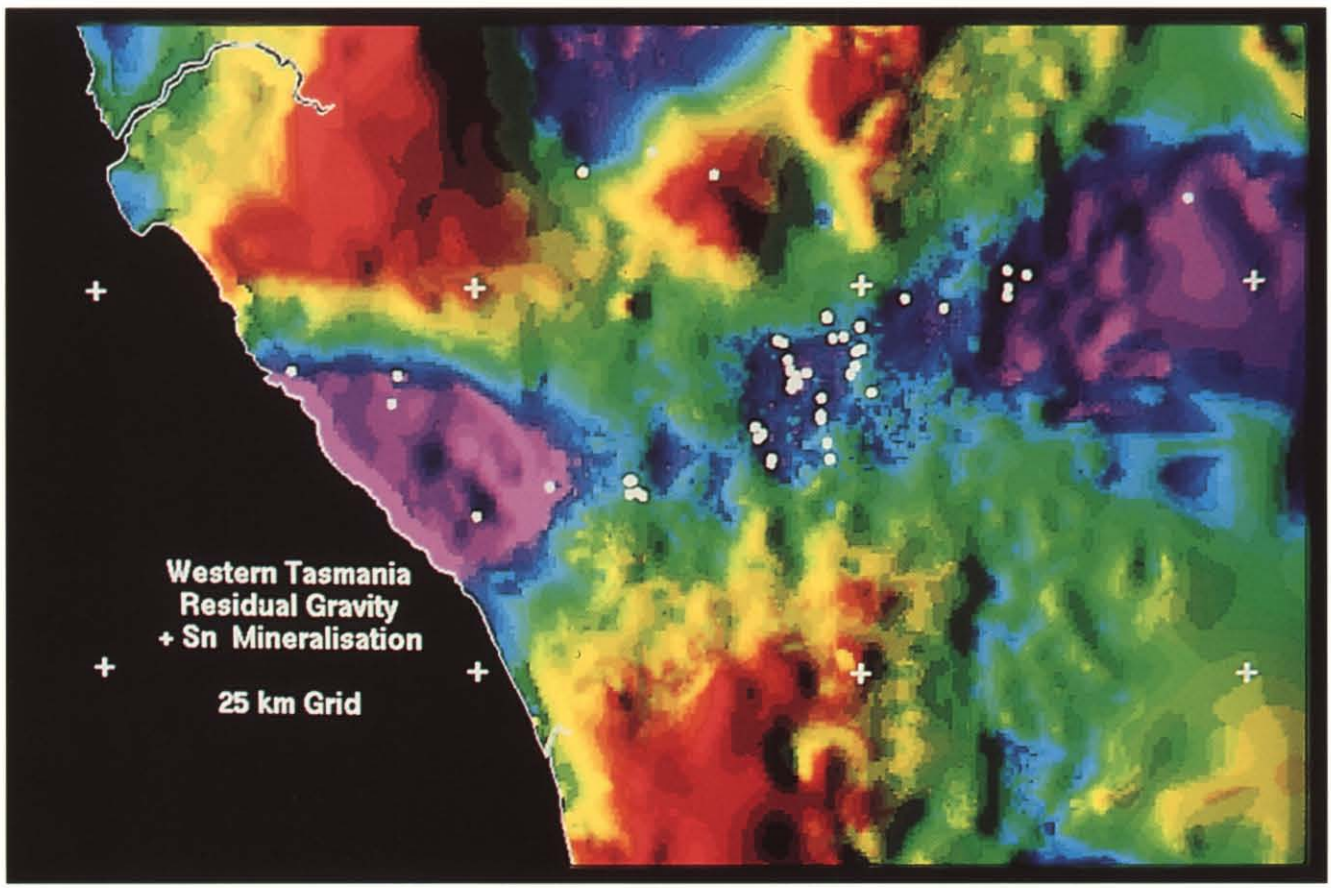


Figure 6*c*.

Western Tasmania — Residual gravuty and tin mineralisation

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Figure 6.
(R. R. LARGE — *Tasmanian exploration — the challenge and the opportunity*)

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- the quantity and quality of geological, geochemical and geophysical databases provided by the Government;
- access to land with mineral potential.

The challenge for explorers and Governments is to maintain these factors in a favourable balance which enables us to grasp the opportunity and make new discoveries.

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1/27

Finding Cambrian keys: An essay in controversy, prospectivity and tectonic implications

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ABSTRACT

There is a need, in terms of Tasmanian geology, to consider a bigger picture and preserve appropriate perspectives. Failure to do this may lead, and has led, to false or limited conclusions. We blithely talk about orogenies and so on but rarely consider the entire sequence of events involved, their impact on mineralising processes and how such events might be flagged today, or their final result. We need to think in terms of evolved and inherited structural and sedimentological controls, lateral and vertical dislocations, and concealment of indicators. When we think of mineralising controls or sources, whether at faults, margins, in volcanic piles and so on, it is easy to look locally and surficially and miss the real setting. Further, the entire fragment examined may not be in its original or relative setting.

Petroleum explorers have developed many sound ideas for sequence and structure evolution but they force simplicity on their exploration by considering mainly the relatively undeformed parts of evolved basins. Mineral exploration often must treat the "unprospective" part of a petroleum explorer's section. But the issues and controls, in structural terms, are inseparable and we must take both the shallow and deep views into our thinking.

All this applies to Tasmanian mineral exploration — and Cambrian events. If we are looking for granitoid-related Devonian mineralisation styles then we need to seek out only the granitoid and roof controls. In many cases these, and the methods required, are well defined. We may seek targets directly. Cambrian targets are more like needles in an evolved and complex haystack. Appraisal depends on knowing what belongs where, where it was at the time of mineralisation, what has happened since, and where the controlling elements were. What if our beloved Mt Read Volcanics are affected by all this? Indeed, were they formed as key indicative elements of a developing structural package?

This essay asserts that a realistic perspective of Tasmanian geology and its development cannot be established without taking a broader view which shows that western Tasmania is not unique and that any concepts based solely upon that region will be misleading. Past concepts have overlooked the multiple mélange-like nature of Tasmania, the repeated thrusting regimes and the significance, and exploration use, of the Lower Cambrian mafic rocks.

A concept involving long-term extension processes with modern and ancient analogues, punctuated with wrench-compressional events, can account for the evolution of the Tasmanian crust from the mid Proterozoic to the Jurassic (and with variants to the present). Critical or key elements in this evolution are penetrative crustal structures. While occasionally recognisable at surface, crustal geophysical methods must be used to properly confirm these structures. If other, local, characteristics of such special sites are also observed nearby then an exploration target has been defined.

Mineralised sites can be associated with primary penetrative structures, however these may have been modified with time provided the original crustal setting has been recovered. Rock suites such as the Mt Read Volcanics can be shown to occupy particular crustal settings within an evolving extensional regime, and are not limited to a single province such as western Tasmania. The associations between early Palaeozoic structures, mineralisation, volcanic sequences and Devonian overprints reflect persistent and inherited controls. Above all, such associations show that the mineral potential of the entire Tasmanian continental mass is very great indeed. It is up to us, as explorers, to fully lift the lid on this cornucopia.

PROLOGUE

Before considering the issue of how to find a Cambrian key it is first necessary to define the keys and their characteristics, explain why Cambrian sites are important, and why they appear so difficult to find. Some aspects of these definitions and comments strike to the very heart of the many major controversies and issues in Tasmanian geology which must be seen afresh. The recent explosion in understanding and the removal of many forms of blinkered vision forces wholesale review of all previous concepts and the demolition of several — along with many assumptions. Yet, it will be argued, only the exploration approach is really at issue — and it must now be seen in a STATEWIDE perspective and not restricted only to a well-known mineralised belt in

LEAMAN, D. E. 1992. Finding Cambrian keys: An essay in controversy, prospectivity and tectonic implications. *Bull. geol. Surv. Tasm.* 70:124–148.

western Tasmania. There is, in principle, no difference in exploration approach required regardless of location, whether western, central, northern or southern Tasmania.

The Cambrian mineral potential of Tasmania is wide open. Only one part of the province — that of central western Tasmania — has been considered to date and it will be shown that this amounts only to surface scraping in considerable ignorance. This region and the remainder of the island have yet to be explored seriously, and yet Tasmania is already a world-class base metal province!

INTRODUCTION

Metallic mineralisation in Tasmania is intimately associated either with Devonian granitoids or Cambrian volcanism or tectonism (including mafic rocks). Although the Devonian-related prospectivity is clearly important it may be argued that the Cambrian province is the more important — and its structural elements certainly controlled the Devonian evolution — to the extent that the younger mineralising event was a sideshow in comparison. This perspective accounts for the use of the word Cambrian in the title of this paper.

But, assuming the possible existence of a number of large, mineralised sites of Cambrian age, just how does one find them? These are the key sites. A few have been found already, but most are locked away and concealed by at least two major deformations and related dislocations, or post-Carboniferous cover. This essay examines some of the issues involved and some of the techniques which might be used to find the keys which unlock these sites for detailed exploration.

CAMBRIAN CONTROVERSIES AND PREVIOUS CONCEPTS

In order to appreciate the basis and implication of the concepts proposed here it is essential that some elements of Tasmanian geology be clarified or placed in perspective.

The recently published (1988) volume *Geology and Mineral Resources of Tasmania* provides several discussions dealing with the Lower Palaeozoic tectonic history and conflicting theories — including rifting, plate motions and mafic allochthons.

This was summarised by Corbett (1989) but all such discussions are fatally flawed if they emphasise only those relationships seen in western Tasmania. Do these represent the beginning and end of the Cambrian story in Tasmania or beyond? Not at all. They are barely representative of the total condition when viewed on a larger scale (below).

Each of the previous concepts involves presumptions about the origin of the various igneous rocks and their original setting based on an array of geochemical indicators, which leads to some absurdities. Corbett essentially concludes that either something is wrong with various of the assumptions or a new conception is required. But many of the presumptions about arcs, back arcs, oceanic sources, subduction zone needs, continental collisions and so on, are unproven arm waving and may evaporate, especially if we are dealing with a multiply-compressed mélange in which the pieces do not always preserve original relationships or crustal locations. In short, the geochemical-petrology-environment arguments are interesting but may often be irrelevant to finding exploration keys. There has been too much re-arrangement, and this is the first thing which has to be recognised. We have to step back and take a longer view — both in time and space — and not necessarily assume that all modern oceanic processes are relevant to the late Proterozoic.

The second thing is to admit that the exposed rocks of western Tasmania are not special, or unique, in any way. Not in composition, structural evolution or provenance. If it could be shown that rocks of the late Precambrian through to the late Ordovician, say, exist in other parts of Tasmania, or elsewhere, then many special theories used to account for the Mt Read Volcanic "arc" would have to be reviewed (scrapped, actually). Note that my time range fully encompasses the Cambrian.

Some of the enigmas presented by current published thinking relate to the Penguin Orogeny, the relationship of the volcanic rocks and the Tyennan Precambrian boundary, the role and origin of the various Precambrian blocks scattered around northern Tasmania, the placement and development of "rift-ocean" floor settings at the scale implied, and the apparent narrowness of the volcanic belt itself when compared with similar belts.

Every one of these enigmas can be resolved.

SOME ADDITIONAL FACTS

Reappraisal of Tasmanian geology depends on three datasets. All are incomplete, but sufficient is known to extract a consistent story. The Tasmanian gravity database converted into a residual form (fig. 1*, 2) provides the foundations for understanding the larger components within the Tasmanian crust. The columns of the temple of understanding are supplied by the many fragments of aeromagnetic data including the Midlands survey (e.g. fig. 3). The embellishments on the cornice are provided by the repeatedly inherited impressions of older structures which have influenced events since their genesis. These are evident even in modern topography, with or without Mesozoic or Cainozoic dislocation, and surface mapping can be interpreted in terms of them.

When exposed Cambrian rocks are examined it is always difficult to separate Devonian and older influences. The younger influences always appear more important or less ambiguous.

The gravity map reveals several important elements including the scale of the Devonian granitoids, their distribution and differences between west and eastern Tasmania, and the Tertiary basins. But the most significant features are strongly positive. Only one is now reasonably coherent. In western Tasmania such a belt extends SSW and then south from Bass Strait and has one side along the Arthur Lineament. The eastern side passes east of Waratah, through Dundas and south via Birchs Inlet. The bending is sympathetic to the entire northern portion of the so-called Tyennan core near Cradle Mountain and the wrap around of the volcanic arc. Is there a relationship in this pattern? Note the Cambrian grain near Boco (fig. 4). Similar positive effects may be observed in the central north of the island and

* NOTE: Figures 1 and 15 are located in the pocket at the rear of this Bulletin

3/27

throughout the central plateau region, but the pattern is more disrupted. The gravity field also demonstrates the existence of regular and huge fracture systems within the Tasmanian crust.

NNW trends can be recognised from the far northeast to the West Coast and block out the central core. Many gold deposits in Northeast Tasmania are related to one of these.

Leaman (1988*a, d*) proposed at least two deep troughs (rifts) incorporating late Precambrian materials within the Tasmania region, based on such data. If we consider the materials which are exposed and associated with the western anomaly we see that the rocks of the Burnie and Oonah Formations fall within this zone — and nowhere else. Units such as those of the Success Creek and Crimson Creek Formations and their correlates tend to overlap and be more widespread, typical mature basin sag onlaps. The large tracts of mafic volcanic rocks have similar dispositions. All these materials offer the required property contrasts and imply crustal penetration of the contrasts for up to ten kilometres. There can be no doubt that the margins of this western anomaly represent first-order structures of probable deep rift or trough form. And they have been largely preserved as we should expect — if the roots of the troughs have not been dislocated, and horizontal offsets are at shallow depths with respect to the modern surface.

This is clearly not the case in central Tasmania from the north coast to the Maydena–Adamsfield region. The gravity field shows that similar materials and patterns persist, but they are much disrupted.

The combination of the gravity and magnetic data sets beneath the Derwent valley system and in southern Tasmania shows that elements of the western pattern have been retained. Sequences with similar properties capped by thick mafic accumulations occur in the lower Midlands and south of Huonville to the south coast. These piles are up to 7 km thick with pronounced penetrative margins (figs 10 to 12).

All this information shows that these pre-Lower Cambrian rocks are universal within the Tasmania region and not restricted to a part of western Tasmania. More importantly they accumulated in deep, narrow trenches. The total number of such gape trenches is uncertain pending further work. Stacking during the Devonian orogenies has terminally disrupted and repeated significant elements of the overlapped and more (originally) widespread units (fig. 8). This stacking is important for its ability to repeat critical parts of the sequence — including volcanic piles.

This view of the late Precambrian rocks implies that they formed part of a giant basin many times wider than present-day Tasmania. The parts we now see clearly simply represent the deeper rift axis cores or "pop-ups", while the onlapped and thinned (relatively) portions are often shuffled into thrust stacks. This makes better sense of the involvement of the Precambrian blocks in all parts of the crustal structure.

Again, one must be careful — about timing. The distribution and styles of the Devonian granitoids show that large parts of the sequence, including apparently very large Precambrian blocks, were still mobile until the late Devonian and earliest Carboniferous. This is the only way to explain the granitoids of the King Island, Rocky Cape and South West regions (Leaman and Richardson, 1992). The same principles apply to the entire north coast region north of Deloraine and Cethana.

We should therefore presume a greater generality for the rocks said to be afflicted by the Penguin Orogeny if that orogeny is taken to affect the Burnie and Oonah Formations. I note that there is a possible conflict in definitions of this event within the literature. If an event occurred at about 700 Ma then it is the Penguin Orogeny. But note that the rocks affected may not then have existed, or been any part of what is now Tasmania, given the allochthoneity which can be demonstrated for most parts of the Precambrian blocks.

If we distinguish between an older and younger Precambrian sequence, with the latter in basin initiation gapes as suggested above, then we must define a new orogeny. I think the Heazlewood Orogeny to be an appropriate name. The time? Late Lower Cambrian. The recently-formed Burnie, Oonah, Success Creek and Crimson Creek Formations were deformed. Given the likely evolution of the gross extensional basin containing this sequence (compare fig. 5) it is probable that the gape fill rocks were more seriously deformed and parts may now show textures and structuring not unlike some of the older rocks that they onlapped.

My Heazlewood event introduced quite large volumes of ultramafic and mafic materials. Berry and Crawford (1988) have proposed broad-scale allochthonous coverage of pre-existing materials. This option cannot be denied but realistic alternative possibilities include emplacement of several slabs of material — as indicated by the amply documented process described by Middleton (1984) (fig. 6). Part of this material may be intrusive and part detached. Evidence for this option is based on the location and distribution of deep or massive accumulations of the material. Even near the largest accumulation, at Heazlewood, there is evidence of the material having been drawn upward and outward along the old deep trough margin for more than 30 kilometres. Gravity and magnetic data imply this (Leaman, 1988*a, d*). At least three other deep centres (N Boco, S Penguin, W Deloraine and possibly SW Bridport) can be identified magnetically in northern Tasmania.

In every other case the ultramafic bodies are now thin but extensive stringers. Magnetic data show these to be ubiquitous and to occur throughout all parts of Tasmania (e.g. fig. 3). Several occur wholly within Precambrian blocks. It is difficult to separate original relationships from younger tectonic re-emplacements during late Cambrian or Devonian events. These bodies extend into the eastern Mathinna Beds and granitoid province and clearly form part of the basement to these materials. This is consistent with the Devonian uplift of such materials, with Precambrian rocks, in thrust blocks moved from the east, as at Beaconsfield.

This type of evidence, in association with the gravity and magnetic maps, shows that the crustal construction of Tasmania is of west Tasmania style — no matter what materials happen to be exposed at surface. There is no evidence for a gross crustal suture (or 'terrane change') in the Tamar region. There are other explanations — such as a structural nappe front (below). The concept of a Tamar Lineament is not supported by any crustal data set (see also Wellman, 1989) and the term should be dropped. The largest change in physical character extends from East Devonport to Sorell — within the western 'terrane'.

Other Cambrian units are also ubiquitous. Mt Read-type volcanic rocks occur on the eastern side of the Tyennan "core" of the island at Golden Valley, the Den and near Hobart. They may be inferred to occur in a belt south to Cygnet from Hobart (Leaman, 1990*a*). In all cases they

appear to occur on a shelf of Precambrian rocks which was either exposed or thinly covered at the time of volcanism. All this really means is that they were deposited in elevated regions, rather than in the trough basins. The associated sedimentation, such as the Dundas Group, is undoubtedly also common, and this was placed in the depressed zones nearby — probably as direct time correlates and facies variants.

If we attempt to recreate the old basin cores then it seems likely that the volcanic accumulations were either quite common and perhaps covered a wide area, or were accumulated near a particular set of old primary margins. In either solution there is a sense of ubiquity. At no stage is there any need for collisions or subduction (see also Middleton, 1984). The Late Cambrian and Ordovician rocks were also clearly general. Shelf deposits covered the entire Tasmania region by the late Ordovician. But why not before? The latest Cambrian sediments prior to the conglomerates may also have done so — as the Success Creek and Crimson Creek Formations may have done long before them. The thick conglomerates imply dramatic events and revitalisation of structures. In every case these occur marginal to the older structures of crustal scale. None of these were listric.

The direct implication of all this is to suggest that the same processes have operated across a large area, involved large volumes of material, and have generated a sequence of extensional environments with short compressional periods of wrench origin caused by slow rotation of the continental mass (with evolving basin) against the extensional stress field.

If we were to consider this as a basin history and viewed it in terms common to petroleum exploration (e.g. fig. 5) we would have no difficulty with its origin, nor with its scale — probably many hundreds of kilometres across. The rocks of Tasmania's late Precambrian to Carboniferous represent a series of basinal developments with symmetrical and asymmetrical extensions punctuated by wrench-based compressions and an ultimate multiple sag phase. The entire environment is one of extension. Even the Permo-Triassic deposition can be seen in this context as a further sag phase before the effects of continental splitting altered the regional environment. The Triassic itself suggests the grand scale of the evolution — far larger than modern Tasmania.

In each of the wrench phases leading to the ultimate compressions of the Devonian orogenies, pre-existing structures have controlled events and the formation of new structures. Thus structures like the Henty and Great Lyell Faults, which are old, may now display a range of conflicting motions or reversals or rotations, and may now no longer be quite in their original positions. This recognition is important for exploration, especially if we seek Cambrian targets some of which may be concealed, dislocated or relocated.

Devonian deformations have been important in two ways; the introduction of large granitoid bodies (especially in the eastern portion of Tasmania which was clearly closer to the axis of later deposition) and re-arrangement of pre-existing structures. Note also that roof effects above or around the plutons may add to the structural complexity if the story is read from the top down.

This entire scenario carries several important implications, and it does not have to be perfect for these to be applicable. The Cambrian key elements will not be readily inferred from surface evidence, as these will be confused by younger effects and it is probably unlikely that any reliable story will ever be extracted for the rocks older than about 600 Ma due to the extensive rearrangements. The depositional and structural sequence implies a large basin development with important local elements — all determined by previous features. Further, prospective Cambrian materials are not restricted to western Tasmania. They are not now, and never were. We should expect similar histories, correlations, styles and provenances in western Victoria, Antarctica, New Zealand and, perhaps, South America beneath the Andes. Of all these sites the crucial elements are most accessible in modern Tasmania.

The stress field did not change greatly with time. This can be shown from the persistence of sub N-S trends from the late Precambrian structures to the late Devonian granite margin of eastern Tasmania (Leaman and Richardson, 1992). In such an extensional environment in which stresses may have swung no more than 45° either side of north, sub E-W transforms should be common. These are recognisable and also ubiquitous and effective right into the Jurassic. More local stress fields within the rifts of the basins, at early stages, did deviate (see fig. 4). Modern analogues show this to be common. Wrenching and inversion follows such variations.

Within the N-S rifts we might expect, following the wrench phases, some subsidiary rotations of axial trend — within the primary trough axis — and these may be observed. I propose that it is these relationships which account for the common near-NE and NW trends. Deposition and rending within the Dundas Trough north of Rosebery and south of the basalt cap of northern Tasmania follows application of such wrenching and internal extension. This pattern may be observed across northwestern Tasmania NW of Cradle Mountain, while the conjugate can be observed to the south within the trough — but now largely concealed by the numerous detachments and reversals such as represented by the Rosebery Fault.

Large scale bending of the old trough axis, marginal faulting and volcanic rocks are related to Devonian deformation.

This entire sequence of events fully explains the setting of onset of deposition of conglomerates and features such as the Haulage Unconformity. These are normal components in active basin development.

CLARIFICATION OF PROPOSED CONCEPT

I want to be very clear about what is being proposed.

The basic model or analogue used to explain the various components of the proposed history from the late Proterozoic to the present is well known to petroleum geologists and interpreters of seismic records, although such workers usually limit their interest to the upper and younger parts of such sections. The common denominators of basin evolution can be recognised in structures and deposition back to the Archaean and, with only minor variation — well within the options and local controls applying to any given basin — may be recognised in modern structures.

This model requires no special pleading, complicated tectonic processes or assumptions such as involved in subduction or collisional models. I accept no such assumptions. I do argue that modern oceans date only from the Mesozoic on planet Earth, and that before this waterways and deep seas occupied the axes of subsidence related to basins. The basin model requires tension only — an extensional regime in the long term. Anisotropies and

5/27

rotations have induced the wrench and compressional effects evident at many stages. Igneous activity is related to the mantle causes which initiate the tension. Any ultimate expulsion or inversion of the basin is also related to these causes and mantle transformations generated during the extension process. Plutons, nappes and related features are side effects of first order inversions.

This story, in Tasmania, begins with generation of some deep gapes which clearly invite mantle changes (Middleton, 1984) and then mafic volcanism. These gapes appear as subparallel or *en echelon* features at least 100 km long, 25 km wide and 10 km deep (Leaman, 1988*a, d*). They may have been essentially symmetrical in section and were well filled and probably overlapped by the time of Success Creek Formation and associated deposition and volcanism. The structures were fully covered by the Crimson Creek Formation. This sequence of units represents fill of active troughs, continuing extension to half grabens (style of Baillie and Pickering, 1991), and finally thinner but generous sag fill coverage of a large area. Several breaks in deposition and possibly rotation, erosion and volcanism may be inferred. At least two of these elements are always present in evolving systems of this type when viewed at continental scale. The younger units may not have exceeded 5 km in thickness but the total section may have been more than 15 km near the original gapes. The deep sections will also have become dense, compact, perhaps locally metamorphosed and stressed by events. The entire package will be extremely variable with an array of unit relationships. All normal in a basin.

One could offer Bass Basin as an example at this point. The deep gape, Jurassic in age, is largely filled with mafic volcanic rocks and related products and is then overlapped by a broad spread of half grabens containing Cretaceous and basal Tertiary units with some patchy volcanism. This entire sequence is then covered by a several-stage sag phase Tertiary succession with unconformities, volcanic horizons and erosional breaks. No significant inversion has yet occurred, as the basin remains in tension. The adjacent Gippsland Basin has borne the effects of wrenching and local inversion. Note that the time frame for the Late Precambrian basin development and Bass Basin is similar, about 150 million years. It may be noted that in all such basins — other well documented examples surround Britain — volcanic products may be substantial but spatially and temporally restricted. These relationships and their origin are crucial to our appreciation of Cambrian volcanism in Tasmania (below).

Although this history begins with deep gapes, it is worth considering the rocks which were extended. These were essentially siliceous arenites and lutites initially deformed during the Penguin Orogeny (termination of the sag phase of their basin evolution). What underlies these rocks is unknown but this old sequence, now variably metamorphosed, was at least 5 km thick. These comments imply that the process, which is focused about the Cambrian in this essay, is of long standing.

During or after deposition of the Crimson Creek Formation the now extended and locally very thin crust was wrenched and rearranged. Thermal changes may also have forced uplift, as the basin-crust-mantle proportions would have become very unstable isostatically if we assume an original crustal thickness of only thirty kilometres. I define this as the Heazlewood Orogeny.

The result of the uplift, wrenching(?) and deformation was to reverse many of the listric elements of the structure and emplace slices of the transformed upper mantle. Associated effects would have included uplift and shuffling of blocks of now variably metamorphosed old basement and deep gape fills. The ultramafic rocks of the Lower Cambrian and their probable coverage of large tracts date from this event. Original gape structures or wrench zones will have survived this deformation because of their scale and penetration — as would any older elements of similar type. Uplift, erosion and further extension followed, but these forces were now applied to an homogenised sequence containing an array of materials, metamorphic grades and relationships.

No deep gapes have yet been identified in the third extensional period, and the extension seems to have evolved from the half graben phase. This unstable period, with its variable volcanism localised near particular structural elements, produced the Mt Read Volcanics and its trough-fill associates of the Dundas Trough. In western Tasmania we see only a part of a much larger extensional environment. Similar products occurred across a wide area but the patchy development reflects the frequency and relief of the relative horsts and basement slabs and their association with older, penetrative structures. The style of this period is suggested in Figures 4 and 5.

This regime was catastrophically reversed in early Upper Cambrian (Delamerian) times. The extensional blocks were inverted and the "basement" was reshuffled. The Tyennan core became emergent. The violent activity of the period is marked by the deep, half graben fills of conglomerate (molasse). More extension! The half graben fills reversed the form of earlier structures and many can be linked to older penetrative structures.

Two things should be noted here. Penetrative structures can only be identified with any certainty by crustal geophysics, not surface geological methods. At all stages after the burst of the Lower Cambrian the isostatic balance of the affected crust remained critical and very sensitive to applied stress, loadings, water depth and upper mantle changes.

The major mineralising events are related to this active multiphase extension and volcanism of the extensional period preceding the active inversion of the Late Cambrian. I infer this to mean an appropriately differentiated mantle core beneath the basin and both suitable transmission paths and thermal conditions. This stage and style can be recognised in other basins, and an example from the Ordovician of western Britain is indicated in Figure 5.

After a settling period, further half graben rotation, and more mature deposition, the sag phase of the basin was reached and persisted from the Early Ordovician to the Middle Devonian. At least some of the units of this stage were very widespread shelf-type deposits (e.g. Gordon Limestone). It should be assumed that all younger units were basin wide — perhaps 1000 km. The seaward axis was to the east of "Tasmania" and included at least 4 km of deep, marine, turbiditic facies (flysch).

It was hardly surprising that this giant basin should become unstable along the axis to the east because of the great thickness of sediment and depth of water — especially if the axis were related to older gape and cover fills. Even so, the basin required two major events before termination of this stage.

The first began near the axis and included uplift, inversion, thrusting to the west and serial granitoid intrusion on a major scale. Granitoid compositions are consistent with melts from the inferred "west Tasmania-type basement". This primary event shattered many of the older Precambrian blocks, already disorganised by two previous events, and spread nappes of the axial turbidites towards the western side of the basin. The bounding front of this cover has been termed the Tamar Lineament, even though it really occurs near Devonport, some 50 km west of the River Tamar (fig. 7 and 8). The gross orientations of the plutons and batholith front reveal a persistent east-west extension or stress field throughout this process (fig. 2).

Thirty million years later this process infected the zones lateral to the old basin axis, now inverted. This was a region now patchily exposed across most of Tasmania. Relatively minor plutons were emplaced and various marginal elements of the original basin were overthrust to the east. The Rocky Cape and Cape Sorell blocks are of this type (Leaman, 1986; 1988*b*; 1990*b*). Each carried its basin cover eastward. The now disparate older basement and evolved younger rocks were finally pinned together by the isolated plutons of western Tasmania (Leaman and Richardson, 1989*a;* 1992). Every one of these bodies intrudes Precambrian (or pre-Heazlewood Orogeny) rocks which must therefore have been mobile and active elements of the inversion. Some deformation must also have been localised around these plutons. Each of these Late Devonian to Early Carboniferous events may have been related to developments further north in the Lachlan Fold Belt.

The eastward motions of many blocks now in western Tasmania and granitoid emplacement has transformed elements of many old margins and penetrative structures — including the Arthur Lineament. Only parts of the transformed zone are exposed. Some are covered by the overthrust Rocky Cape Block (Leaman, 1992). The history of this margin is not as auspicious for base metal deposits, as it was less involved in the Middle Cambrian volcanic events and extension. The gold near the lineament may well, however, be related to the older ultramafic insertions along the lineament. Widespread copper occurrences are the challenging anomaly in the Rocky Cape Zone. Near Balfour I have linked these to distillation from overthrust mafic volcanic rocks of the Smithton Trough by Devonian granites (Leaman, 1988*c*). But is this a general solution?

The Devonian–Carboniferous events produced the fourth or fifth (depending on how these are counted) significant deformations of the deeper or oldest sequences. The result was renewed homogenisation, uplift and erosion. But the ruling extensional control was little affected.

Insufficient work has been done to assess Lower Permian formations but these may have been deposited in etched structures reflecting older features, or to have filled half grabens of low relief. But, by the Upper Permian, a broad sag phase is recognisable. This continued sagging resulted in at least 2.5 km of sedimentation by the early Jurassic. The ultimate axis of this sagging is no longer recognisable but the sedimentation was widespread and extended into Antarctica. Its spread is almost certainly of similar scale to the mid Devonian deposition.

The developed crustal history of the basin essayed here doubtless laid the foundations for the Jurassic volcanism, mantle upwelling and continental separations to follow. A completely new cycle appears to have begun during the early Jurassic with the formation of deep, very narrow and isolated grabens. These were intruded by dolerite and predate the intrusions (Leaman, 1975). The feeders and grabens are not randomly located, as concealed major structures can be identified wherever appropriate analysis has been completed (e.g. Leaman, 1990*a*, fig. 12). Recent reprocessing of Fingal Tier gravity data has also revealed that established dolerite feeders lie on a continuation of the Mathinna–Alberton gold-bearing structure (R. G. Richardson, pers. comm.).

This sequence of events and evolved relationships accounts for the large scale of all events and sequences to this point — when the original gape in the Bass Basin began to form, and the elements of Gondwanaland decided upon divorce. These developments resulted in a multi-component extension (still extension!), rotation of some blocks and relative application of the stresses, and sympathetic uplift with further erosion in Tasmania. The uplift produced our modern fault mountains with a relief of about two kilometres. Some older structures, such as the thrust fronts near the Tamar and the Western Tiers, pulled apart; others deformed into new half grabens imposed on the older and narrower Jurassic gapes. This entire process from the Cretaceous is an exact re-run, with volcanism, of events which had occurred at least twice before. Gapes, asymmetric basins, onlaps and transforms.

The post-Cretaceous basins and developments are of interest in that they show where and how the volcanic rocks occur or are preserved. No mineralisation is associated and the products are very limited in compositional range. These young sequences do show how volcanic rocks and related products can be widespread and patchily preserved in times of depositional hiatus. Vents are associated with deep, concealed, penetrative older structures. Is there a lesson here for our Cambrian searches?

While common denominators and subtle, inherited variations may be recognised throughout this proposed history, only one active period is distinct. The conditions and, perhaps, compositional evolution of the Earth have never been repeated. The period is the Middle Cambrian.

RESOLUTION OF SOME ENIGMAS

Some of Corbett's (1989) enigmas may now be dissolved.

The Penguin Orogeny has been confused. The late Precambrian rocks must be built into the sequence with an early Cambrian deformation. They are a deep gape rift sequence leading to a quiet phase prior to wrenching. This was a violent event and introduced ultramafic materials in its culmination. Events prior to 700 Ma, including the Penguin Orogeny, cannot now be readily discerned but are preserved in the variably metamorphosed remnants of oldest Precambrian rocks.

This pattern of events, with Devonian thrusting, can account for the similarities between the rocks of the Smithton Trough, within the Rocky Cape Block, and the rocks of the Arthur Lineament at least partly beneath it. The marginal deformations, additional stress and contrast with less deformed and probably thinner parts of the sequence from elsewhere complete the picture.

The apparent trough shapes, as seen today, are largely irrelevant due to the highly compressed and distorted slicing which took place during the latest Cambrian and Devonian. The bending of the northern zone near Cradle Mountain is

7/27

an artifact of these developments and sequence overlapping or ramping. Any significance previously ascribed on the basis of west Tasmanian relationships dissolves when it is realised that these are not unique.

There is no special significance to the Precambrian blocks around the perimeter of the northern coastal region. These simply reflect the jumble of facing thrust stacks generated up to the late Devonian, and the effect of transforms offsetting earlier rift axes. Each of these Precambrian blocks is allochthonous and overlies parts of the late Precambrian to late Ordovician sequence. (This has important ramifications for Tasmanian petroleum exploration because the Gordon Limestone is a proven source for oil seepages and many apparent seeps occur in Precambrian exposures). More complete outlines of thrust patterns have been given by Leaman (1986, 1990*c*, 1992) — including their role in the Zeehan area — as well as many, presently confidential, company reports which also show that the Mt Read Volcanics have been caught up in some structures. Figures 8, 9 and 14 suggest some general relationships.

Concepts of rift-ocean-arc settings based on local relationships and geochemical indicators are not well founded nor necessary if a continental and large basin scale is applied. The west Tasmanian region represents only a fragment of such a basin and pieces within it cannot therefore be considered exotic without considering a total assembly. Conflicts on the basis of such implications are non existent. Classical relationships, including correlations, provenance, and onlaps, are more diagnostic than trace chemical indicators for which many assumptions must be linked and which cannot be properly controlled for an evolving mantle.

The apparent narrowness of the Mt Read volcanic arc is also an illusion, since the environment may have been very much larger and is now structurally sliced, heaped and repeated. In either case the 'arc' appears much more like other analogues (such as the Andes). Other occurrences will occur in similar zones within the basin and may be expected (e.g. Western Tiers, Glenorchy).

Differentials exist in the nature and grade of regional metamorphism within most units older than Middle Cambrian. In the case of the Precambrian rocks it is possible to imply (as did Turner, 1989) that local history and stresses may account for the differences, even when applied to similar lithologies. This would be quite consistent with a uniform, extended basement now locally stressed and evolved and thrust diapirically into and across the orogen created from the original basin developed (also fig. 6).

There is no doubt that many details remain to be worked out but I believe this style of evolved basin evolution is consistent with known relationships and demonstrable basin styles of other ages or locations. Tasmania remained within the evolving basin zone throughout a long period but was ultimately located near the active axis. The massive scale of the eastern batholiths shows that the final and largest movements occurred east of present day Tasmania, and that the aftershocks occurred in what is now western Tasmania. This is reflected by the ages of the granitoids, with the youngest being in western Tasmania.

Structures and boundaries have persistently evolved and been rejuvenated. It will not be possible to understand the oldest controls until superimposed elements have been unscrambled. Only fundamental crustal lineaments can remain recognisable.

SITING OF MINERALISATION

What are the implications for exploration of such an evolved history? In a word, encouraging. In another, complex. It means that the entire State is prospective for Cambrian mineralisation providing the complicating issues of structural confusion and concealment of various types are treated. Fortunately these problems can be recognised and resolved. The only debit will be that in some areas the target rocks have either been removed at some stage, or are now too deep for mining. These are normal risks in any province.

We have to seek the large and penetrative structures. These will be the elements of the rifts which passed into or carried wrench motions, or which were steep and not listric, or which were reactivated and perhaps reversed and transformed into penetrative structures. Transforms within the rift system form the second class.

If we are seeking sites with Cambrian mineralisation then we need to find those sites in which the above fracture types were active at the appropriate time and, most crucially, were held in tension for a long period. Known mineral deposits do not occur continuously along any fracture system; there must be nodal or special local conditions. The intersections of primary rift and transform faults can provide such conditions since the first provides half of a tensional environment and the second, by acting as an effective shear within the rift environment, but normal to it, can maintain and amplify the local extension to create gape sites (fig. 15).

Such sites are required if we are to achieve the fluid flows normally considered to be required for deposition of a large ore body. These properties are also consistent with sites in modern volcanic areas in which there are high rates of passage and deposition. Note that deposition occurs in the fracture system and may close it very rapidly unless it can be held in tension and continuously re-opened.

We should also expect to find these sites using geological induction. There should be greater alteration, a range of anomalous deposits, and probably more intrusive rocks than normal. Or, at least, a wider range of local compositions in volcanic rocks. This is consistent with vent conditions.

Other, more universal, indicators are described below. Preservation of deposit, however, may depend on some stagnation in order to concentrate it (and not disperse it either in solution or sediment) coupled with active but periodic venting.

Can any of these patterns or indicators be recognised at Mt Lyell, Hercules, Rosebery, Que River or Hellyer? Indeed.

All lie within about 2 km of a demonstrable Middle Cambrian rift marginal fault (defined crustally). Any offset between its ancient, or crustal, location and modern surface position is due to subsequent reversals and displacements. Thus the proto-Henty Fault now underlies the Jack Fault directly at Hellyer. The position of the modern Henty Fault is irrelevant in terms of Cambrian targets. Henty Gold Prospect is a special case in which old and new overlap with a corner of a Devonian granite pluton.

Rosebery and Hercules are more complicated, and confidentiality forbids further discussion here.

All are associated with variable vent volcanism AND intrusion which are locally distinctive. This demonstrates

active venting. All lie on 80° transforms — as preserved in both deep crust or in local detached blocks elsewhere. Even the Devonian granitoids of western Tasmania were largely controlled by these structures. All are also associated with shale and fine-grained rocks. This suggests a slower, stagnant environment which avoids dispersal. Many can also be linked to erosional breaks in volcanic sequences. The Rosebery transform was first identified by Leaman (1986). The likely effective rift line lay to the east of Rosebery where it is possible to project an extension of the proto-Lyell Fault. The Mt Read and Mt Black volcanic piles now lie beside and astride (due to reverse flower motions) this structure.

The evolved nature of the transforms and their control of later structures is very evident in the Lyell region.

This view of western Tasmania is only possible with the combined use of crustal geophysical data sets (gravity and magnetics) and a coherent geological integration at surface. Use of any one set, such as geological — as has been the case until recently, cannot resolve the many issues involved. Nor can any other techniques for shallow penetration or low lateral resolution. This excludes use of most electrical methods due to resolution (mainly) or cost factors.

The gold deposits of northeast Tasmania may, like those near the Arthur Lineament in the west, be related to granitoid intrusion in, or partial remelting of, western Tasmanian (pre-Heazlewood) sequences including at least one large and several smaller pieces of ultramafic rocks. The general distribution of pre-Middle Cambrian materials, as described here, and the magmatic and structural history implied for various regions, indicate a greater base metal and gold potential than previously believed. See also the Little Den Goldfield discussion below. Gold potential in eastern Tasmania may be comparable to central Victoria and for the same reasons proposed there.

THE KEYS

It is now clear just what the keys are. But we need to express them fully in classical geological terms. Within the deep crust the key sites are long-lived zones of extensive fracturing held open by applied and active tensions related to the system providing the host sites.

The geological indicators of such sites include:

- the rift margin or primary rift faults
- fault history data to prove that the structure was active (in terms of being a magma path, or changes in deposition — facies or thickness)
- unconformity relationships to establish activity before, during or after formation of host sequence
- a steadying of deposition or erosion at the key time
- transverse or transform fracture systems
- a range of intrusive and extrusive compositions, or vent complex, to establish source location foci
- review of evolved structure to verify existence of crustal scale changes at depth
- lineament patterns, or fracture frequency determinations, may also assist but care must be taken to ensure consistency with data sets of crustal value, as sliced blocks may be misleading.

It should also be noted that many of these elements may be preserved WITHIN a large allochthonous slice and many of the characteristics may imply a target. This possibility inevitably means, in a region with Cambrian sequences as disrupted as in Tasmania, that a number of apparent key sites will lack the bulk of any mineralisation deposited. It may then be necessary to review the home site by unravelling the slices or avoid those sites which lack any of the primary criteria. Note that displacement will offset crustal and intra-slice structures.

Further, these criteria will apply to the entirety of Tasmania not intruded by granitoid plutons irrespective of the nature of present cover, whether Tertiary basalt as in northwest Tasmania, Permian-Jurassic as in central and southern Tasmania, or Mathinna Beds in eastern Tasmania. A corollary of the latter is that the Devonian gold of the vein deposits of NE Tasmania may have been derived from the Cambrian rocks which underlie the region at modest to mid-crustal depths (above).

FINDING THE KEYS

The above discussion describes a very complex geological picture which can easily disguise some very large golden eggs. So how might we find these rich targets? We can judge the potential richness on the basis of the few sites we know about. Sites which can be mined, and expand in reserves, for up to a century and which contain an array of metals.

It is not the purpose of this paper to spell out in detail how this can be done, but Leaman (1990*a*) provides a detailed example for southeast Tasmania.

The southeast Tasmania example allows appraisal of the implications and methodology — and the key criteria — free of the presumptions which abound in the (presumed) better-known western Tasmania where all the materials crop out. It is because they crop out, and the forest cannot be seen for the trees, that problems have arisen. It is simply too easy to focus on the very local or very detailed issues and lose the sense of scale required. Large ore bodies imply large controlling structures.

The fragmental preservation of all elements of sequence and structure, without clear correlative controls due to paucity of mappable units or fossils, and the abutment by structural inversion or dislocation of disparate elements of the evolved basins, also tends to blind purely geological methods.

The keys cannot be found without the use of geophysical methods with high lateral resolution and crustal range capacity. Only two methods are cost effective in Tasmanian conditions — gravity and magnetics. Magnetotellurics or seismic reflection may assist, or be useful elsewhere, but the former lacks much lateral resolution and is far from easy to evaluate, and the latter can be blinded by the broken nature of the section and high velocity capping materials.

The recommended methods cannot themselves be used in isolation but the gravity method can define gross structure and scale while the magnetic method can define patterns, suggest the nature of dislocations, and provide selective support to the gravity method. Each technique can only be appraised in terms of evolved or impressed structural indications to identify the critical structures.

9/27

The magnetic method derives much of its usefulness, in Tasmanian conditions, from the fact that there are so few strong magnetic sources. These strong sources include the Crimson Creek Formation and its correlates, the ultramafic (not mafic) rocks, the Cambrian granitoids, the Jurassic dolerite and the Tertiary basalts. The effects due to the latter two sources are readily discriminated upon analysis. The combined effect of the first two is to provide an effective magnetic basement which marks the end of the first Cambrian deformation (Heazlewood). Disruption of this time marker is reflected by the distribution of anomalies which are largely produced by the rocks at or below it. Thus the rifts and troughs of the Middle Cambrian can be clearly defined as NE-SW and E-W gapes within a gross N-S frame.

This coupling of structural scale, provided by the gravity data, and the post-Lower Cambrian dislocation information in so far as it affects Cambrian rocks, as provided by the magnetic data, goes far towards defining the required keys.

Figures 10 to 12 provide an extract of the geological evaluation of southeast Tasmania (from Leaman, 1990*a*). This shows how the geophysical data base was used, with minor support from various geological observations, to generate a view of the upper crust and its contents. The analysis was able to demonstrate continuity between mafic suites exposed from the south coast towards the Weld River and Adamsfield; the inclusion of an ultramafic-bearing zone; differentiation between basement types; and distinction between rocks comparable to the Mt Read Volcanics (drilled at Glenorchy) and the mafic or thick underlying sequences comparable to the Oonah Formation and Mainwaring Group of western Tasmania.

The scale of the sections is comparable with those known in western Tasmania. Although the gravity and magnetic models hint at dislocated Precambrian blocks, the limited seismic data available confirms a major change in the Bruny Island–Storm Bay region at about 3 km depth and that a strongly stratified section occurs at depth beneath the homogeneous (seismically) Precambrian units. In every respect this pattern is similar to those which can be inferred at Beaconsfield or Rocky Cape (Leaman *et al.*, 1973; Leaman, 1990*b*; see also figs 7, 8).

The primary trend patterns can be directly associated with modern drainage and terrain features, even though there are few recent (post Carboniferous) faults with these orientations. There are many older structures with the required trends and it is clear that many of these are impressed, in modified or subtle ways, on subsequent units or developments. These quantitative methods, incorporating comprehensive array modelling, are able to indicate general rock distribution and relationships beneath the cover of post-Carboniferous rocks.

If we consider the setting of the well-known gold deposits at Cygnet we find a number of interesting features. Although some gold was mined *in situ*, most gold recovered has been alluvial. The gold has been associated with the Cretaceous alkaline rock suite (dykes, small sills) but most gold is found in the calcareous country rocks about the dykes. These igneous rocks are not chalcophile and yet sulphides are abundant in some areas. Up to 1% Pb is known in some samples. Names such as Copper Alley are very suggestive.

What is the source of this mineralisation?

It is clear that the alkaline rocks are not sources but may be temporary carriers (R. J. Ford, pers. comm.). The gold mineralisation, while concentrated south of Cygnet, is not tightly restricted and occurs in three zones which fan from the head of Port Cygnet. The sulphides occur in a more limited zone, at higher grades, south of Cygnet. This area contains some of the larger alkaline bodies and a probable dolerite feeder. Pyrrhotite is very common in this zone. Review of Figure 12 will show that the location of the Cygnet mineralisation is almost directly above the eastern margin of the southern trough, which is an important and dominant feature. Dolerite has intruded this structure just east of Cygnet — probably its original position — and the alkaline bodies have also occupied a similar site, bowing the materials above a laccolithic mass.

Although the thickness of the basal Permian tillite is not known it is unlikely to exceed a few hundred metres. Both dolerite and syenites have parted and intruded near the unconformity. If these intrusive rocks have occupied a zone previously mineralised then either may have removed part of the ore. Chemical transfer occurred at the first feasible hosts — carbonates of the Lower Permian. I believe we should take such sites seriously as flags of hidden mineralisation. Two further examples are given below but each is associated with the nominal criteria defined above for key sites. The older rocks at Cygnet clearly occupy a key site.

Although the depth of any mineralisation could be as much as 5 km below surface, given the structure, it seems likely that any target lies just below the Permian unconformity or any thin Ordovician cover on the Cambrian rocks where the intrusives have been stepped or edged. Note that the Cambrian materials are an extension of the altered acid–intermediate suite found at Glenorchy. Major sub E-W trends are also visible in gravity data in the southern part of Port Cygnet (fig. 1). This means that all the criteria for finding key sites are represented here, together with definite evidence of mineralisation. Figure 12 also shows an asymmetry in second-stage basins, with the key margin near Port Cygnet. The margin as interpreted (for petroleum purposes) is kinked or stepped near Port Cygnet and this effect is restricted to the second stage (Cambrian) basin. Masked sub E-W (WNW to south–ENE to north) features bound Port Cygnet. Further refinement of the interpretation is possible.

Several sites have been reported throughout central and southern Tasmania in which gold or sulphides are present. Most of these observations date from the turn of the century when many sought gold and were unaware that they should not expect to find it in the post-Carboniferous cover. In each case sulphides, usually pyrite, are present in abundance and are often in Jurassic dolerite — near contacts and near a feeder system. Do such sites, which often lack gold, actually mark a naturally drilled ore or mineralised system? We should not immediately start laughing when a farmer tells us of the sulphides on his property when little more than dolerite or Triassic sandstone are present.

One such site at Neika, west of Hobart, is known to be within a dolerite feeder. This is a particularly interesting site. Figure 13 presents a structural diagram for this part of the Hobart area. No rocks older than Lower–Middle Permian are exposed. Attention may be drawn to the location and orientation of Tertiary structures, Jurassic dolerite discordant sheet limbs and feeders, and Tertiary basalt centres. Post-Permian faulting is also focused and there are major offsets and transfers of motion from the Cascades to the Fern

Tree area. Jurassic and Tertiary motions have been reversed and offset in this zone, and the Tertiary structures are hinged in the same region. A monocline within the Permian rocks is also offset. The monocline directly overlies the primary change in basement structure noted above at Cygnet, and is shown in Figures 12 and 13. The Glenorchy bore hole, with its Cambrian extrusive rocks, lies immediately below or to the east. The folding is almost certainly a rejuvenation of this much older structure. There is a correspondence of association with many sites in western Tasmania.

If the fault and intrusive patterns are examined it will be seen that these align within a narrow corridor not more than 1.5 km wide which is oriented a little north of east. Regional data show that this extends eastward to Dunalley and Marion Bay on the east coast of Tasmania. Dolerite feeder systems are offset along the corridor, yet there is no direct evidence of shear motions in any exposed rocks. There is only one conclusion possible. A zone of structural weakness, subsequently intruded by the dolerite, was offset prior to deposition of the cover. This structure has clearly affected the Cambrian basin developments from the time of the Crimson Creek/Mainwaring Group equivalents, was almost certainly active during later volcanism, and could easily have carried mineralisation near the intersection with the primary N-S structures near Neika. It is, therefore, conceivable that the dolerite feeder, occupying the same weakness, could have ripped away part of any such mineralisation. A part of it was frozen into the intrusion. Such a site satisfies all the criteria for a key site — beneath the Permian cover. Note that in both cases the cover, or cover content, is irrelevant. It is possible to make direct inferences through it by careful use of geophysical data or by examination of the implications of evolved younger structures and landforms. In the Neika and Cygnet cases the focus is a little blurred, but in each case the target has already been defined — without any detailed analysis (feasible with extant data) — within an area little more than one kilometre square.

This method of accepting all clues, unwrapping or unscrambling young structural implications, and combining crustal geophysical implications can be extended to the small fragments of exposed Cambrian(?) rocks known to carry gold near Connorville. Figure 14 presents a fragment of a regional structural study of the pre-Permian rocks, coupled with a surface geological map. The reason why the streams present the orientations observed becomes immediately apparent — as does the cause of the offset in the alignment of the terrain and local small faults. Gold-bearing veins in the region also lie near this intersection of shears, which can be shown to extend great distances. These are crustal features. ENE elements dominate the vein system.

It may be argued, in view of the stacked nature of the concealed structuring (fig. 8), that such relationships should not be apparent. Much may depend here on whether the gold is Cambrian or Devonian in age. We may infer Devonian as it can be shown that the offset pattern of the Ben Lomond Granite (figs 1, 2), which is the youngest of all the eastern plutons, is 'offset' by the same regional trend.

The Little Den Goldfield example illustrates the use of evolved structures to infer and approximately locate large concealed structures and controls, but also to separate the issue of which age of involvement is predominant at the site (fig. 14). This area also illustrates the effect of pull aparts (compare fig. 8).

The coupling of these principles and criteria will work in western Tasmania and one example is offered; Hellyer.

Regional geophysical data suggest that the Hellyer site is located close to the margin of a Cambrian trough. We may call this the 'Proto Henty Fault' and it is several kilometres west of the present position of the fault. The Jack Fault represents a rejuvenation of this structure and overlies it at a very acute angle. These structures are intersected by an 80° degree transform defined in gravity and magnetic data sets — at Hellyer. We may say that the site is selected, within the regional resolution of the data sets, as an area of about a square kilometre. If we then examine the nature of the volcanics, and intrusive rocks, in the area, and changes in thickness of other units consistent with active margins, then the site fulfills all criteria. Note that the geological factors alone are quite inadequate to provide target focus, as these cannot "see" the big features and fundamental controls.

This broader approach is essential in other parts of western Tasmania where structural complexity has disrupted the section so much that it is rarely possible to confirm or deny changes in rock compositions or patterns, or demonstrate the localisation of any major thickness changes. The gravity data set is not so blinded and this information is retained — it sees the big picture, deep in the crust.

CAMBRIAN POTENTIAL

It is clear from the foregoing discussion that the already well-established potential of the Cambrian rocks of western Tasmania represents only the tip of an iceberg. Other sites, concealed or not yet evaluated, must exist. Many transform structures were inferred by Leaman (1986, 1987) and the rift structures extend for more than 100 kilometres (exposed).

This essay, however, suggests that this environment — or more strictly fragments of it — extend far more widely and that the entire State has potential for these styles of mineralisation.

Many may argue that away from western Tasmania the potential targets are too deeply buried. This remains to be seen. It should be noted that the Mt Read correlates (?) at Glenorchy were at a depth of only 600 m, and that depths of this range are now routinely drilled in western Tasmania. Not only may target depths be less in some areas of central Tasmania but may be much more in western Tasmania where thrust slices have repeated parts of the sequence. This is a trap few have yet allowed for.

Potential exists for an array of possibilities. All require the usual exploration cautions and specification parameters of grade, depth and region or risk.

DEVONIAN OVERPRINTS

Devonian tectonic and igneous events have been superimposed on all previous effects. Consideration of just what these events might have been indicates that we should expect several results. The granitoids of Tasmania were not intruded as a single event, rather as two separate sequences with a time differential of about 30 Ma. We would expect to see a variety of developed structural changes associated with this process and a range of rejuvenations, compressions near the roof-wall elbows, and extensions in the roof. All of this will be overprinted upon the regional compressive or shearing events. If the granitoids have occupied two time

frames then it is also likely that such events will occupy similar time frames.

This sequence may well account for the intra-deformational nature of many quartz veins and the cross over or opposing thrust stacks identified in W and NW Tasmania by Leaman (1986, 1988*b*, 1988*c*). Many granites follow the 80° trend and may show passive or fracture punch emplacement.

This complex history has two negative effects and two positive results. The positive results are simply the remobilisation of some pre-existing mineralisation, and perhaps economic accumulation as well as the primary emplacement of large amounts of gold, tin, tungsten and perhaps lead-zinc. The negative effects are the possible remobilisation of large Cambrian deposits and redeposition in less attractive forms; a situation which must be discriminated if it occurs in Cambrian rocks which have been extensively intruded in all parts of Tasmania, or a total rewriting of structural surfaces and styles. The latter effect is the most destructive for geological and exploration analysis as it leaves the observer with only the most recent and often ambiguous view of the structures and the forces at work.

The superimposition problem has been alluded to many times above. It is very difficult to remove Devonian–Carboniferous effects from a structural analysis when the rocks are examined at outcrop scale. Some of the conflicts possible can be illustrated by listing some of the recognised shear patterns in western Tasmania north of Queenstown to Bass Strait. This incomplete list includes recognition of shears at about 40°, 80°, 290–300° and 325°. It may be argued that the 40° and 290° set are dextral and sinistral respectively on the basis of outcrop observation (D. Selley, pers. comm.). However, if we consider the structures in regional terms, based say on magnetic patterns or gravity shifts of margins — large scale effects, we find that the 40° set may not always be dextral, that the 300° or 325° features may be either sinistral or dextral, as may the 80° structures. The latter appear to be usually dextral.

It may be admitted that small-scale judgments may be clouded by the most recent motions and that large-scale judgments may be rendered uncertain due to feature correlation problems. The point to be made, however, is that great care and all data sources must be considered if a realistic structural sequence is to be deduced; especially if the conditions pertinent to Cambrian key sites are the focus of interest. What we see today, by looking closely, is not especially or immediately of benefit in determining this (fig. 15).

It is for all these reasons that the presence of post-Permian cover may sometimes be an asset. We cannot be misled by the most recent structuring, and the methods which must be used tend to focus on the largest elements of the concealed structure. And it is these which are relevant to exploration of Cambrian sites. The examples above illustrate this for central and southern Tasmania; but the principles apply even when we believe we can understand or decode the exposed sequences in western Tasmania.

CLUES FROM TODAY

The case histories provided for central and southern Tasmania illustrate the persistence and inheritance of many structural controls — regardless of their concealment by thrust stacks or more recent sedimentation. Subtle fracture regimes from zones of fundamental weakness continue to be expressed — even if no direct and obvious faulting occurs — such that modern drainage and coastal patterns can still reflect these trends. This also means that trend or lineament analysis may also yield useful information.

Where such analysis involves use of geophysical data, with some potential for deep probing, care must be taken to assess the likely depth range or depth of the sourcing effects, as it is possible to recognise, in magnetic data for example, alteration effects which appear marked but which are restricted to only one slice of the structure. The fundamental and original position of the feature may be elsewhere; the Devonian shifts strike again! This relationship, or the possibility of resolving it, will only be recognised geophysically in most cases because normal geological methods are blinded by surface issues (fig. 15).

Other useful clues may be provided by direct indicators of mineralisation or mineralising processes. Thus surface identification of alteration, magnetic inference of the altered volumes (e.g. Leaman, 1987), or the suggestion of the presence of sulphides — even if in rocks which are neither carriers nor hosts — provide important clues. Much modern exploration has already been based on the first of these three approaches but it, in isolation, lacks the discrimination offered by the second in terms of true scale. While the second is viable in all conditions, the first can only be used in parts of western Tasmania where the target rocks are actually exposed.

If it is good enough to use the content of conglomerates or breccias as an indicator of local sources during deposition or wall rocks to magma passage, then the record of abnormal materials in other rocks should also be taken seriously, even if we do not know precisely how they were carried or survived the journey. We should be grateful for these flukes of geological history and treat the neighbourhood of the occurrences of sulphide concentrations as potential targets. If these fall into regionally credible sites in terms of the concealed rocks, then the only unknown is depth of target. If we consider what we do know about the relationships in western Tasmania then we may infer that the mineralised sequence is not near the base of any large trough structure; it will lie high in the sequence or on the marginal lip. I infer that most of these oddities have been derived from sites at or near the covering Permian unconformity, where the intrusive energy is transformed from vertical to sub-horizontal motion (dolerite) (Leaman, 1975) and where various phase changes may also be emphasised due to approach to the surface (depth range of 1 to 3 km maximum).

What these relatively rare sites in central Tasmania prove, however, is the general possibility of extensive and interesting mineral terranes across the entirety of Tasmania.

The thickness of cover would appear to present various types of obstacle to exploration and development of this potential. Four types of cover sequence may be defined in terms of Cambrian targets: Tertiary basalt; Permo-Triassic sedimentation with Jurassic dolerite; Mathinna Beds; and Precambrian rocks. There may also be patches of Ordovician to Devonian cover but these appear thin and patchy on present information and analysis. The presence of the third and fourth classes is likely to preclude any economic development because of the thickness of the overthrust slabs. The first and second rarely exceed 300 or 1500 m respectively, and may be rendered transparent with appropriate methods (Leaman, 1986; 1990*a*; Bendall *et al.*, 1991). The thickness of the second class is also misleading,

12/27

as it is commonly much less than 600 to 1000 metres. Evaluation of those regions in which the cover is less than, say, 500 m, where key structures may be inferred, is a high priority in terms of general research and exploration.

CONCLUSION

The Cambrian rocks of Tasmania must be seen as part of a much larger province and to have had a relatively normal basin development. The depositional environment over a very long period was extensional with wrench-related compressive punctuations. Mineralisation and volcanism in this setting have been related to certain of the rift and transform faults which produced generally orthogonal control patterns at critical or key sites. Marked activity on these structures had ceased by the latest Cambrian, and most acid volcanism is related to a period in which basin development was very advanced, and deep.

Had these structures been peripheral to the basin or the ultimate application of granitoids and primary compressions upon uplift, we should have little difficulty conceiving the key sites, or perhaps, finding them. We might have an "Irish" situation in terms of structural simplicity, if not precise style. Unfortunately, the massive uplift forces were applied directly to the Tasmania region — which clearly lay near the basin axis at the crucial time. This has led to major structural rearrangements, confusion in correlation, multiple stacking of parts of the section, and intrusion of large granitoids. Appraisal of this chaos has not been helped by the broad-scale post-Carboniferous cover.

The apparent down side of this evolution, which has made things very difficult to decode structurally due to dominance of the latest effects, is that the appraisal and exploration of Cambrian rocks and the critical sites within them is no longer simple. The up side falls in several classes which outweigh the down side views. Firstly, the Devonian activity introduced much mineral potential of its own. Secondly, the Cambrian province is much larger than previously thought, and even in western Tasmania where the rocks are exposed there is greater potential than would appear from any sighting of a geological map. Thirdly, it is possible to infer the approximate positions of key sites regardless of cover or structural conditions which have concealed or complicated many regions.

It is possible to conceive an area-exploration scale graduated in terms of cover thickness, content, risk and potential which encompasses the entire island. I am not sure that western Tasmania would rank as the long-term optimum zone for investment on this scale. We may conclude from this that if Tasmania is already a world class Cambrian base-metal province based on the visible materials which form only a fraction of what is actually present, then this island SHOULD have a long and prosperous future given the indications of current work.

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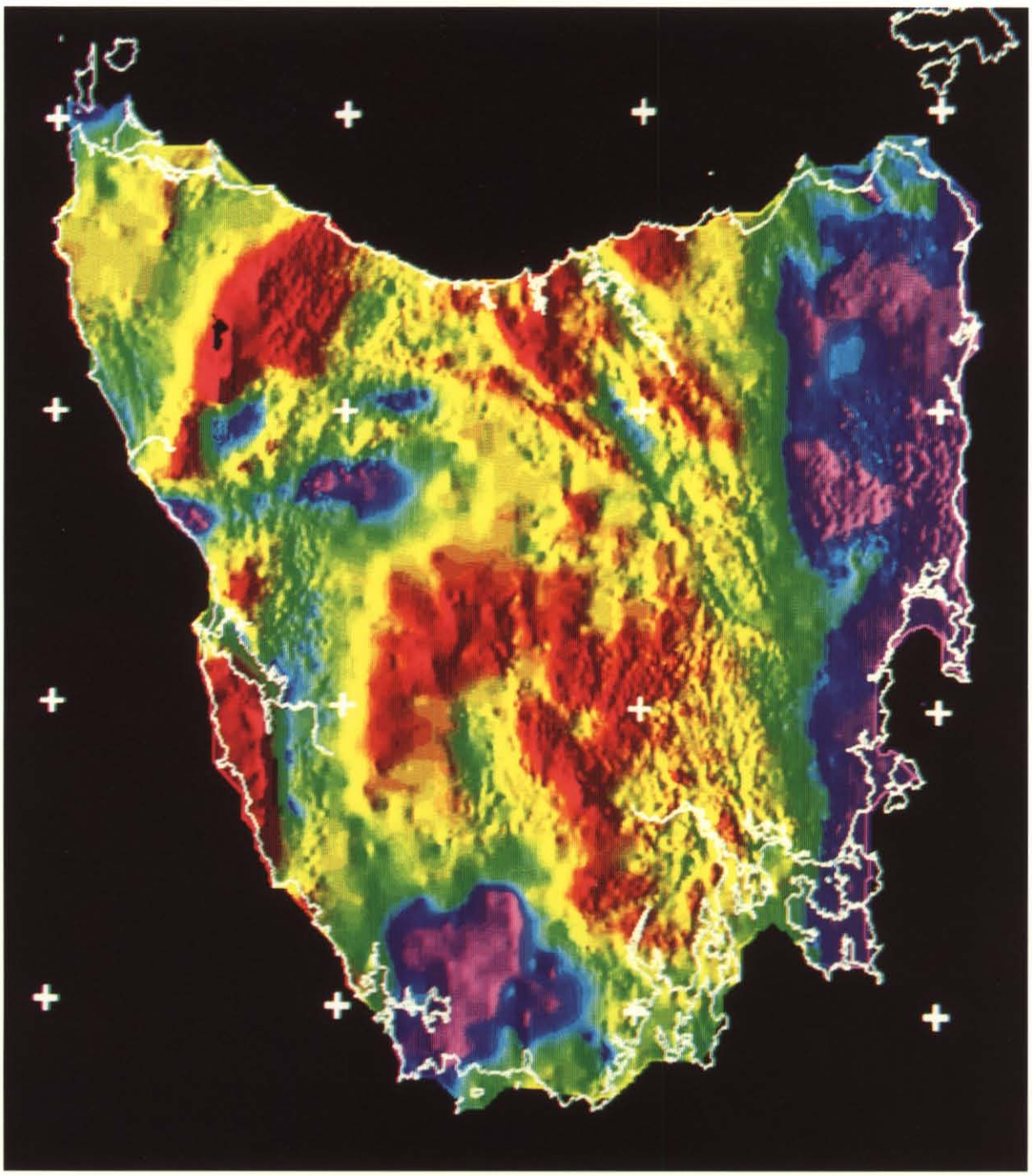


Figure 1.
(D. E. LEAMAN — *Finding Cambrian keys)*

Residual Bouguer Anomaly map of Tasmania. Based on Mantle 91 model method (Leaman and Richardson, 1989*b*). Bouguer density 2.67 t/ m^3.
(Image courtesy M. Roach, CODES).

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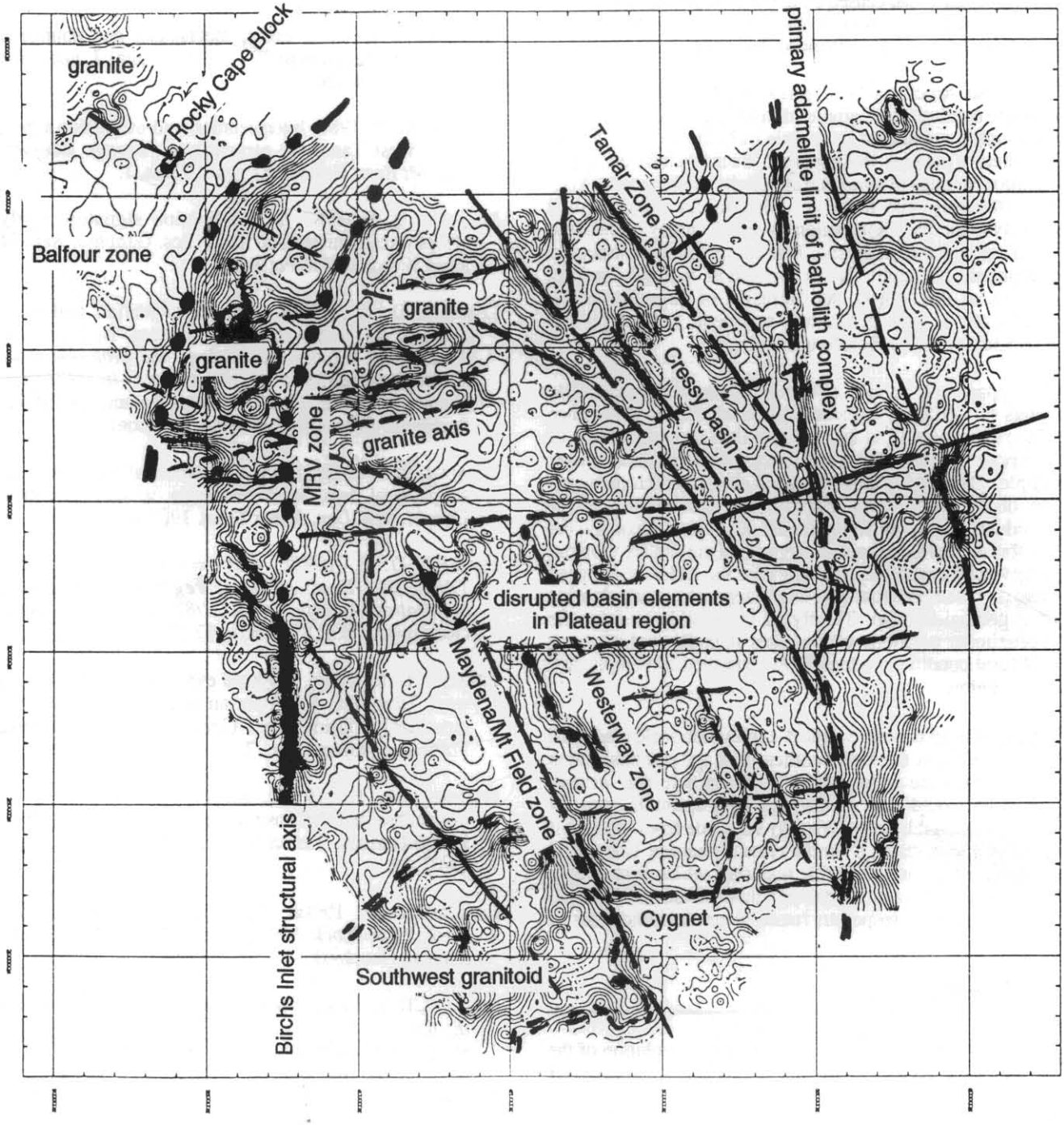


Figure 2

Residual Bouguer Anomaly and some labelling of features. attention is drawn to contrasts involving pre-Lower cambrian rocks and some major offsets and granitoids. Note the general distribution of granitoids.

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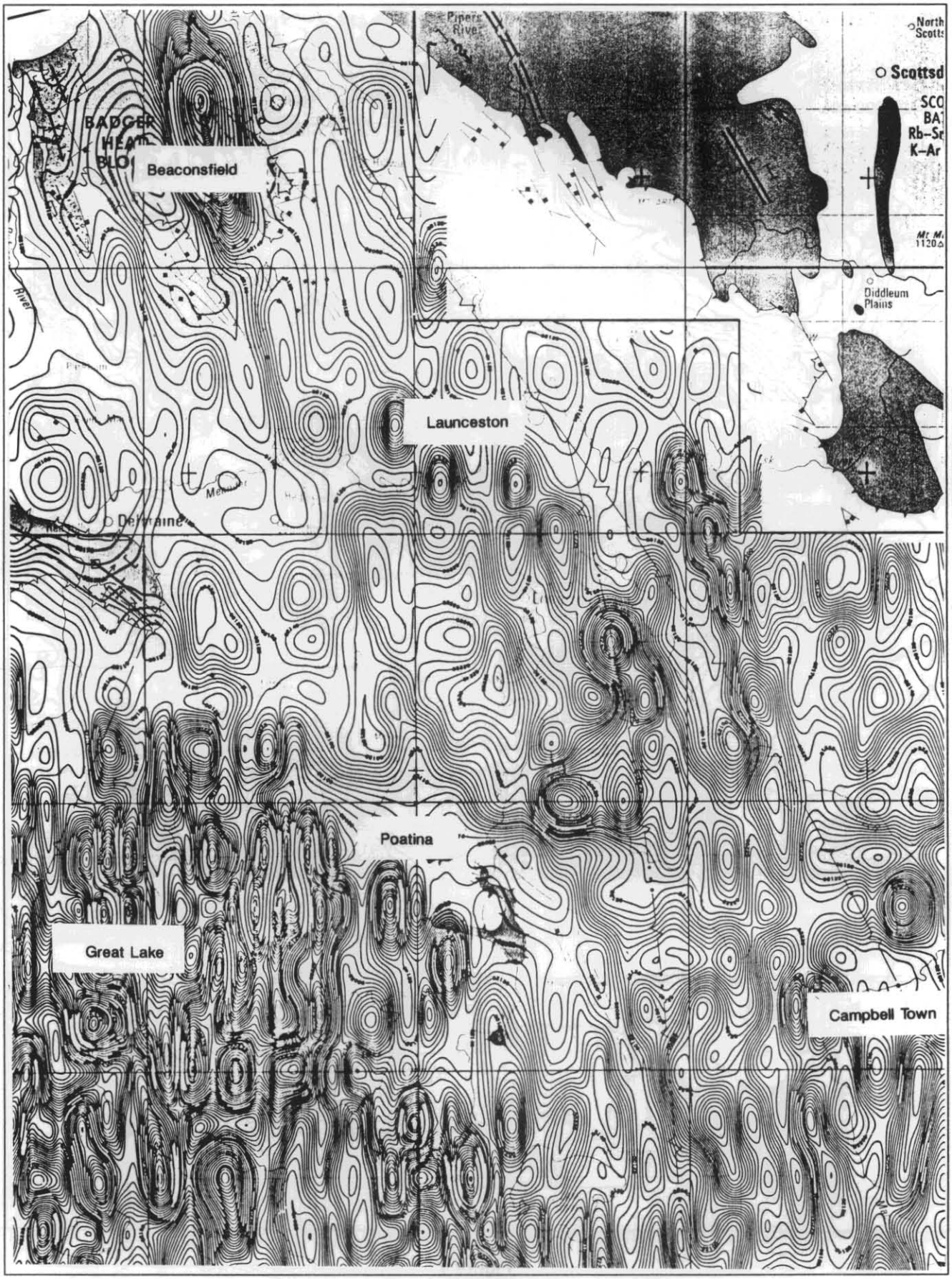
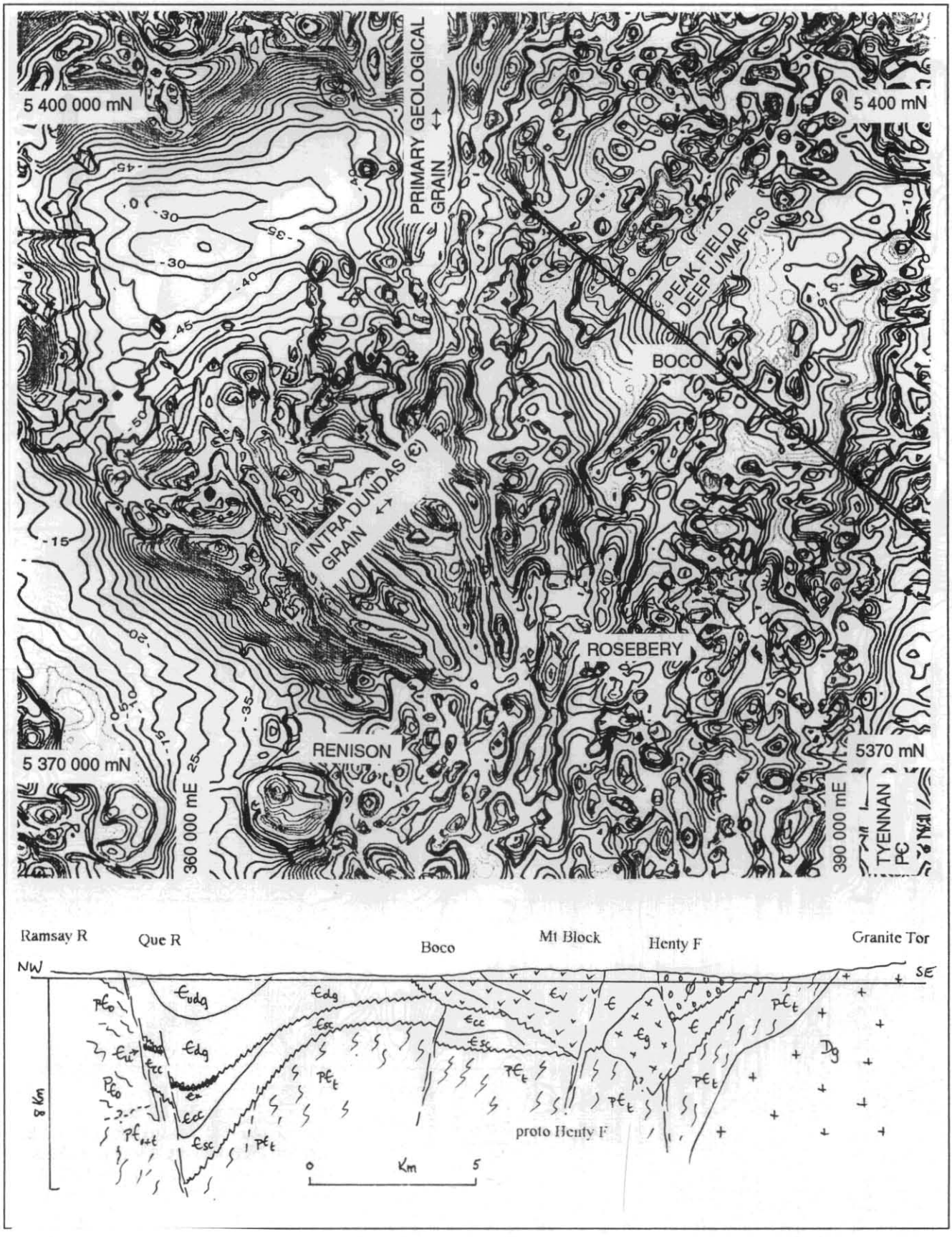


Figure 3

Part of the regional aeromagnetic survey across the midlands. Data courtesy of Conga Oil. Note the extended grain of many features with trends related to, and extending from, exposed ultramafic rocks (as at Beaconsfield). Magnetic data do not reflect post-Jurassic elements in the Tamar region. There is no evidence for a Tamar suture or lineament or terrane join. See also Wellman (1989).

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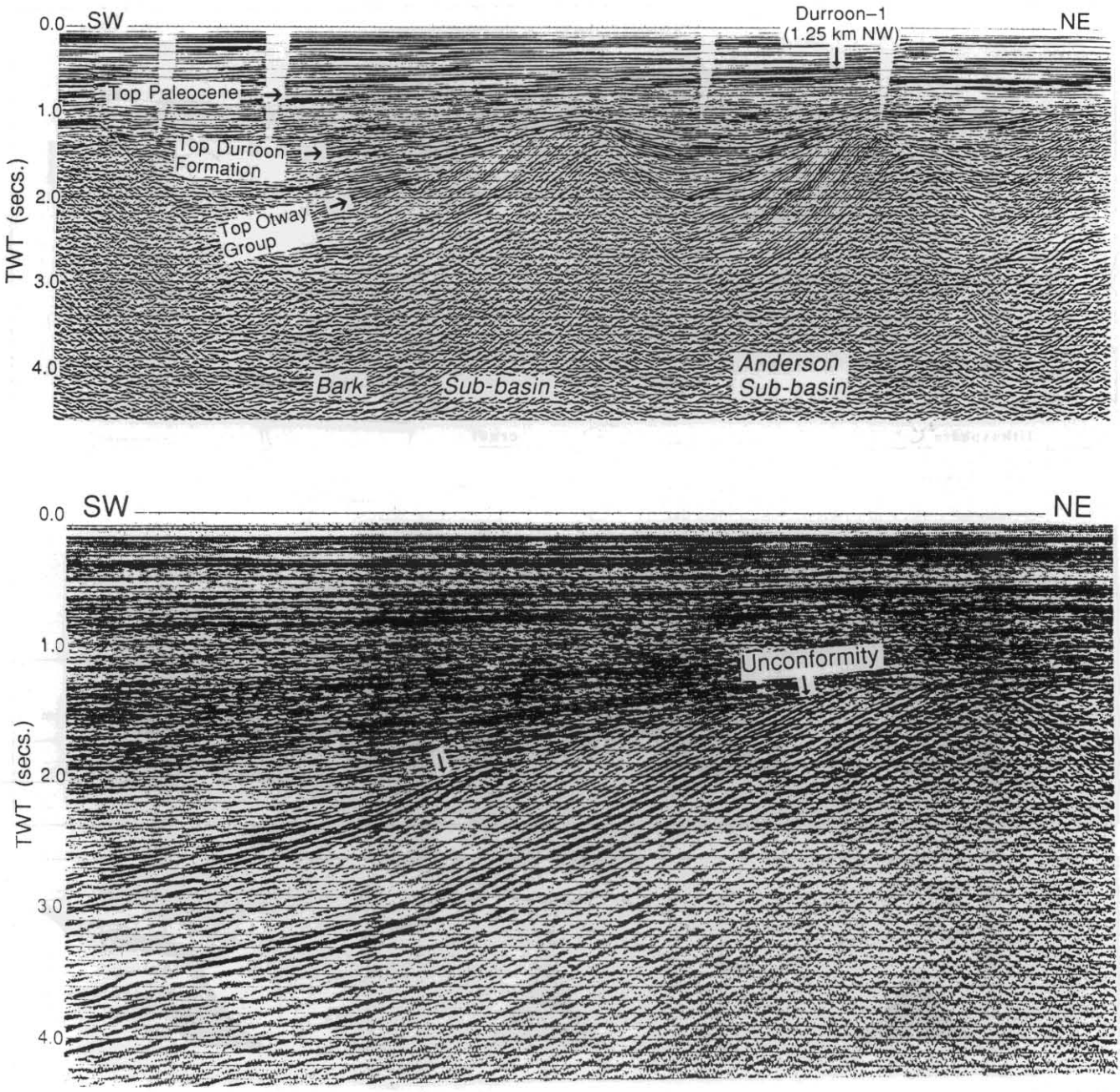
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Figure 4

Part of the 1981 aeromagnetic survey of western Tasmania (Leaman, 1986) corrected for many terrain effects and converted to a residual form after removal of a regional based on continuation to 1500 m terrain clearance. The compilation reveals much fine texture and trend changes within the "trough" axis adjacent to the Mt Read Volcanics. The section suggests a possible interpretation based on a preliminary version of the processed data and residual gravity data. The interpretation can be refined but clearly implies deep narrow old troughs and overprinted half grabens prior to the Late Cambrian.



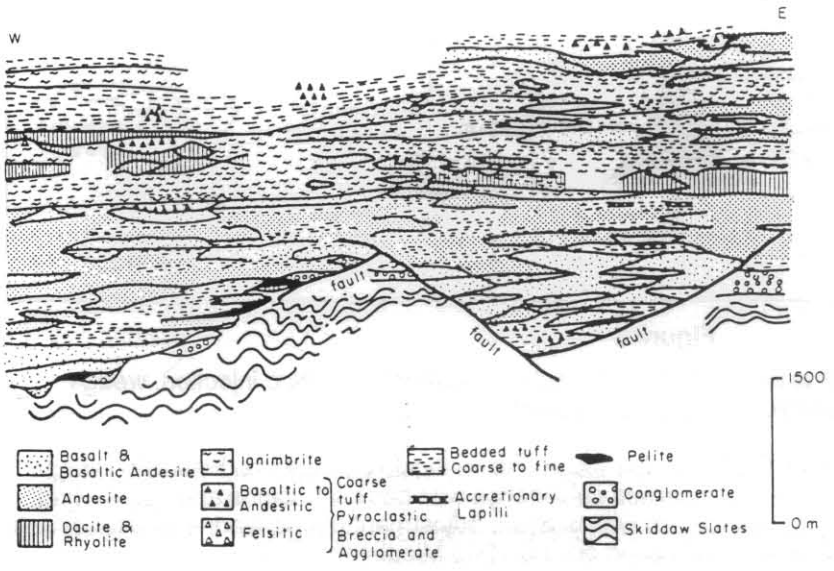
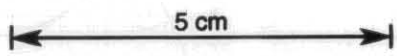


Figure 5

The reflection sections (from the Durroon Basin, Baillie and Pickering, 1991) indicate the style of relationships within basins of all ages. Note that seismic data tends to provide an unclear view of the oldest parts of the structure and that other data must also be used. The lower diagram indicates schematically the stratigraphic complexity produced by overlapping volcanic edifices within the Borrowdale volcanic succession from Buttermere to Haweswater in western England. The section is 30 km long. After Stillman (1986).



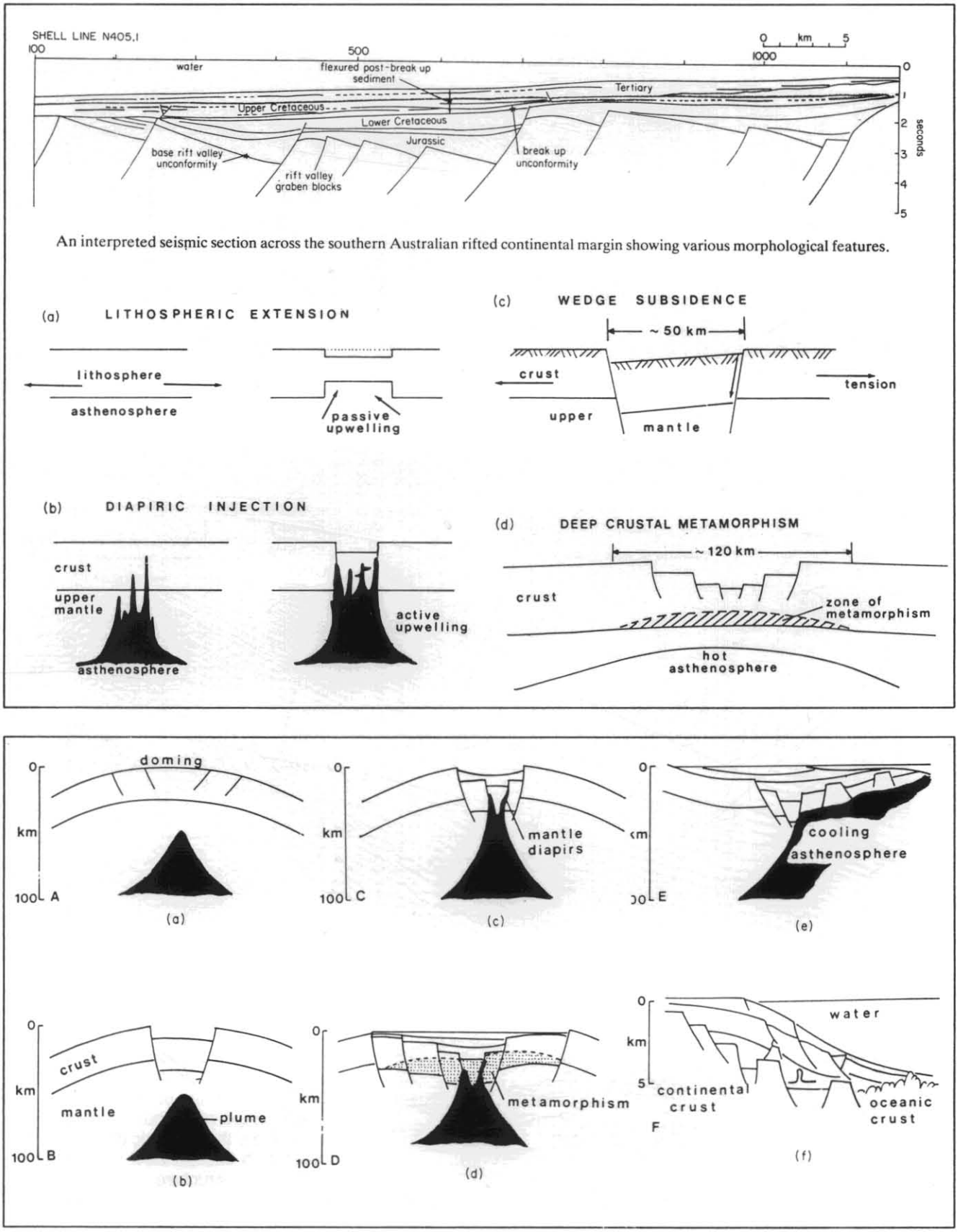


Figure 6

Top. Four possible mechanisms of rift valley formation, lithospheric extension, diapiric injection, wedge subsidence, deep crustal metamorphism.

Bottom. A possible sequence of mechanisms leading to formation of a continental margin sedimentary margin. Thermal doming with erosion, wedge subsidence, localised subsidence with basic intrusions and some filling, regional subsidence involving metamorphism, subsidence with isostatic adjustment (some marine influence) and thermal subsidence if complete disruption occurs. (See Middleton, 1984).

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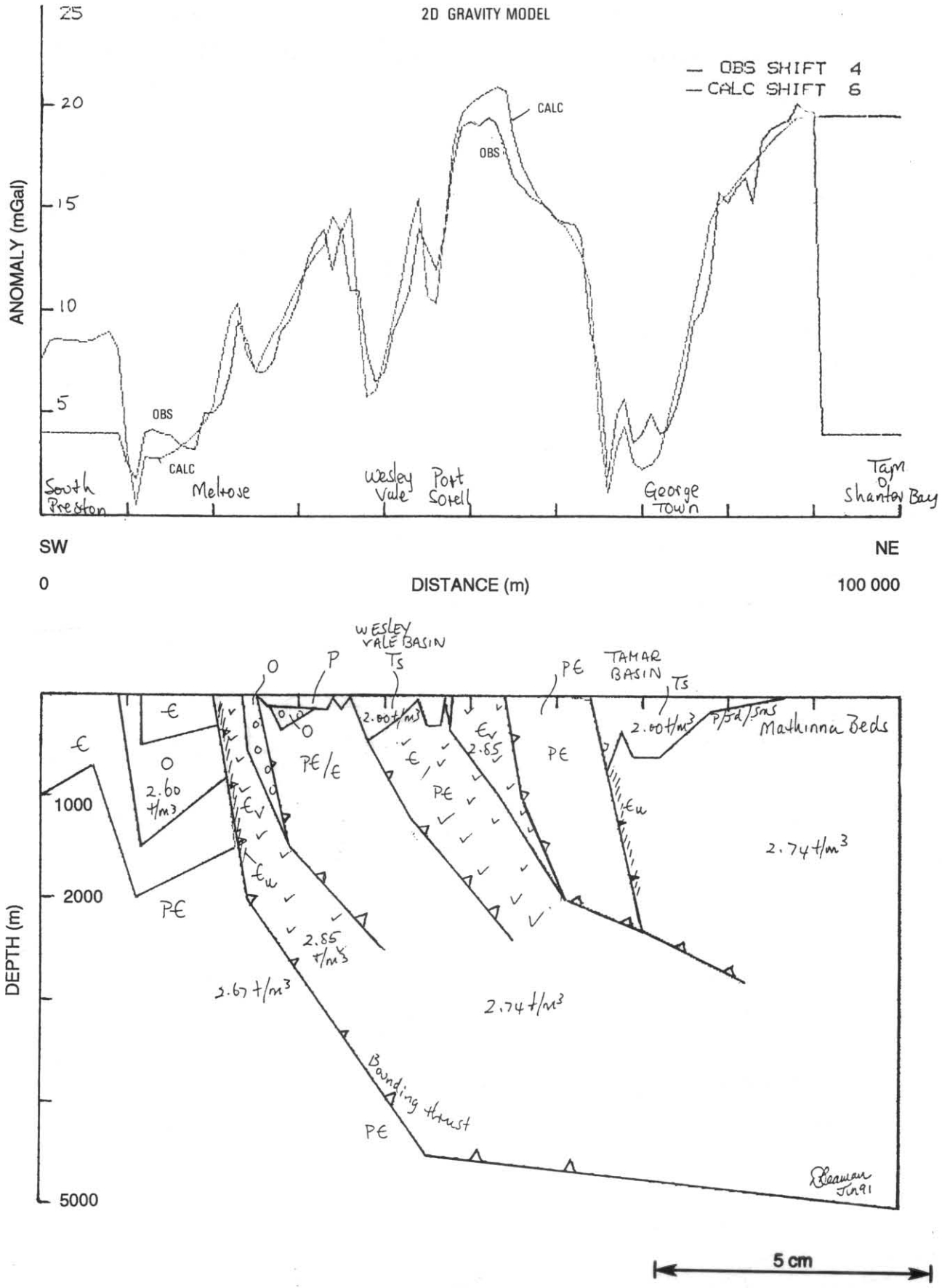
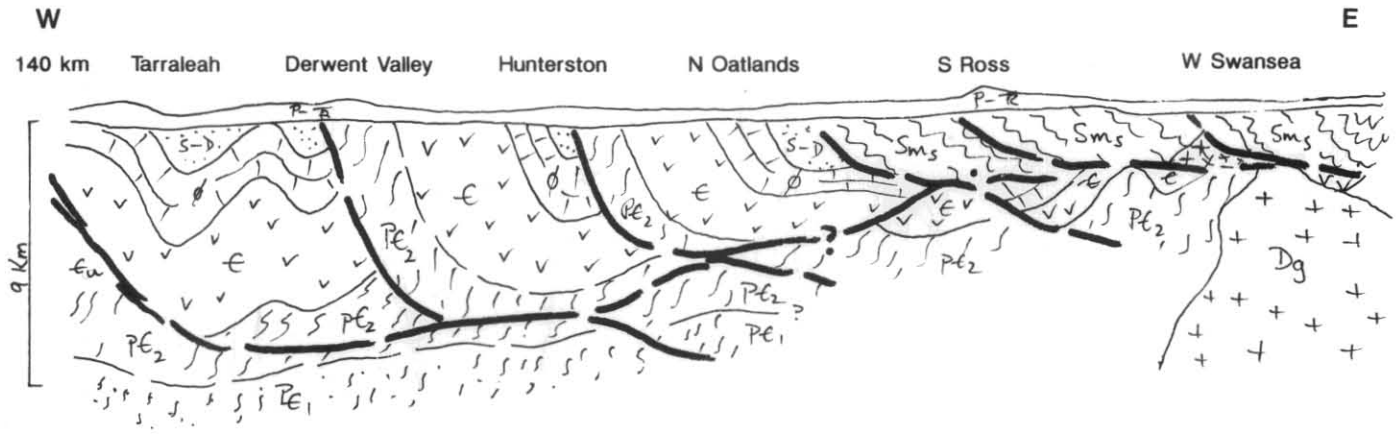


Figure 7

Section revealing inferred relationships in northern Tasmania. Note the dislocated and overthrust nature of Precambrian blocks — all from the east. Tertiary and Jurassic structures are associated with pull back of the larger detachments.

Along strike elements of the western sequence underlying the primary detachment have been incorporated within the thrust complex which includes the deep basin Mathinna facies. Figure 7 shows such pieces west of the Tamar River near Beaconsfield but similar variations occur east and south of Hobart.



SUGGESTED RELATIONSHIPS AND STRUCTURAL STYLE

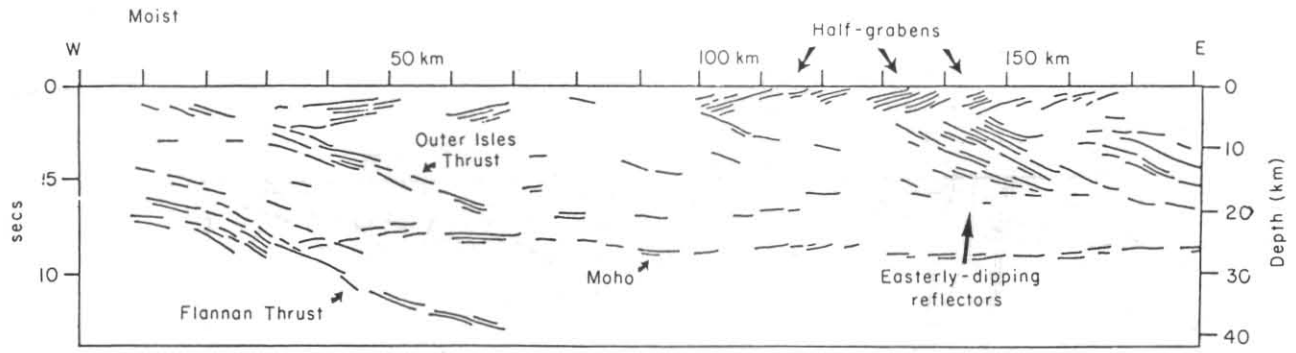


Figure 8

Regional conception of structures in eastern and central Tasmania, based on preliminary long line modelling of gravity and magnetic data. Note the continuance eastward of the western basement type and style. The major detachments incorporate slices of ultramafic rocks and can be mapped magnetically (see fig. 3). Pull back of these structures accounts for the Derwent, Cressy, Coal River and Tamar sub-basins of the post Triassic. The overall asymmetry of the section is related to the greater uplift to the east related to both the original basin axis and the batholith emplacement. The lower section shows similar relationships in northern Scotland (after Brewer, 1983), where North Sea-related tensions have pulled back the older detachments to create half grabens.

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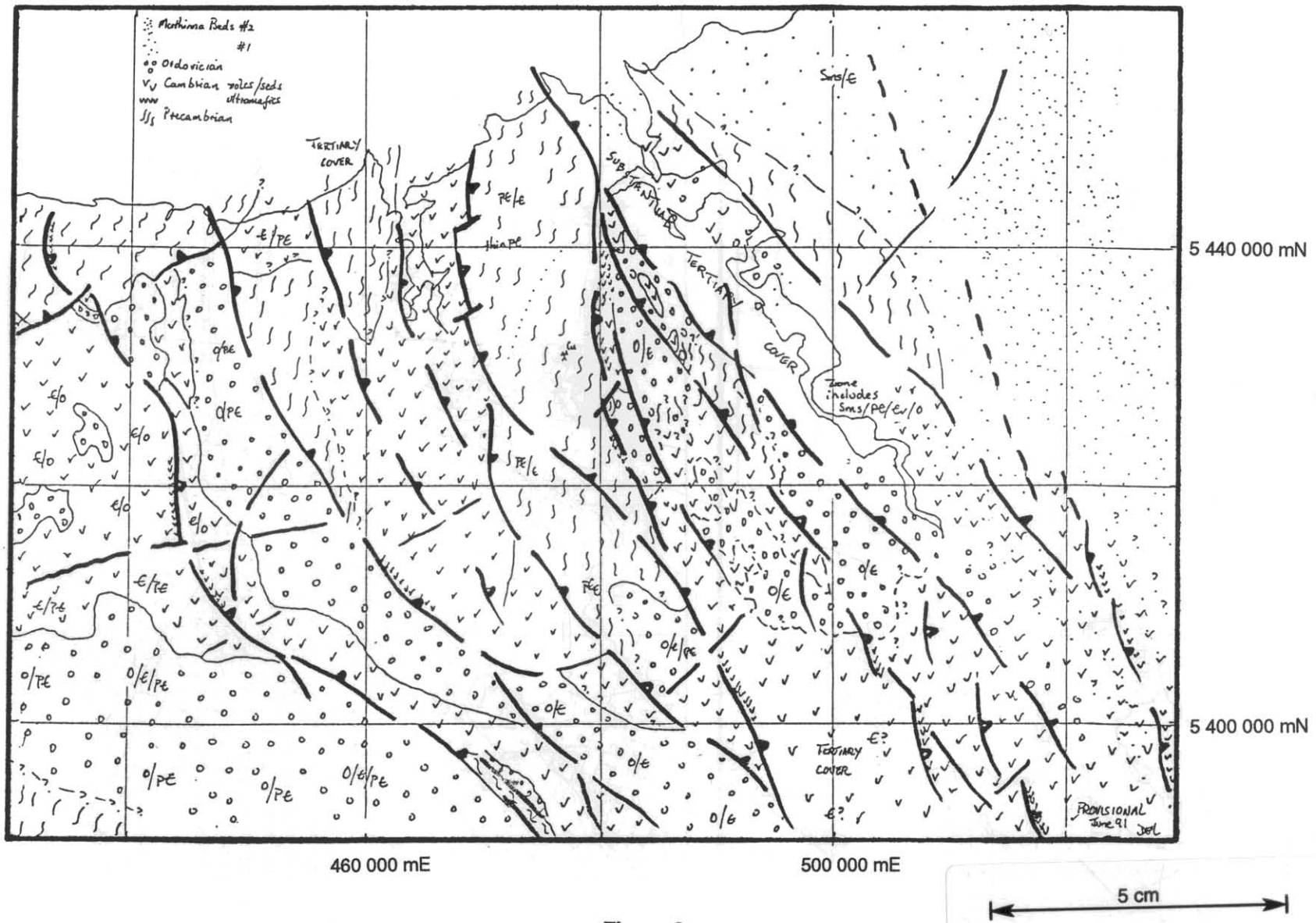


Figure 9

The inferred pattern of major pre-Carboniferous units and structures in Northern Tasmania. The distribution is as would be seen if the cover were removed. (Courtesy Conga Oil Pty Ltd).

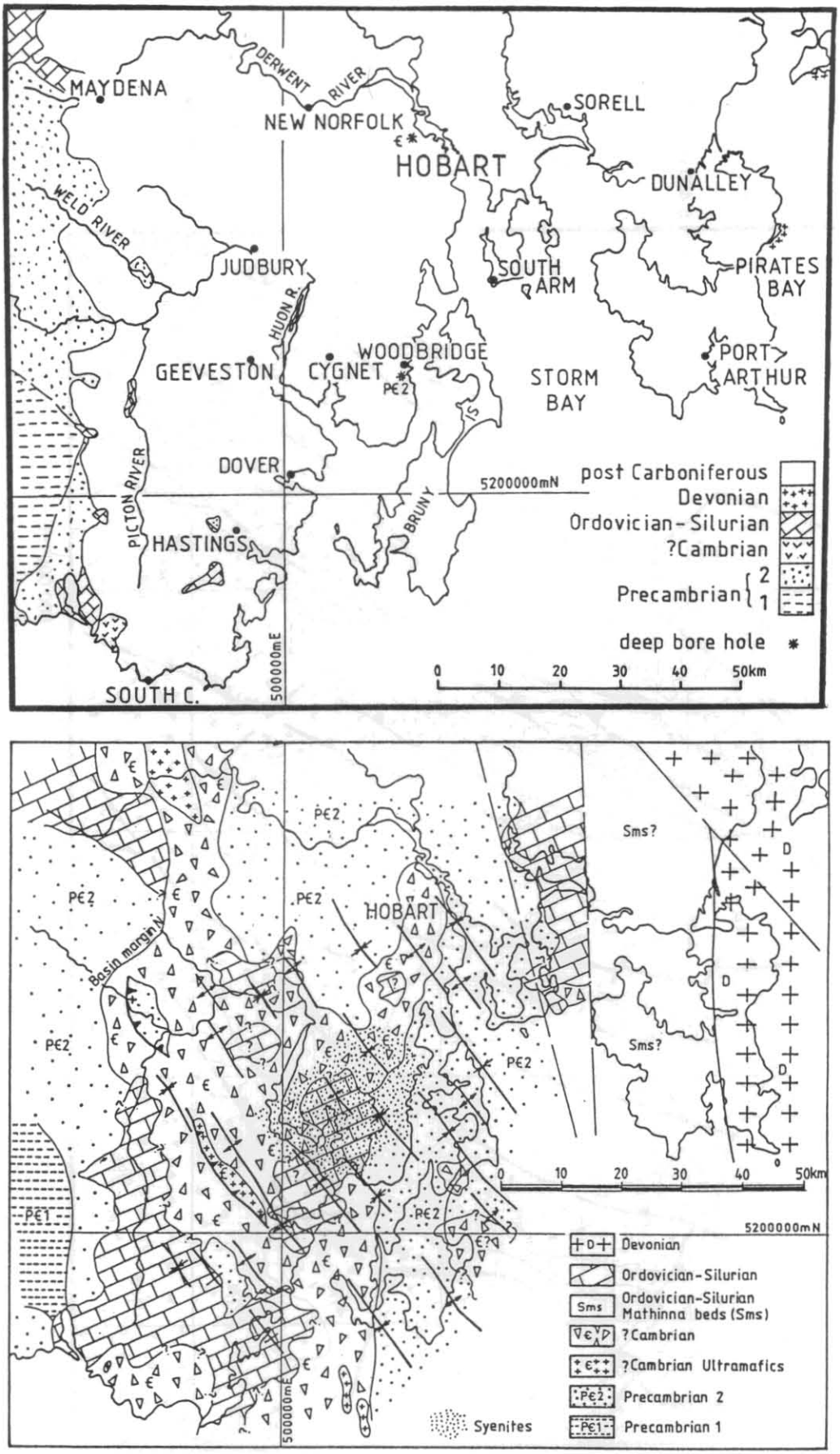


Figure 10

The upper map indicates the exposure and knowledge of the pre-Carboniferous cover in southern Tasmania. The lower map shows an interpretation of rocks at the unconformity. This is a typical west Tasmania terrane.

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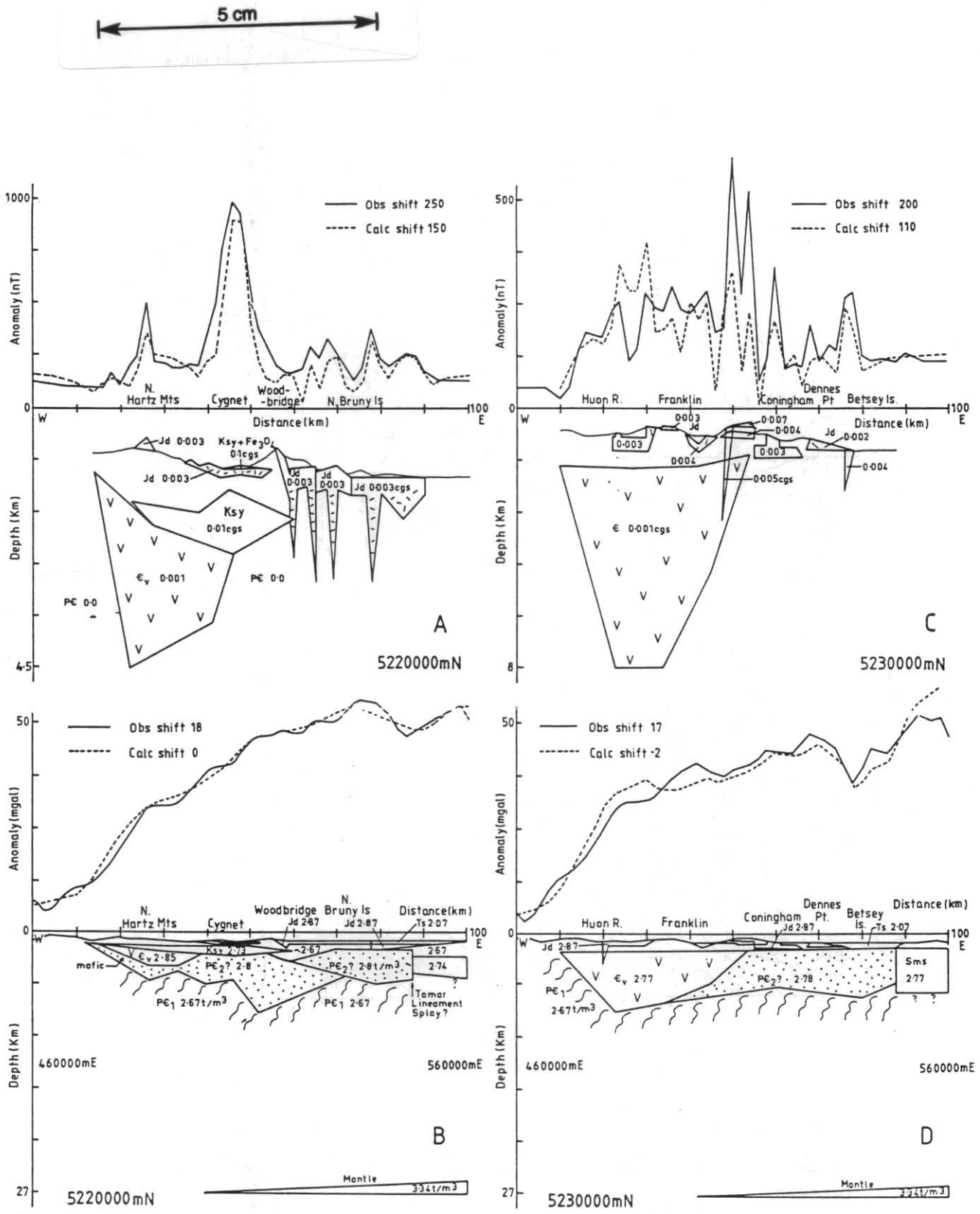


Figure 11

The models illustrate some of the basis for the interpretations offered, for the Cygnet or Huon region in particular. The style is identical to that inferred in central and northern Tasmania.

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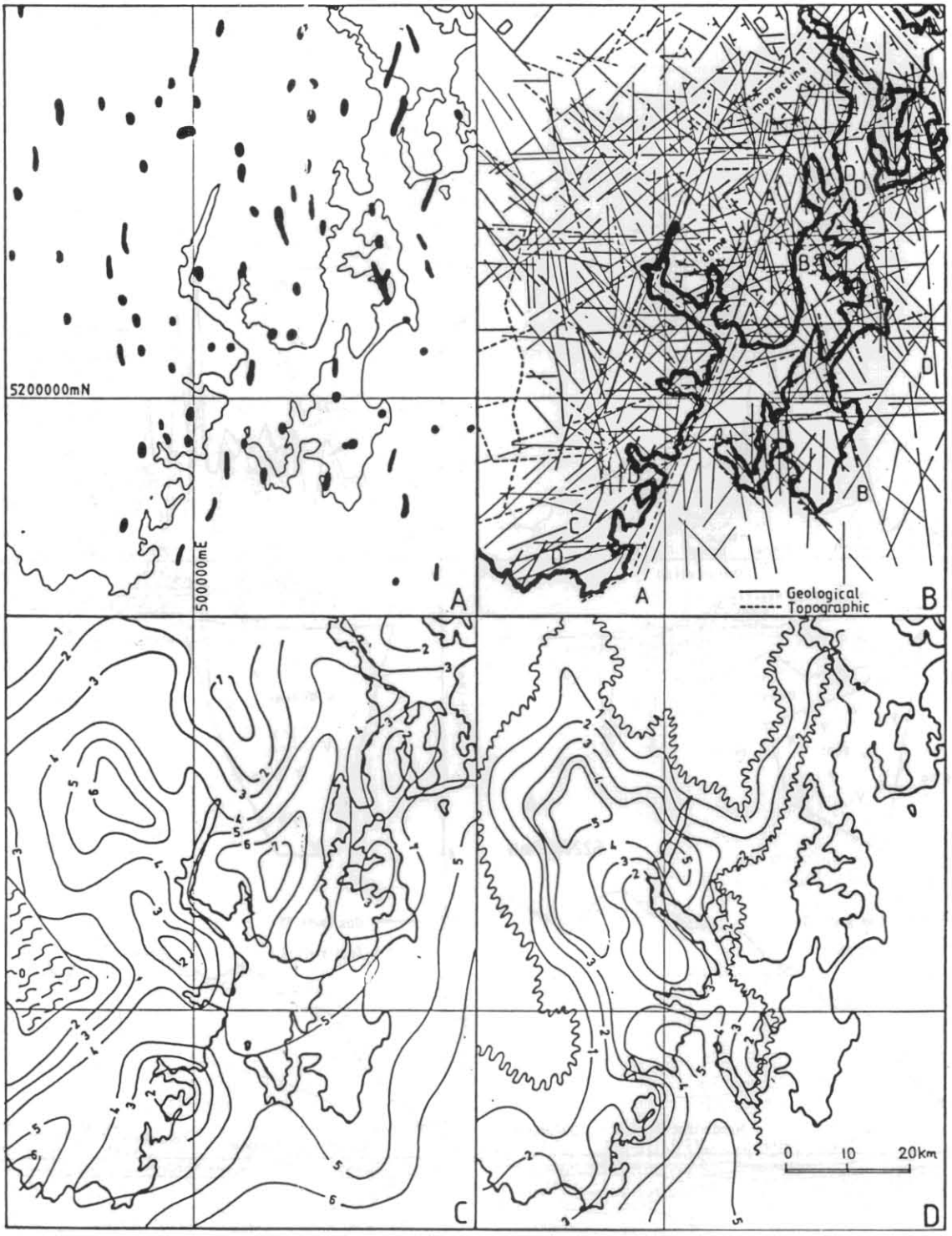


Figure 12

Summary of gravity and magnetic interpretation.

A. Jurassic dolerite feeders, location and shapes as defined by available data.
B. Compilation of all trend information (firm and broken lines represent post-Carboniferous or topographic features, fine lines represent features identified by geophysical data.
C. Combined method interpretation of depth to top of Tyennan region type Precambrian basement.
D. Interpretation of depth to base (?) Cambrian volcanic sequences (all contours in km below sea level).

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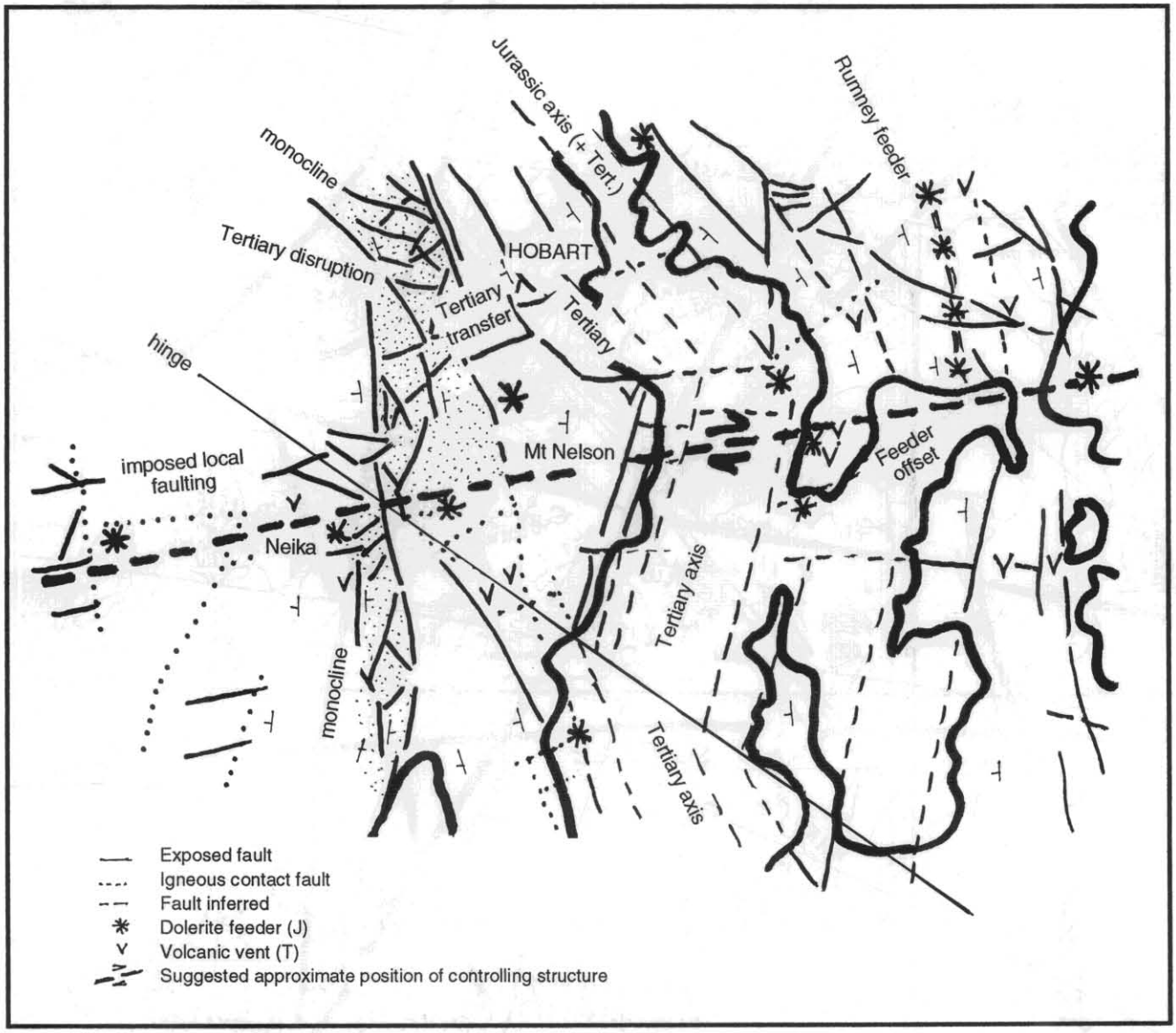


Figure 13

Possible relationships between structures observed in post-Carboniferous rocks of the Hobart area and major concealed structures. Diagram suggests one feature only. Note the trend changes, vent locations and sub-parallel sympathetic faults associated. Offset defined by monocline and eastern feeder axis (heavy dots mark matched locations). It is possible to infer both dextral and sinistral motions on different parts of the structure shown depending upon features selected. A complex history is almost certain.

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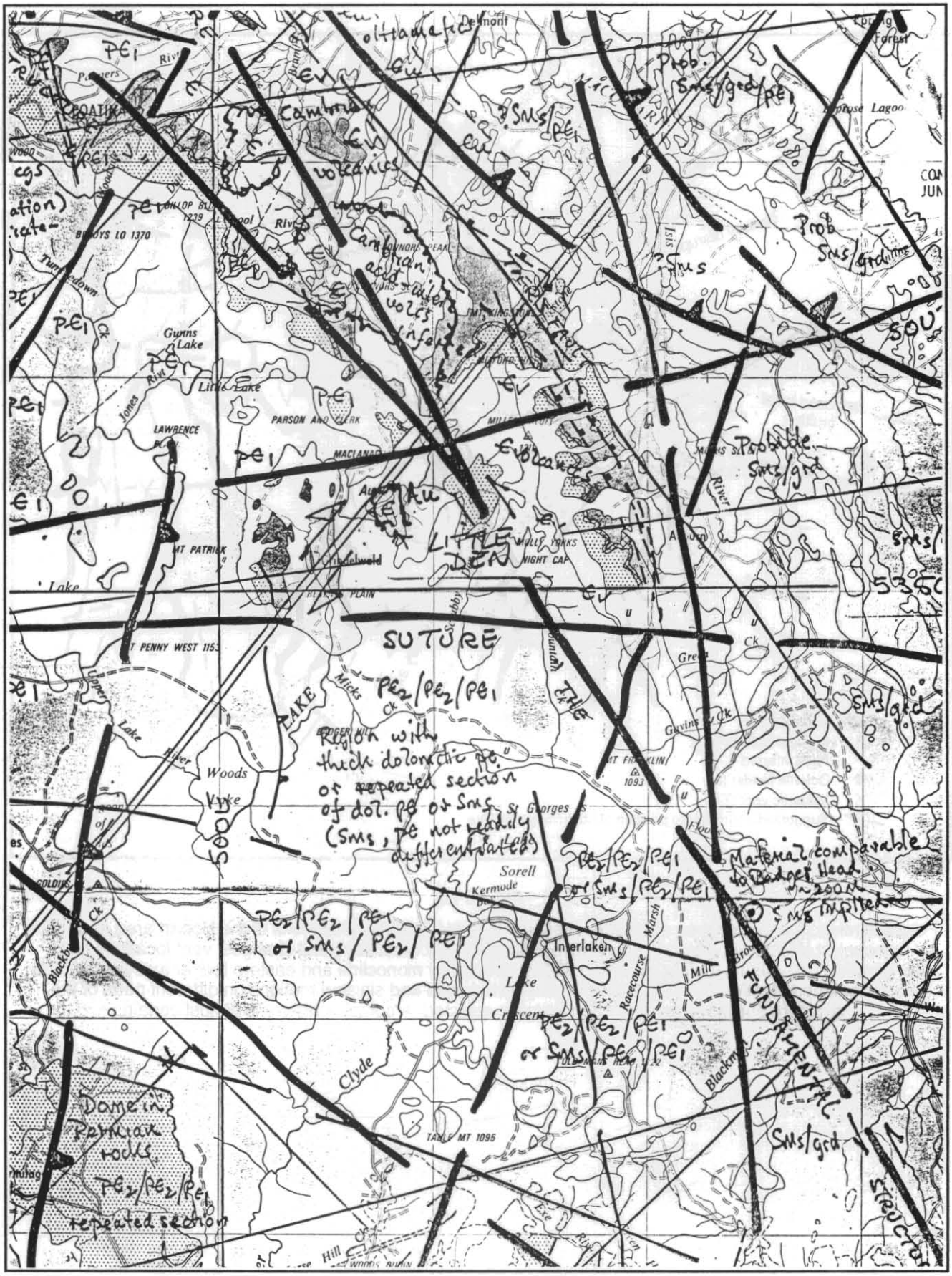


Figure 14

Little Den Goldfield area showing an elemental pre-Permian interpretation. Note the intimate relationships between these older features and both the mineralisation — and orientation of veins, and the pull apart structures toward Cressy. Note the detachment beneath the Hermitage dome in the southwest of the map and the orientation of the dolerite contacts everywhere. Young features mirror old.

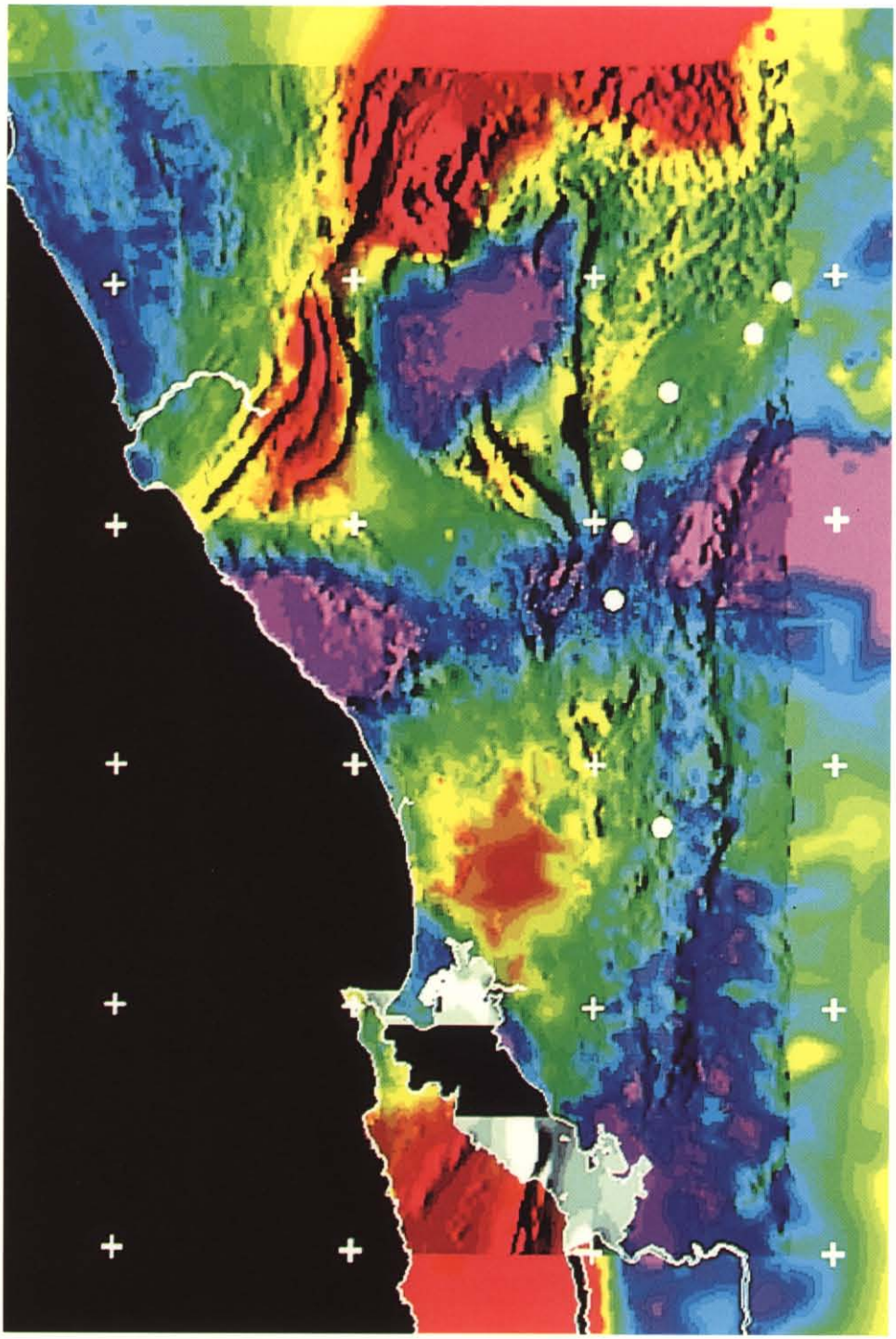


Figure 15.
(D. E. LEAMAN — *Finding Cambrian keys)*

Image showing Tasmania Department of Mines databases superimposed. Residual gravity (as in fig. 1) shown in colour (blue, low) and 1981 aeromagnetics corrected to a 250 m drape (not residuals as in fig. 4) in shadow.

Principal Cambrian mineralised sites are shown. From south to north Mt Lyell, Hercules, Rosebery, Chester, Boco, Que River and Hellyer. Note that all sites lie west of the magnetic ridge which marks the proximity of the exposed Tyennan Precambrian, but are near the main N-S gravity gradient (fig. 2). In addition, sub E-W trends can be recognised at/near each site. These trends are at about 80–85° and 280°. The first is universally observed. Small offsets (up to 4 km) of the mineralised sites, as currently known, may be due to Late Cambrian rotation and (possibly) two Devonian events which have developed flower structures and overthrust some parts of the volcanic piles. This displacement has been generally westward. Allowance for such evolution would place every site near a primary margin-transform intersection that was active during volcanism of the second rifting stage. (Image courtesy M. Roach, CODES).

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Gold exploration and the use of magnetic methods in northeast Tasmania

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ABSTRACT

A review of the physical characteristics of and available data about major gold deposits in northeastern Tasmania suggests that these deposits can be linked to particular granitoid compositions and regional and local trend patterns. Rather subdued ENE elements appear to be crucial, and large deposits occur where regional and local trends of this type are superimposed. The actual details of a mineralised site are governed by local conditions including lithology changes or fold conditions but these are not diagnostic.

Magnetic surveys, in the form of regional and specific area surveys, seem the simplest way of locating target sites in terms of these concepts and conditions, and the use of magnetic data has been critical to definition of the common characters listed. Ground surveys can limit exploration to specific prospects once the target zones are established. These methods, with support from semi-regional gravity surveys, can provide comprehensive structural, genetic and target evaluation, and achieve site discrimination in terms of potentially economic deposits.

The review study indicates that "Golden Gate"-style mineralisation may be recognisable but subtle, and that only some of the plethora of small workings possess similar characteristics. If this is indeed indicative of worthwhile prospectivity then the same techniques could be applied to blind target possibilities.

INTRODUCTION

Much gold has been recovered from many small to large workings in northeast Tasmania. Most occurrences were irregular and often thin vein systems variable in size, continuity, orientation and grade. Many occurred in a single NNW-trending zone about 500 m wide extending from near Mangana to the coast at Lyndhurst. The presence of so many sites along a single axis does not mean, however, that vein systems within or along the axis are controlled by the regional orientation; they appear to be virtually randomly oriented within it. Previous workers have assumed the regional orientation, or structure, to be ascendant but consideration of the spread of occurrences, including the significant Lisle, Lefroy and Beaconsfield workings, suggests that more than one element has controlled mineralisation. The NNW trend may be recognised widely, but never appears specific to mineralised sites.

No consistent geological or geophysical patterns have ever been recorded for Tasmania's gold deposits. Most exploration over the past century has been based on the pan or the trench, or inspection, where possible, of previous workings. The lack of obvious criteria or controls and a monotonous, repetitive host geology of Mathinna Beds has deterred science-based exploration. The rocks, and their complex deformed structures, are not easily understood. The presence of important mineralisation in this environment is simply frustrating.

Geochemical and geophysical methods are recent innovations in exploration programs. The apparent association of gold with sulphides or arsenic has encouraged many trials, but no characteristic responses have yet been proven. Anomalies also tend to be diffuse. There is also no necessary basis to the assumption that arsenic is a gold indicator. Reid (1925) observed that while there is a correlation between gold content and arsenic there is a cut off, and high arsenic/ arsenopyrite levels are usually lacking in gold.

Geophysics has been applied even more sparingly. This reflects the assumption that no useful physical contrasts exist in the relevant materials. Quartz is notoriously difficult to identify and the Mathinna Beds host rocks have also been considered homogeneous. These assumptions have long been known to be invalid but the province has never attracted the innovation required to apply workable exploration technologies. Leaman (1974), in the pioneering geophysical research on these rocks at Lefroy, showed that self potential, thermal and piezoelectric methods can define the quartz systems (but not say whether they are mineralised) and that magnetic methods yielded some curious results only recently explained. Most of these methods are not in the "in general use" category and have not been taken up.

Genetic relationships have also been a long-standing puzzle. Workers such as Klominsky and Groves (1970) have recognised the affinity of the gold with biotite hornblende granodiorite and implied a direct genetic relationship. While this association seems reasonable in some localities it has always been generally rejected, as the important Mathinna, Mangana, Lefroy and Beaconsfield sites appear far removed from granitoids of any type. This is another fallacy. Workers since 1973 have ignored the findings of Leaman *et al.* (1973) who suggested that granodiorite is less than 1.5 km beneath the mineralisation at Lefroy.

Regional mappers in northeast Tasmania have attempted detailed subdivision of the granite and adamellite families of the two major batholiths (Scottsdale and Blue Tier) but have

LEAMAN, D. E. 1992. Gold exploration and the use of magnetic methods in northeast Tasmania. *Bull. geol. Surv. Tasm.* 70:149–160.

2/12

placed all granodiorites into a single class. Textural and magnetic property differences suggest that this should not be done (Leaman, 1992*a*). It should not, therefore, be accepted either that granodiorites are not associated with gold because they are nowhere to be seen or because there seems no reliable relationship with them. The latter condition ignores the possibility of a single family member forming the key source and control upon mineralisation.

Vein orientations and local structures in the Mathinna Beds hosts have also be found to be variable where recorded. Local controls appear dominant, even where major regional control would be expected — as along the Mathinna to Alberton zone. Vein patterns do not appear to be systematic or significant. These problems are compounded by poor outcrop generally, deep weathering in some units, and a complex, several-generation vein suite.

Grades and vein extent also remain a crucial problem for any evaluation. A very few mines have provided significant production; most workings have been marginal or limited in development. This usually reflects variation in grade with depth, but may indicate under capitalisation, which was endemic when the region was in full production. Major reductions in grade, often of an order of magnitude, have been noted near the level of regional weathering or water tables. Only some sites maintain grade levels to significant depths (>50 m) and it is these rare sites, such as the Golden Gate at Mathinna or the Tasmania at Beaconsfield, which have produced large quantities of gold. It is clear therefore that some form of discriminator must be found which can separate the golden eggs from the chaff, as all may look the same near the surface. Presuming they outcrop of course...

EXPLORATION NEEDS

A principal aim of any exploration is to assess and define the identifying characteristics of such important sites and determine their presence elsewhere. This approach then allows ranking or discrimination of the many known small workings or new target prospects. In this respect the Mathinna area, and the Golden Gate Mine with its production of 7895 kg, must be used as the prototypical yardstick until a greater understanding is achieved for the entire province. It represents a large vein system in typical host materials. Alluvial deposits, such as Lisle, are excluded from this discussion.

Some indication of the current understanding and knowledge about this important, and once highly productive, gold province can be obtained by considering the magnitude of published descriptions. The topic has rated a half page or less than two pages respectively in the 1962 and 1989 editions of the 'Geology of Tasmania'.

Let us consider what an explorer may need to know or what may be essential to site definition.

Systematic exploration is usually based on some conception of general or genetic setting. In this case an ability to define host structures or units (basic detailed mapping not possible from outcrops) as well as vein location and orientations, coupled with the facility to discriminate mineralised from unmineralised terrain, is required.

Any method able to achieve target focus or discrimination in the apparently bland, poorly exposed, vein-rich terrain of the Mathinna Beds would be rightly considered a sound right arm. If it was applicable at all scales and low cost as well; perhaps a saviour...

Such a method exists.

Magnetic methods are able to provide information in respect of all regional-to-focus requirements. Leaman (1992*a*) has recorded a twenty year research and specification history, initially considering common as well as exotic geophysical methods with structural bias, to support this claim. This paper considers only examples and conclusions based on that research.

A more fundamental issue relates to the worthiness of the region in the first place. The region has been a producer of some note but does it have the potential to be a great producer? Leaman (1992*b*) shows that the basic setting of northeast Tasmania is comparable with other very rich provinces, and that the gold was possibly derived from large Cambrian ultramafic bodies during the Devonian uplift–intrusion cycle. This under-rated region is worth some effort.

DISCUSSION

Mineralised sites at Mathinna, Mangana, Dans Rivulet, Golden Ridge, Alberton, Mt Horror, Warrentinna, Lyndhurst, Gladstone, Burns Creek, Lisle, Golconda, Lefroy, Back Creek, The Glen, Beaconsfield and Little Den (fig. 1) have been assessed for regional context and common denominators.

Few of these sites are well served by any type of data set. Only a few have been covered by any aerial magnetic data and fewer by adequate ground survey. Most are covered by a regional gravity survey but the station density is uneven and generally coarse.

The figures provide an indication of the best data available and of some of the conclusions which may be drawn.

Figures 2 and 8 illustrate how high quality aeromagnetic surveys can define formation scale, continuity and lithological variations, as well as structural offsets, within the almost non-magnetic Mathinna Beds. This is prized information given the difficulties of mapping these rocks. See Leaman (1987*b*, 1990, 1992*a*) and Richardson (1992) for some indication of the specification required.

Figure 3 provides an example of an older survey using poorer specifications. It is still most informative and draws attention to the primary variations in the units of the Lisle region. Structure can be mapped across at least part of the area and it is not wholly consistent with published regional mapping. Many other elements are exposed by such surveys. Several of the surveys cover blocks of granodiorite, and demonstrate that these intrusive rocks present a range of properties and relationships. Some are strongly magnetic. See also Leaman (1992*a*).

These examples prove that the magnetic method can define most of the structural and stratigraphic elements of northeast Tasmania.

Figures 6 and 7 illustrate the nature of magnetic responses due to the presence of granodiorite and the type of inferences which may be drawn. Figure 6 shows that granodiorite lies both east and west of Mathinna — as well as beneath it. This crude model does not discriminate compositions or true

thicknesses. Figure 7 suggests that several granodiorite members are present in the Lisle–Golconda area but that only one is associated with the known gold deposits. The properties of this intrusive are almost identical with those inferred in the vicinity of Golden Ridge, Mathinna, Lyndhurst and Gladstone. This correlation, wherever data is available, seems more than coincidence.

Gravity data, or nearby exposure, at other sites indicates that granodiorites are a genetic element in these gold deposits, including Beaconsfield. These intrusives are now remnants of the original plutons because of diapiric intrusion and dilation by later granite-adamellites. The critical composition, marked by its physical properties, appears to be the first intruded on the basis of rock relationships. Any genetic relationship may be in terms of fluid generation, transfer and fracture control, rather than any compositional control.

Thus magnetic methods may have assisted (with gravity methods) creation of a genetic model. Regional exploration may need to consider the location of particular members of the granodiorite family.

Figures 4 and 5 provide examples of the use of medium resolution ground surveys to trace vein system orientation (Gladstone) or define anomalous, possible altered or mineralised, zones (Tower Hill). Veins produce spikes due to oxidation and alteration in the wall rock. Each vein produces a double spike which is usually integrated as a single feature. Background variations with spike responses appear to mark mineralised areas. Very high resolution ground surveys have shown that such areas are very limited and, where previously worked, very productive. Vein alteration trends in such zones always curl asymptotically to sub E-W trends, even though more obvious structures may trend NNE or NNW. This curl of trends would explain the common observation of E-W trends at many sites while veins in the surrounding hosts display scattered orientations. Primary stress controls at the time of emplacement seem to be reflected by these observations but many more sites need to be examined using very detailed surveys.

Figure 8 stresses the need for very high quality data if all the required information is to be recovered. The contour interval is 0.5 nT. The left plot provides a basic compilation of the data while the right plot draws attention to some very subtle ENE trends. Initial analysis (Leaman, 1990) overlooked these, including failure to view appropriately shaded sun images, and they were only recognised after consideration of common factors seen in other data and other sites.

Other factors reviewed included suggestions from gravity data, vein information and drainage patterns. The trend is apparently general at prime sites and must be sought. Its poor representation in this data set is due to a 3:1 line bias in favour of E-W lines even though the line spacing is about 100–150 metres. This line bias must be changed for future surveys.

The examples shown in Figures 2 and 8 demonstrate that magnetic data can also define structures of some subtlety but regional persistence. Mineralised sites (or zones) are positively discriminated.

SUMMATION

The observations noted in the above discussion may be condensed into five factors.

1. A granodiorite association is definite at many sites and can be inferred (within 1.5 km) at others (including perhaps Little Den and Beaconsfield). A genetic link is implied — if only in terms of heat engine, circulation and fracture association with primary plutons.

2. The key granodiorite lithology forms part of a primary intrusion, and possesses low density and susceptibility properties.

3. The quartz veins occupy fracture fills in the roof of this body, and the essential deformations predated or were contemporaneous with the intrusion. Subsequent venation and disruption reflect the disturbance associated with intrusion of the batholith series.

4. Mineralised sites are complex but mappable units and clear disruptions of the units are not necessary elements in the process controlling venation or mineralisation. While vein systems may be locally controlled by shallow features, the fundamental controls are exercised regionally or from depth. Thus a range of vein orientations is to be expected at mineralised sites. Particular sites may occur in fold limbs, axes or ductility differences in the host sequence. These are random elements.

5. Sites appear to occur at nodes along ENE or E-W trending features and intersections. Large deposits occur where local features of this trend are superimposed on regional elements. These are the non random elements.

Thus magnetic methods, although dismissed because "nothing is magnetic" and no adequate data were acquired until 1987, are able to provide critical targetting or discriminating focus in terms of all exploration needs at all scales.

All companies generating the data used here have never had, or taken, the opportunity to utilise it in the manner suggested because of financial collapse or withdrawal from tenements. It is time that the approach suggested here was properly tested on new targets.

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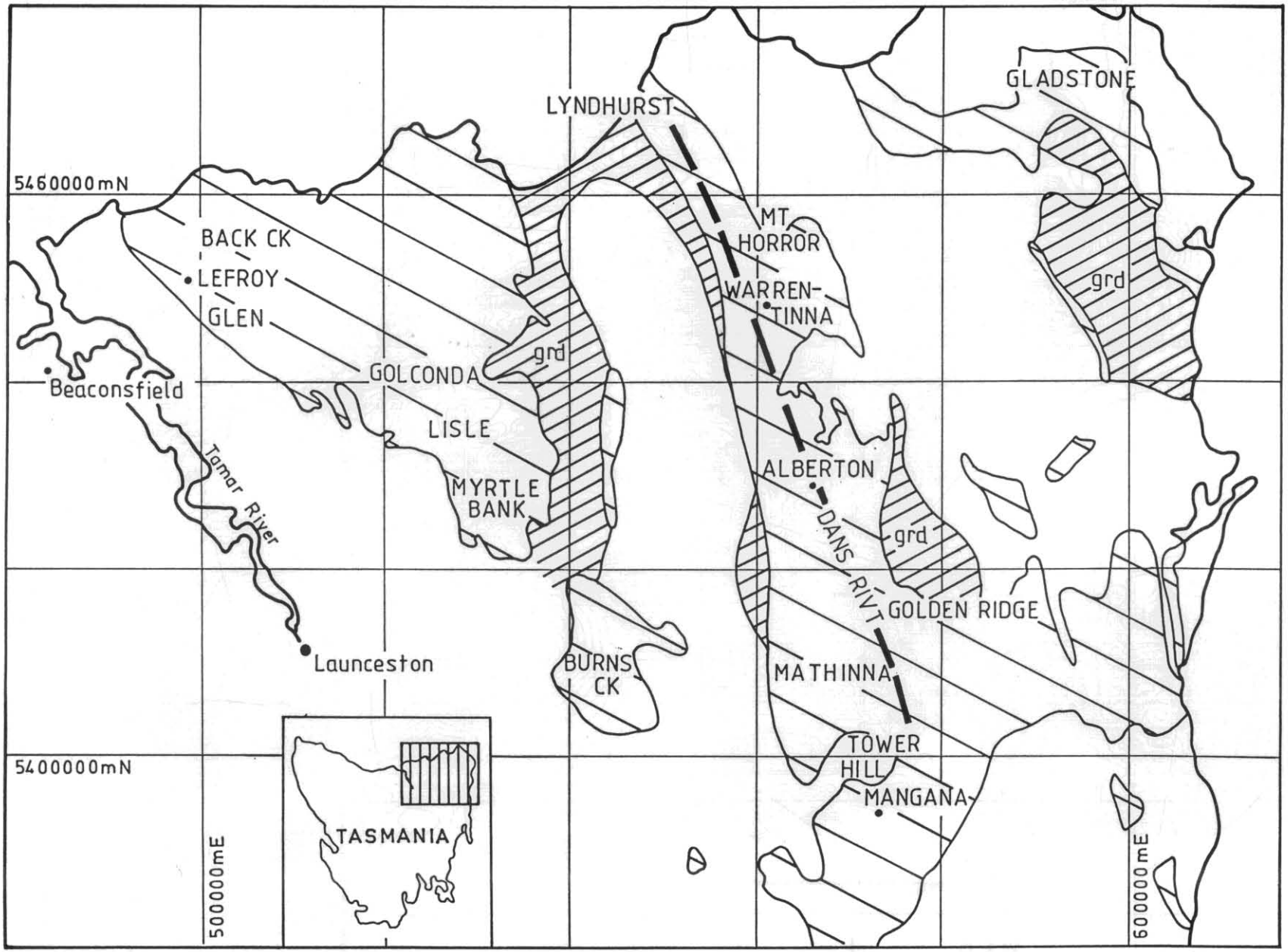


Figure 1. Locality map showing principal goldfields. Mathinna Beds are shown by open diagonal pattern and generic granodiorite in dense pattern.

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6/12

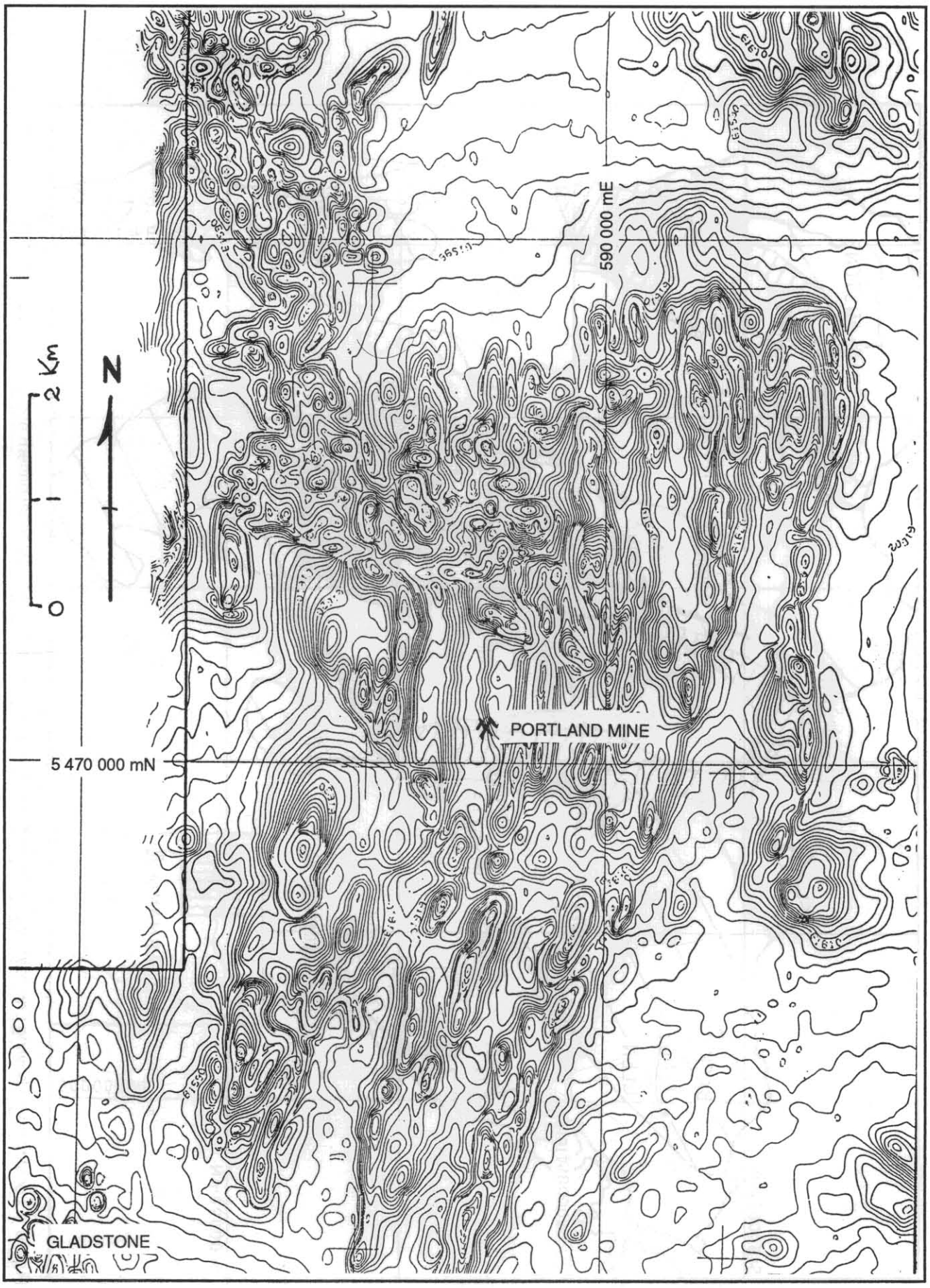


Figure 2

Part of the aeromagnetic survey of the Gladstone area (Leaman, 1987*b*). Note the texture within the block of Mathinna Beds about the mine. Very subtle and poorly defined sub E-W trends can be recognised in the data.

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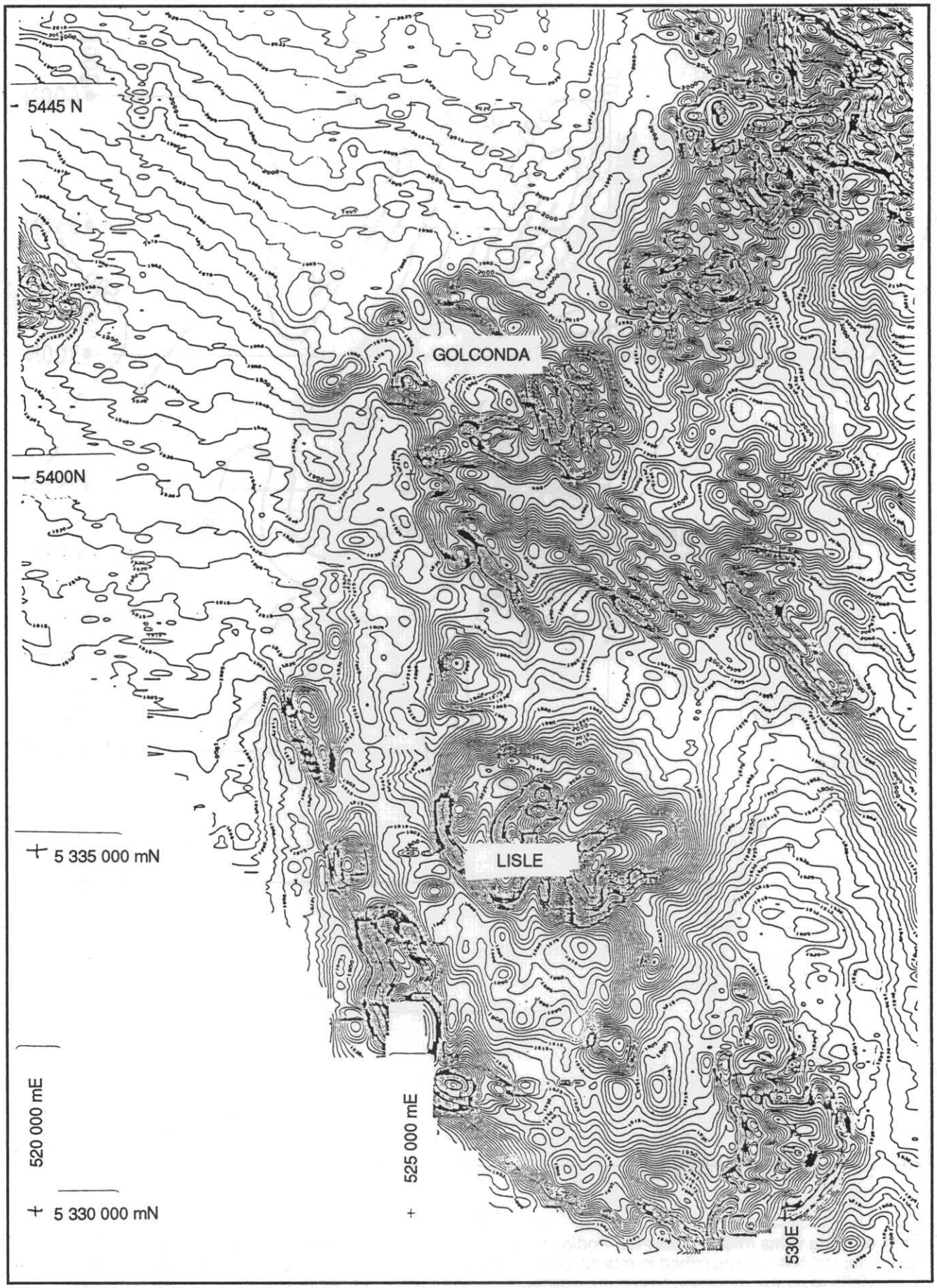


Figure 3

Most of an older aeromagnetic survey in the Lisle–Golconda area. Mathinna Beds responses and the effect of granodiorite and thermal haloes produces an array of patterns. An interpretation of this data is shown in Figure 7.

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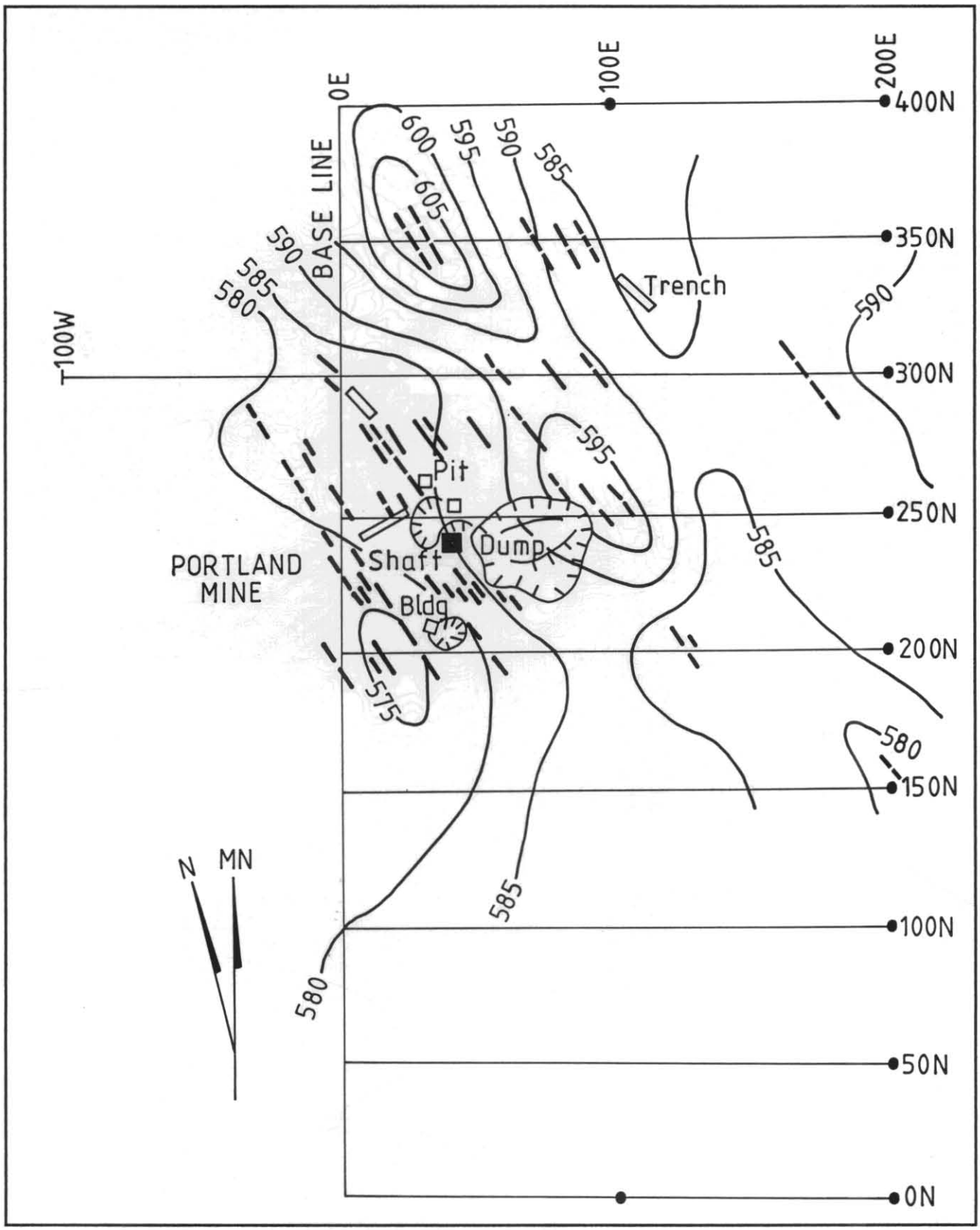


Figure 4

Plan showing veins mapped near the Portland Mine by ground magnetics (Leaman, 1987*a*). Although the veins are oriented NW, as described in reports during mining, all occur in or near a 200 m corridor oriented ENE as defined by the magnetic field more regionally. Gross lithological effects are also oriented NW-NNW.

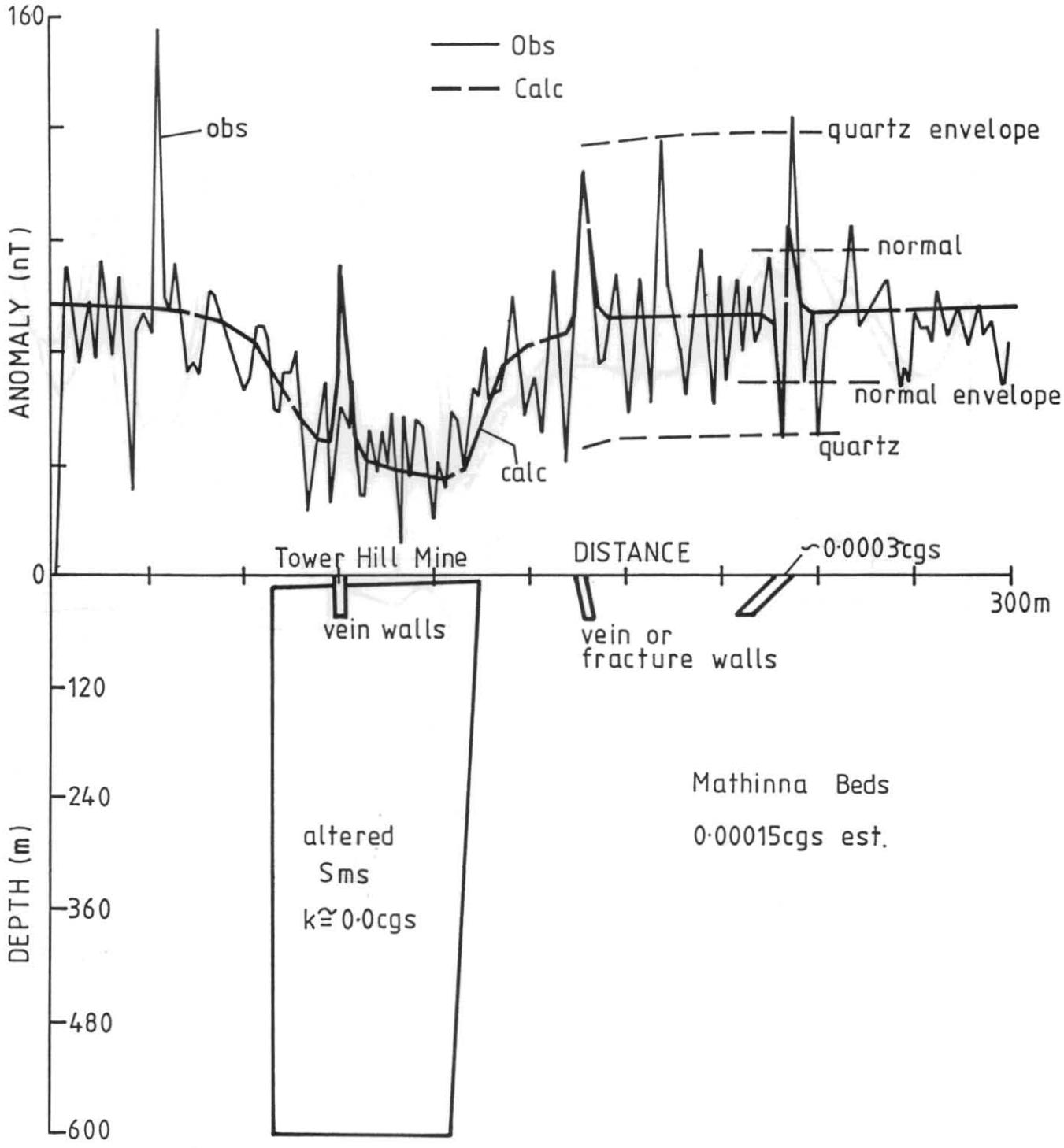


Figure 5

Example of results of ground survey near the Tower Hill Mine (Leaman, 1989). Spikes reflect shallow veins while the broad dip in field intensity reflects local host changes about the mine. Spikes are due to property changes of up to three orders of magnitude in the vein walls. Spikes can be mapped by detailed survey.

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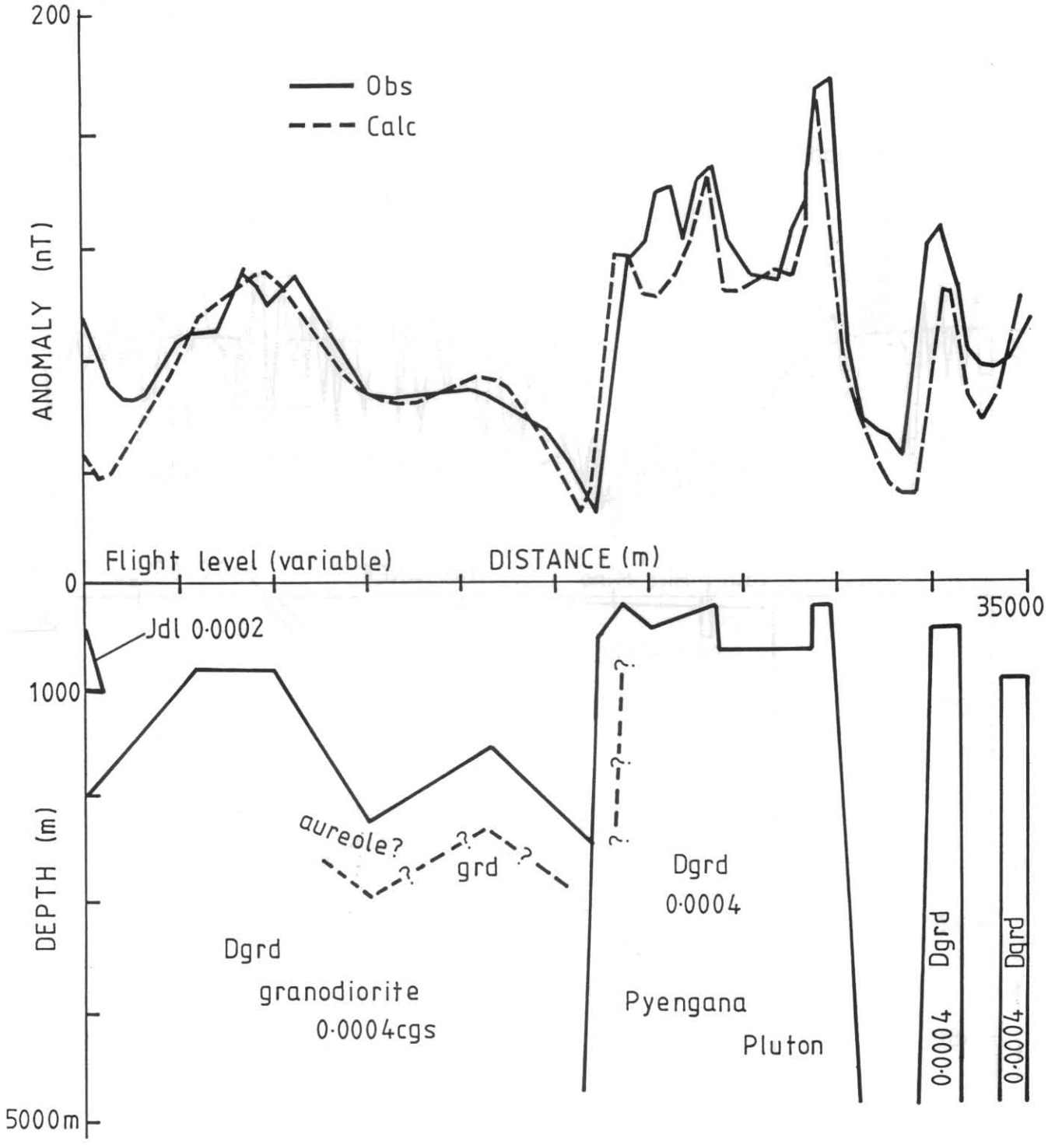
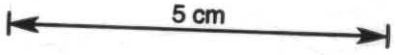


Figure 6

Section across the South Esk Valley near Mathinna showing continuity of granodiorite between exposures to the west and east (Richardson, 1989). This early interpretation makes no allowance for possible variations in granodiorite properties or limited volumes of material after subsequent granite intrusion deep in the section. The implication is general, however, much as inferred by Leaman *et al.* (1973).



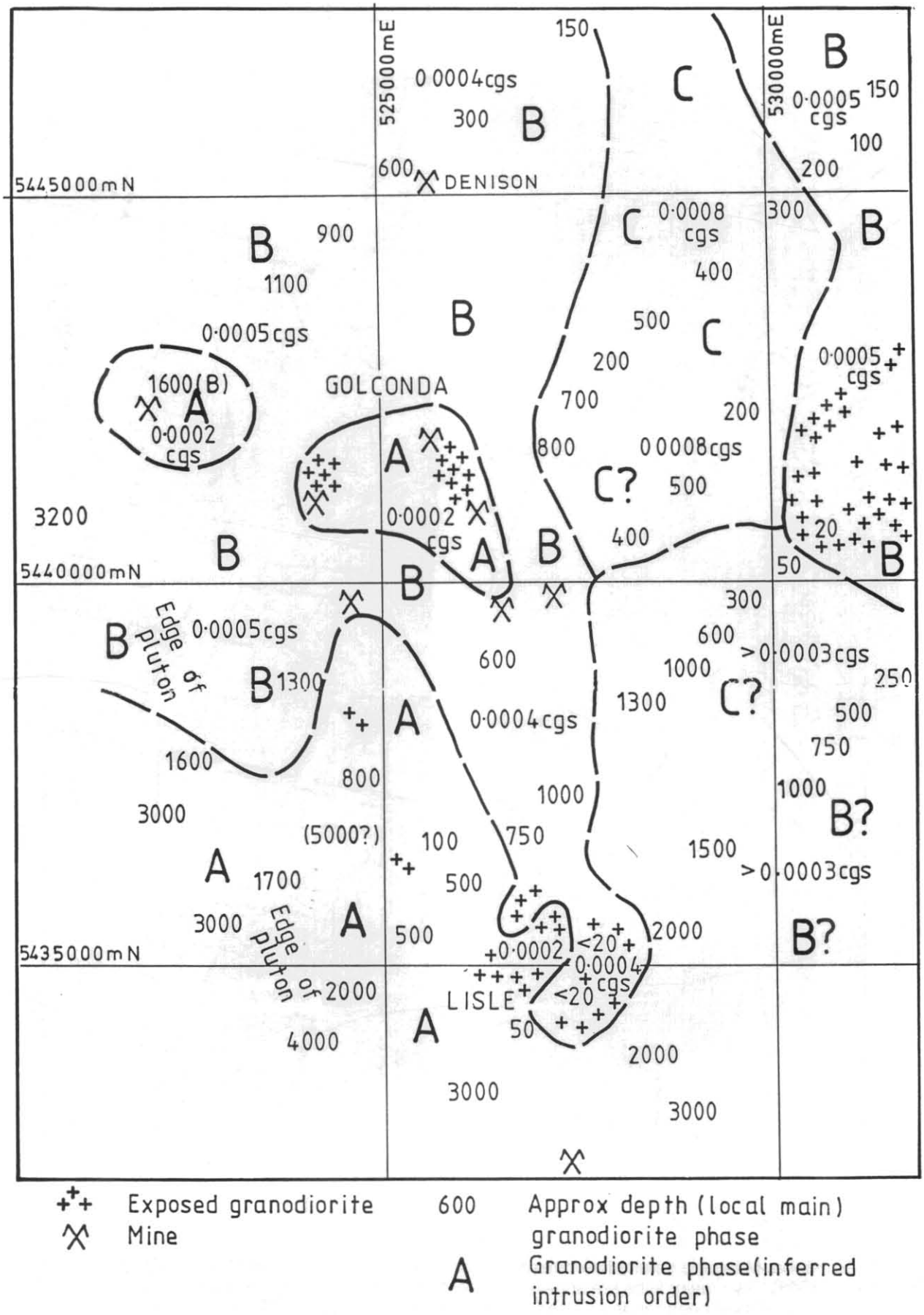


Figure 7

An interpretation of the possible distribution of granodiorite types in the Lisle–Golconda area. These plutons intrude each other in the inferred order and have largely escaped subsequent dilation and intrusion by later granitoids of the Scottsdale Batholith. The alluvial gold at Lisle is concentrated in a valley trap where erosion has worked the roof of body A and its metamorphic halo in the country rocks.

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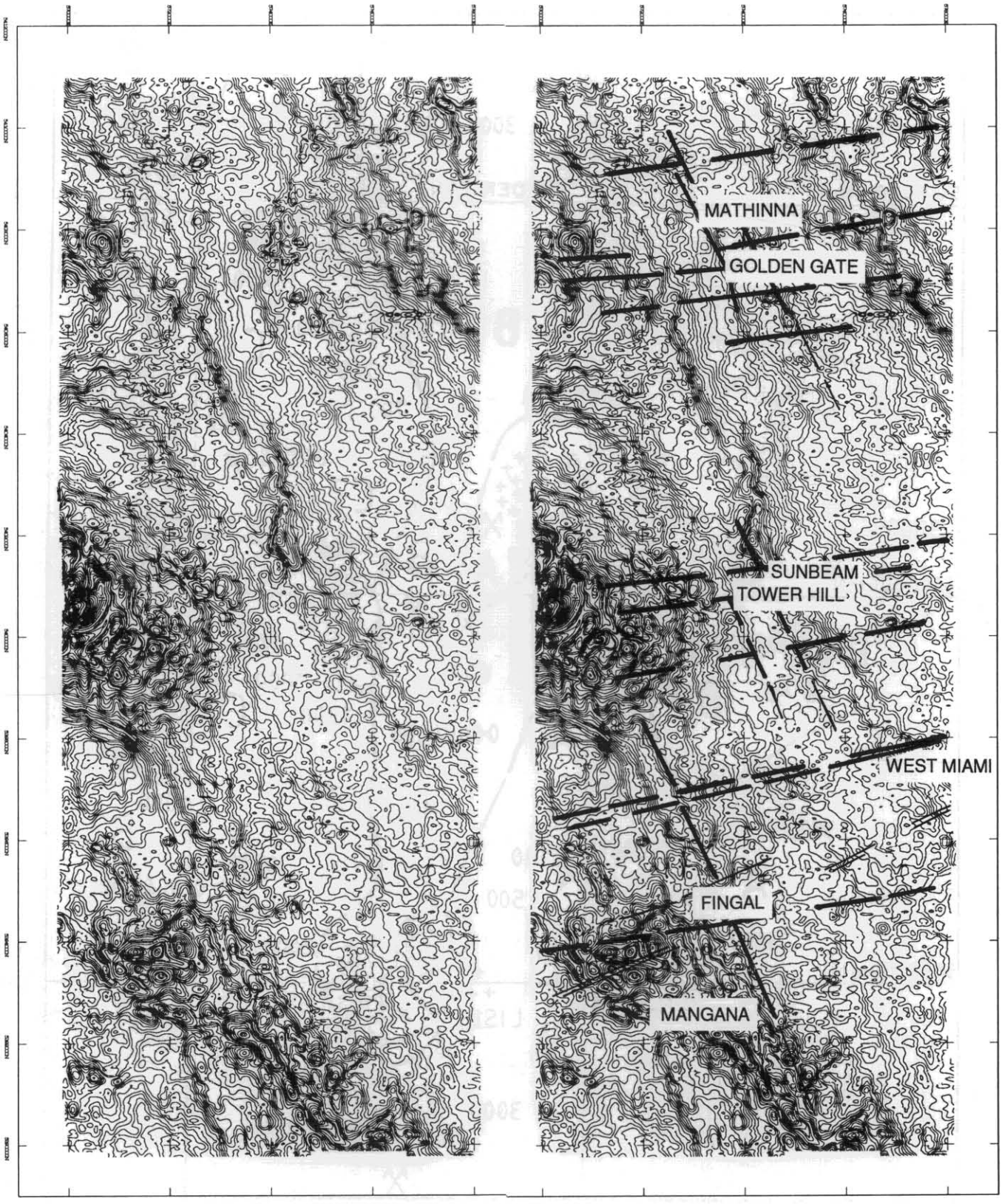


Figure 8

The Mathinna–Mangana detailed aeromagnetic survey with contour interval of 0.5 nT (Leaman, 1990; Richardson, 1992). Two major sites are shown and attention is drawn to some of the more subtle trends in this data. These trends have been rendered poorly because of an unfortunate E-W line bias. More obvious trends are related to lithological changes in the Mathinna Beds.

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Mount Read Volcanics: Host sequence to Cambrian massive sulphide deposits in western Tasmania

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INTRODUCTION

The Mount Read Volcanics of western Tasmania is famous worldwide for the abundance and richness of deposits of massive sulphides that they contain. Hellyer, Rosebery, Mount Lyell, Hercules and Que River all win ore from within the volcanics (fig. 1). Sea-floor volcanic-hosted massive sulphide (VHMS) mineralisation involves processes that partly depend on and affect the enclosing, contemporaneous host sequence. Therefore, understanding the genesis of known ore bodies, and successful exploration for new deposits, rely on a clear definition of the setting and character of the host volcanic rocks.

Although generally recognised as highly prospective for VHMS mineralisation, the Mount Read Volcanics present a formidable challenge in this regard. The volcanics have been affected by regional deformation and metamorphism, and locally hydrothermal alteration is intense. Useful exposures of the volcanics are very limited in extent and unevenly distributed, and some areas are enormously difficult to access. All these factors make geological mapping, the first step in exploration, a particularly difficult task.

In spite of the difficulties, a number of recent developments have paved the way for further major advances in understanding the Mount Read Volcanics. In particular, high-quality 1:25 000 scale geological maps which use consistent stratigraphic nomenclature are now available for the full extent of the volcanics. The maps are the outcome of systematic regional mapping by geologists of the Tasmania Department of Mines (Corbett, 1992), and provide a comprehensive database upon which other research projects can build. Secondly, progress in understanding the processes and products of sea-floor felsic volcanism has greatly accelerated in recent times. Deep-ocean volcanic environments are now accessible to direct observation by means of deep tow cameras, SEAMARC and GLORIA sonar technology, submersibles, and drilling. Field studies of submarine volcanic sequences that are now well-exposed on land are currently in vogue in physical volcanology. A particularly important recent discovery is the frequent occurrence of syn-sedimentary sills in deep-ocean extensional settings, and their potential to initiate and sustain hydrothermal circulation in unconsolidated host sediments (Einsele *et al.*, 1980; Einsele, 1986; ODP Leg 139, 1992). Finally, detailed research into the textural and mineralogical effects of hydrothermal alteration on volcanic host rocks to massive sulphide deposits suggest the power of alteration facies mapping as a tool in exploration. This paper briefly reviews recent achievements in these areas, and their implications for mineral exploration in the Mount Read Volcanics.

REGIONAL LITHOSTRATIGRAPHY IN THE MOUNT READ VOLCANICS

Systematic 1:25 000 scale regional mapping has led to the recognition of four main lithostratigraphic units (fig. 1; Corbett, 1992; Crawford *et al.*, 1992):

(i) the Central Volcanic Complex is dominated by feldspar-phyric rhyolitic lavas and very thick, pumiceous volcaniclastic units;

(ii) the Eastern quartz-phyric sequence comprises quartz and feldspar-bearing lavas, intrusions and volcaniclastic units;

(iii) the Western volcano-sedimentary sequences include packages dominated by well-bedded, volcaniclastic and Precambrian basement-derived sandstone and conglomerate which in places contain Cambrian marine fossils. There are three geographically-defined packages: the Yolande River sequence, the Dundas Group and the Mount Charter Group. The Yolande River sequence and the Mount Charter Group both locally contain significant thicknesses of andesitic and dacitic lavas and intrusions;

(iv) the Tyndall Group consists of quartz-bearing volcaniclastic units, minor rhyolitic lava, minor welded ignimbrite, and non-volcanic sandstone and mudstone.

Regional mapping has also established the importance of major faults, such as the Henty Fault and Rosebery Fault, and provides an invaluable framework for further detailed structural studies.

PHYSICAL VOLCANOLOGY OF THE MOUNT READ VOLCANICS

One of the most significant recent breakthroughs in understanding volcanic sequences has been the recognition of the control exerted by emplacement or depositional processes on facies geometry. Volcanic sequences typically contain the products of both effusive and explosive eruption styles. Each style has the potential to generate a variety of volcanic facies with markedly different internal textures, structures, geometry and extent. For example, extrusion of felsic lava onto the sea floor is normally accompanied by (fig. 2):

(1) genesis of autoclastic facies (especially quench-fragmented hyaloclastite);

McPHIE, J.; GEMMELL, J. B. 1992. Mount Read Volcanics: Host sequence to Cambrian massive sulphide deposits in western Tasmania. *Bull. geol. Surv. Tasm.* 70:161–166.

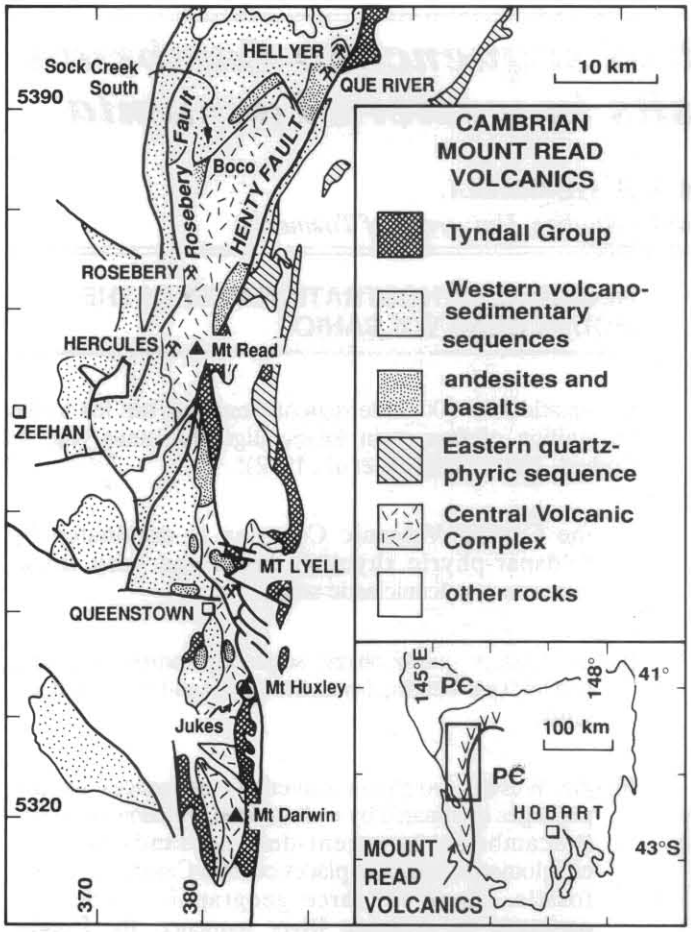


Figure 1

Distribution of the principal lithostratigraphic formations and major massive sulphide deposits in the Cambrian Mount Read Volcanics of western Tasmania (based on Corbett, 1992)

(2) complex mixing between the wet, poorly-consolidated sediment substrate and lava (producing peperite);

(3) resedimentation processes primarily derived from the growing autoclastic pile (resedimented hyaloclastite); and

(4) intrusion of magma pods and lodes into the lava pile.

Contemporaneous volcanic facies equivalents will be texturally diverse (fig. 2*b*), and correct correlation depends on recognition of genetically-related volcanic facies associations.

Submarine volcanic sequences also contain units which are laterally juxtaposed but which are not genetically related. For example, felsic lava domes are constructional and create topography which may be later infilled by pumiceous mass-flow deposits from an extrabasinal source (fig. 3). Correlation of drill-hole sections which include coherent lavas and mass-flow emplaced volcaniclastic units should consider such a facies relationship, among other possibilities.

Research using this approach has clarified the principal volcanic facies and facies architecture of the Mount Read Volcanics (fig. 4; McPhie and Allen, 1992):

(i) normal background sedimentation is recorded by pelagic mudstone and turbidite sandstone of mixed or Precambrian metamorphic basement provenance;

(ii) background sedimentation was episodically interrupted by emplacement of lavas and volcaniclastic mass-flow deposits;

(iii) lavas and related autoclastic deposits (autobreccia, hyaloclastite breccia, and re-deposited equivalents) occur separately or in clusters within more extensive volcano-sedimentary sequences;

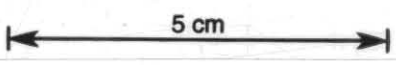
(iv) in many cases, rising magma that encountered unconsolidated, relatively low density, water-saturated sediment remained embedded below the surface and/or mixed extensively with the host sediment; surface flows commonly foundered into the weak sediment substrate and advanced as shallow sills; and

(v) mass flows which deposited widespread pumiceous and/or crystal-rich sandstone-breccia units included some cases which correlated directly with explosive eruptions and other cases which were the results of resedimentation after temporary storage.

The volcanic facies in this architecture may include the products of both intrabasinal and basin margin or extrabasinal eruptions. Silicic lava and lava breccia sequences are likely to be from intrabasinal sources. Sources of extensive and voluminous pumiceous volcaniclastic mass-flow deposits are less easily constrained. The implied explosive eruption style is likely to have been restricted to volcanic centres in parts of the basin that were shallower than about 1000 m, or else in basin margin or nearby subaerial settings. The mass-flow packages generated from large explosive eruptions are likely to be widely distributed, rapidly emplaced, and readily distinguishable from enclosing facies. They therefore provide very good stratigraphic markers.

The relevance of understanding emplacement processes to mineral exploration in the Mount Read Volcanics was recently highlighted by the discovery of clasts of massive sulphide in volcanic breccia exposed by Hydro-Electric Commission excavations of the Newton Dam spillway (Gibson, 1991). The breccia contains a wealth of information on the source of the sulphide clasts, transportation and depositional processes, and setting. The clast assemblage reflects a dacite lava-dominated source. Some dacite clasts and clast clusters show jigsaw-fit texture, suggesting *in situ* dilation of prepared quench fractures. The breccia forms the basal part of a single sedimentation unit and is overlain sharply by diffusely bedded, crystal-rich sandstone that forms the top of the unit. This lithofacies organisation indicates deposition from a high-density, subaqueous, gravelly-sandy, volcaniclastic turbidity current in a below-wave-base environment (cf. Lowe, 1982). The unit may record collapse of an unstable part of an active dacite lava dome, on the flanks of which was a substantial massive sulphide deposit. The location of the source of the sulphide clasts cannot be determined from the exposure and remains a tantalising mystery.

Facies analysis reveals that the sea-floor hydrothermal systems responsible for the massive sulphide mineralisation in the Mount Read Volcanics operated in a variety of volcanic hosts and settings. In particular, the volcanic facies associations that dominate the Western volcano-sedimentary



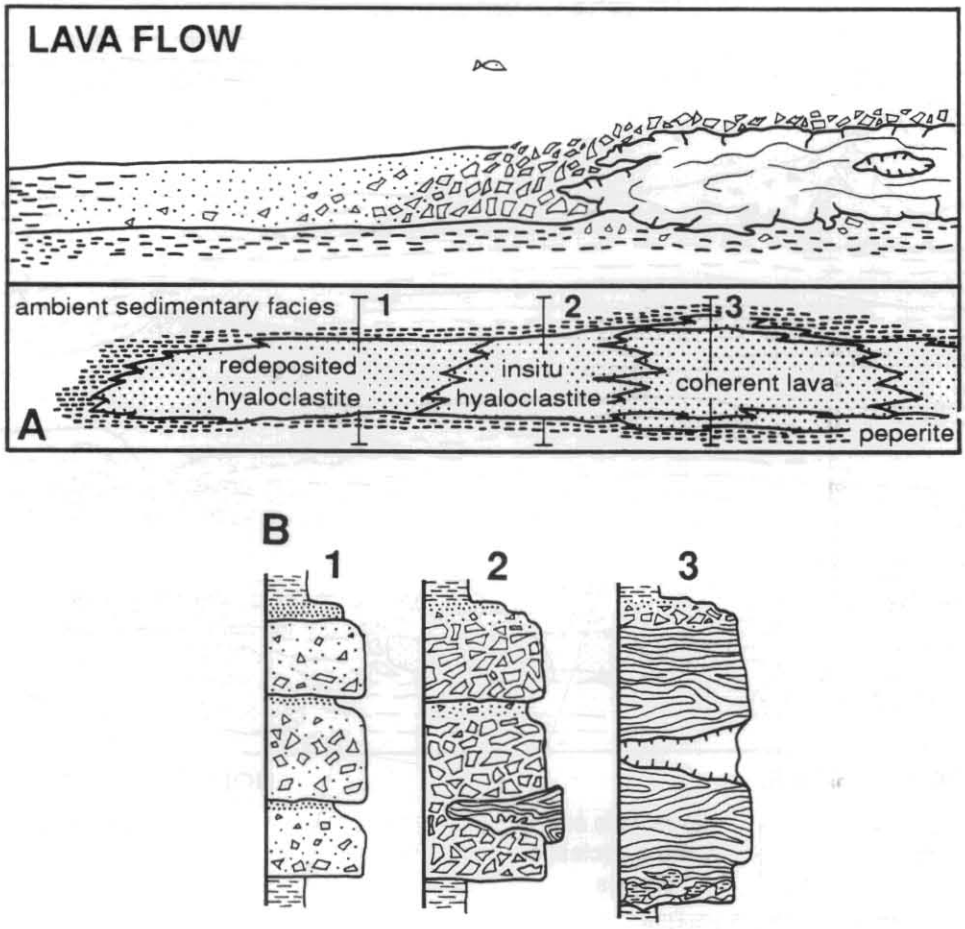


Figure 2

Character and arrangement of facies that develop in association with the emplacement of a felsic lava flow on the sea floor.
(a) The ideal genetically-related and contemporaneous volcanic facies association.
(b) Drill hole sections at different positions (1, 2, 3) in the ideal volcanic facies association.

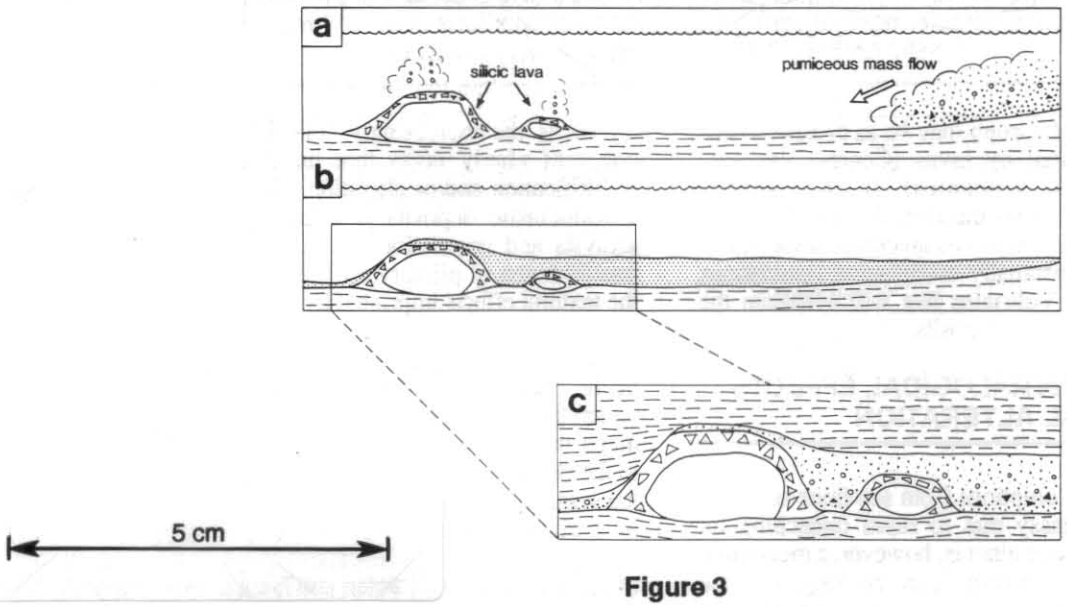


Figure 3

Sketches illustrating a case of contemporaneous, laterally equivalent volcanic facies that are not genetically related. (a) A freshly emplaced silicic lava dome and breccia carapace has constructed considerable sea-floor topography. Pumiceous mass flows sourced elsewhere sweep into the basin. Such mass flows are sediment gravity flows that in general are constrained to flow downslope. Some may be generated directly by eruptions or else result from resedimentation of volcaniclastic debris after temporary storage. (b) The mass flows deposit a widespread, relatively thin volcaniclastic layer that fills in the topography created by the lava dome and breccia. (c) Final facies geometry in detail: the background sedimentary facies encloses two genetically distinct volcanic facies that are directly juxtaposed and that were emplaced essentially contemporaneously.

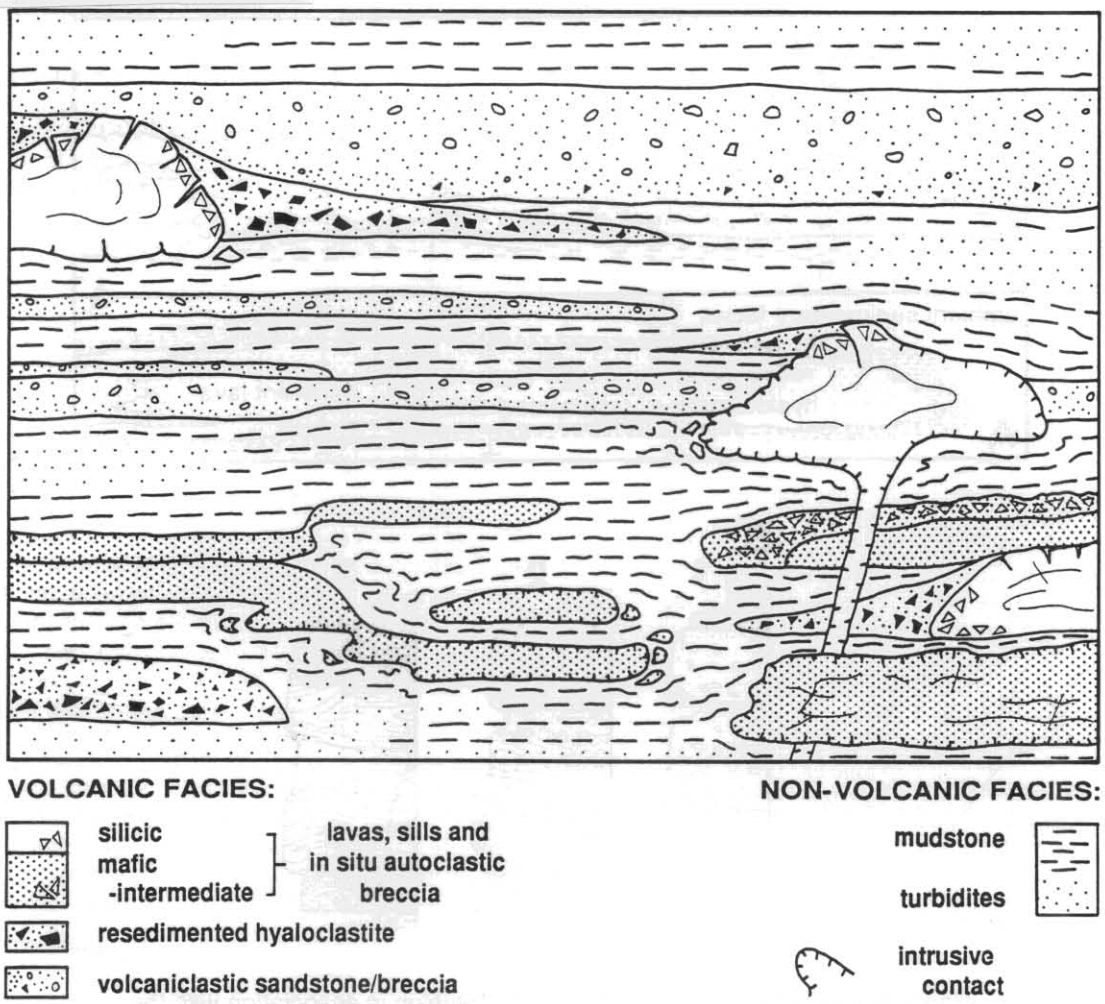


Figure 4

Principal elements in the facies architecture of the Mount Read Volcanics, western Tasmania. Sills are at least as important as surface flows. Volcaniclastic mass-flow deposits include resedimented hyaloclastite from intrabasinal lava flows and domes, and thick tabular units of pumice breccia that provide good markers for correlation. There are considerable regional variations in relative proportions of lava flows, sills and volcaniclastic units, and in volcanic versus non-volcanic facies.

sequences and the Tyndall Group may be as prospective as the formations dominated by lavas (Central Volcanic Complex, Que–Hellyer Volcanics). In fact, such a volcaniclastic association hosts the Hercules and Rosebery massive sulphide deposits. These volcaniclastic associations also offer a means of eventually establishing correlations within the Mount Read Volcanics that will constrain the relative ages of the known ore deposits.

TEXTURAL AND MINERALOGICAL EFFECTS OF HYDROTHERMAL ALTERATION

The products of volcanic eruptions from sea-floor vents are commonly originally glassy due to rapid quenching on contact with water. Volcanic glass is, however, a metastable solid which devitrifies during slow cooling, or else eventually crystallises in response to metamorphism or alteration. Volcanic glass readily hydrates, especially in subaqueous settings. Hydration involves a slight increase in volume that produces fine arcuate cracks (perlitic fractures) throughout the glass. The textural effects of hydration, devitrification and alteration of glassy volcanic rocks may be dramatic, and result in a potentially bewildering array of new textures, some of which closely resemble other primary volcanic textures (Allen, 1988). One of the most conspicuous effects is the increasingly "clastic" texture assumed by coherent glassy lavas that have undergone hydration, devitrification and/or alteration. Distinguishing lavas from volcaniclastic deposits is critically important in facies analysis and correlation studies, and depends on correct interpretation of primary textures, as well as recognition of the textural effects imprinted by alteration.

Awareness of the textural effects of hydrothermal alteration in the Mount Read Volcanics has greatly refined current understanding of the volcanic facies that host some of the major massive sulphide deposits. For example, the footwall to the Hercules and Rosebery massive sulphide ore deposits has a macroscopic texture comprising phyllosilicate lenses in a siliceous matrix that closely resembles a welded ignimbrite. However, detailed textural and lithofacies studies (Allen and Cas, 1990; Allen and Hunns, 1990) have shown that the texture is the result of domainal phyllosilicate and siliceous alteration. The primary texture is locally well preserved in siliceous domains, and comprises abundant, variably oriented, tube pumice clasts in which vesicles are uncollapsed, indicating that the deposit was non-welded. Deciphering the textural effects of alteration has allowed definition of the lithofacies characteristics. The footwall sequence in fact comprises very thick graded units of pumice

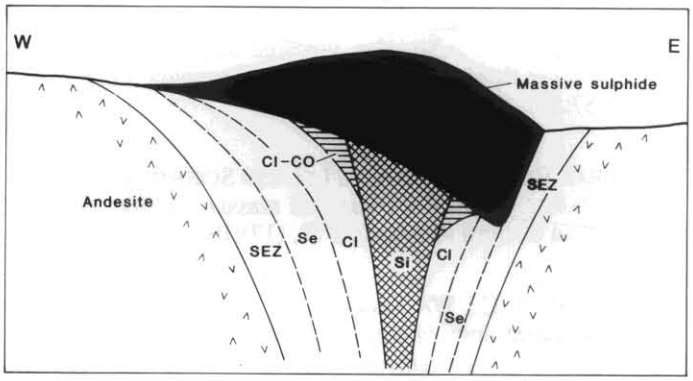


Figure 5

Schematic reconstruction of the alteration zones in the centre of the hydrothermal system below the Hellyer massive sulphide deposit. SEZ, stringer envelope zone; Cl, chlorite; CO, carbonate (primarily dolomite); Se, sericite; Si, quartz.

breccia that were deposited from voluminous submarine mass flows (Allen and Cas, 1990).

Studies of the mineralogical and compositional changes that accompany hydrothermal alteration have enormous importance for the recognition of potentially mineralised sequences. The known ore deposits in the Mount Read Volcanics are associated with alteration styles that vary in extent, intensity and character. One of the most carefully documented is the footwall alteration to the Hellyer massive sulphide deposit (Gemmell and Large, 1992). The main feature is a vertically extensive alteration pipe, immediately below the ore body (fig. 5). The pipe has plan dimensions of 1500 × 350 m, and has been explored to 550 m into the footwall below the ore body. Elsewhere nearby, the less-altered footwall comprises massive and pillowed basaltic sheets overlain by a thick sequence of feldspar-phyric andesitic and dacitic lavas, sills and related clastic deposits (Waters and Wallace, 1992).

Within the pipe, hydrothermal alteration has almost entirely overprinted the original textures and mineralogy. Four well-defined alteration zones have been recognised (fig. 5):

(i) the siliceous core (silica ± sericite ± chlorite);

(ii) the chlorite zone (chlorite ± sericite ± carbonate);

(iii) the sericite zone (sericite ± chlorite);

(iv) the outermost, stringer envelope zone (silica ± sericite).

Within the siliceous core, a stronger system of syn-mineralising veins is well developed. Mineralisation in the core of the stringer system is Cu-rich, and grades outward to being more Pb + Zn-rich.

There are several aspects of the alteration associated with the Hellyer ore body which illustrate the influence exerted by the host volcanic sequence. In particular, the sharp definition of the alteration pipe reflects the relatively competent nature of the footwall volcanics, together with a syn-volcanic structural control, both of which had the effect of narrowly focusing the hydrothermal system. The ore body is overlain by volcaniclastic mass-flow deposits and sheets of basalt. Both these volcanic facies were rapidly emplaced, and were clearly important in the preservation of the massive sulphide mound. In fact, basalt above the central portion of the massive sulphide shows fuchsite + carbonate + barite alteration, indicating that the hydrothermal system was still vigorously active at the time of burial. Correct discrimination of hangingwall and footwall alteration styles thus requires an appreciation of the character and emplacement processes of the enclosing volcanic facies.

CONCLUSIONS

Regional 1:25 000 scale maps now available for the entire Mount Read Volcanics provide a framework for the application of other research techniques aimed at understanding the relationship between the Cambrian volcanism and mineralisation. Recognition of distinctive volcanic facies and facies associations in the Mount Read Volcanics is critical in reconstructing the original facies architecture, and in achieving correct correlations at a range of scales. This requires an appreciation of eruptive and emplacement processes, their influence on the character and geometry of volcanic facies, and the textural and mineralogical effects of hydrothermal alteration. The stage is set for accelerated progress in Mount Read Volcanics research, and the most useful investigations will be those that integrate volcanic facies analysis with alteration and mineralisation studies.

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Stratigraphic-facies associations and their relationship to mineralisation in the Mount Read Volcanics

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ABSTRACT

The highly mineralised Cambrian Mount Read Volcanics form an arcuate belt along the western margin of the Precambrian Tyennan region. Volcanic-hosted massive sulphide (VHMS) deposits at Hellyer, Que River, Rosebery, Hercules, and Mt Lyell occur in a sequence of deformed, regionally metamorphosed (lower greenschist facies), and hydrothermally-altered volcanic rocks.

The Mount Read Volcanics can be broadly subdivided into a lava-rich eastern and central belt with the Eastern quartz-phyric sequence interfingering with the feldspar-phyric Central Volcanic Complex. They both interfinger with the western volcano-sedimentary successions (Yolande River succession, Dundas Group and the Mount Charter Group). The youngest part of this volcanism is time equivalent to a belt-wide period of andesitic-basaltic volcanism and VHMS deposit formation (Hellyer, Que River and some at Mt Lyell). A period of extension and rifting occurred at this time, with a tholeiitic dyke swarm concentrated along the Henty Fault and tholeiitic pillow basalts in the Henty Fault wedge.

Recent volcanological studies have suggested that the final phase of volcanism which produced the widespread mass-flow deposits of the Tyndall Group and Southwell Subgroup resulted in an extensive basal marker sequence. If the widespread extent of this marker sequence is confirmed then the previous position of the Rosebery–Hercules mineralisation, as early during the Central Volcanic Complex formation, will result in a re-interpretation which places those VHMS deposits at time-equivalent or slightly younger than the Que–Hellyer mineralisation.

INTRODUCTION

A major part of the Mount Read Volcanics Project (MRVP) conducted by the Department of Mines over the past seven years has been the 1:25 000 scale mapping program. During this period, the mineralised part of the belt from Elliott Bay in the southwest to Moina in the northwest has been mapped, with the thirteenth sheet (Mt Jukes–Mt Darwin) due for publication late this year (Corbett *et al.*, in press).

Data derived from the mapping, coupled with ongoing volcanological, geochemical and ore deposit studies, has resulted in an evolving view of the relationships of the various rock units (see Corbett, 1992; McPhie and Allen, 1992; Allen and Cas, 1990; Corbett and Lees, 1987; Crawford *et al.*, 1992; Berry and Crawford, 1988). As noted by Corbett (1992), ".... originally complex facies relationships are now very difficult to unravel, and correlations along and across the belt continue to be controversial and in need of constant reassessment". The recent mapping in the Mt Jukes–Mt Darwin area confirms this statement, with a reappraisal of the Central Volcanic Complex–Eastern quartz-phyric sequence–Tyndall Group relationships.

This paper summarises the work from the MRVP mapping, and with the work of others, updates our views on the stratigraphy of the Mount Read Volcanics and its relationship to mineralisation.

SUMMARY OF THE MAJOR STRATIGRAPHIC-FACIES ASSOCIATIONS OF THE MOUNT READ VOLCANICS

The following is a summary of the major units we recognise (see fig. 1).

STICHT RANGE BEDS

A succession of siliciclastic sandstone, conglomerate and siltstone predominantly derived from and unconformably overlying Precambrian basement occurs along the eastern margin of the belt. Outcrop is found from Back Peak–Mt Remus in the north, Lake Mackintosh to Lake Dora, and from the D'Aguilar Range to Elliott Bay in the south. An upward gradation into volcaniclastic rocks in most areas suggests it represents the basal unit to the Mount Read Volcanics. Baillie (1989) reports a Middle Cambrian fossil age.

EASTERN QUARTZ-PHYRIC SEQUENCE

A complex sequence of quartz-phyric volcaniclastic rocks mixed with lavas (usually quartz-feldspar phyric) and porphyries (quartz-feldspar ± biotite-phyric) occurs mainly along the eastern side of the belt. There have been problems over the years in understanding this sequence, as it includes volcaniclastic conglomerates which pass directly into younger but identical units of the upper Tyndall Group, but it also includes lavas and clastic rocks which appear to be lateral equivalents of the Central Volcanic Complex which

PEMBERTON, J.; CORBETT, K. D. 1992. Stratigraphic-facies associations and their relationship to mineralisation in the Mount Read Volcanics. *Bull. geol. Surv. Tasm.* 70:167–176.

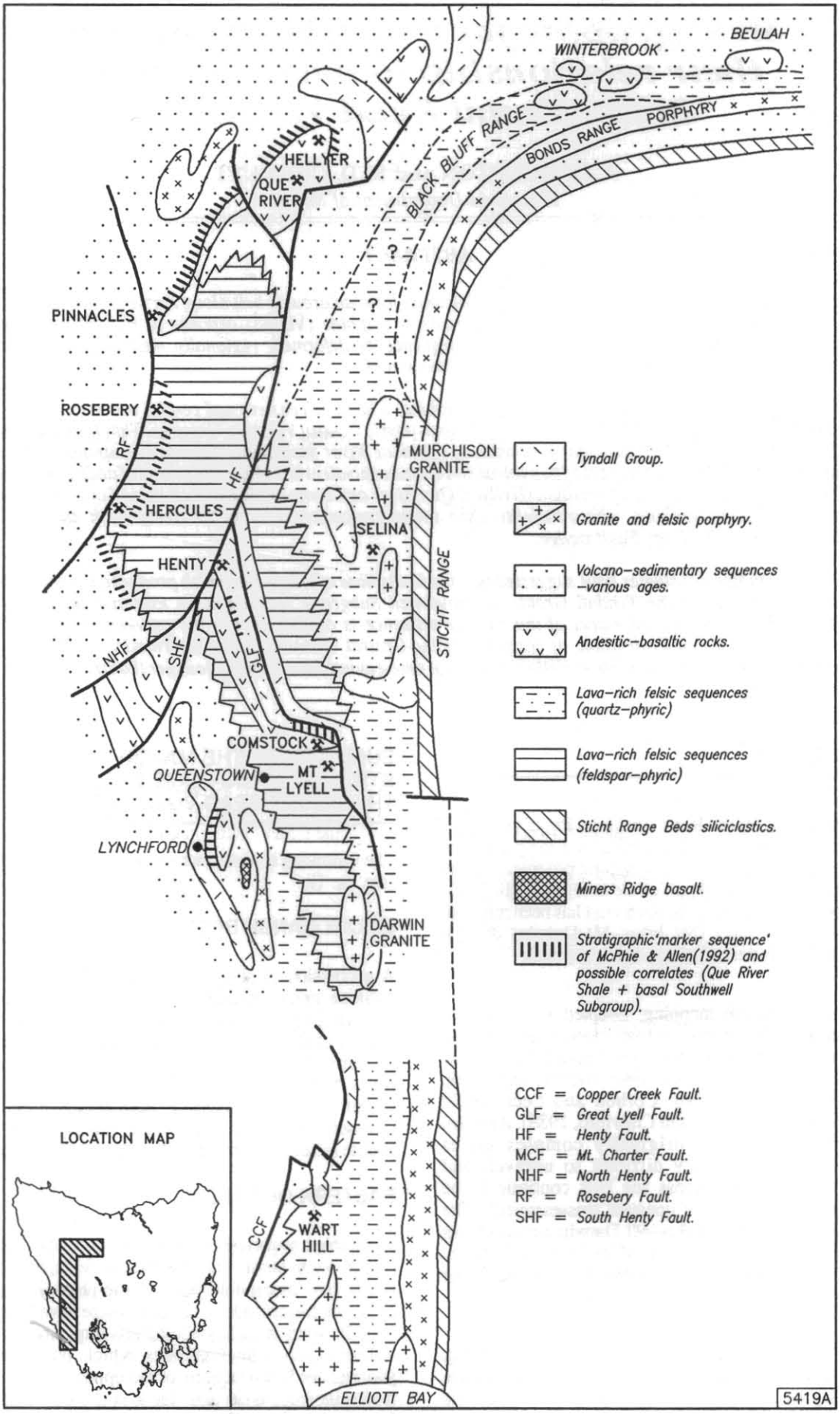


Figure 1

Stratigraphy of the Mt Read Volcanics between Elliott Bay and Beulah.

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predates the Tyndall Group. McNeill and Corbett (1992) resolved this problem (partially) in the Murchison area by referring to the bulk of the sequence as the 'Eastern quartz-phyric sequence', and used 'Tyndall Group Correlates' for the volcaniclastic conglomerate units which contained granite clasts. This problem is discussed further in the sections on the Tyndall Group and Mt Jukes–Mt Darwin. The quartz-phyric volcanic rocks east of the Copper Creek Fault at Elliott Bay are considered to be part of this grouping.

CENTRAL VOLCANIC COMPLEX

The Central Volcanic Complex is dominated by feldspar-phyric porphyritic lavas and domes with minor amounts of clastic rocks. These rocks are distinctive in the field, with a paucity or absence of quartz phenocrysts, a spherulitic nature, and are often pink-coloured because of K feldspar-chlorite-hematite-magnetite alteration.

Recent mapping in the Mt Jukes–Mt Darwin area has shown that the feldspar-phyric rocks interfinger with the quartz-phyric rocks, both to the east and west. Similar relationships are seen at Stirling Valley, Murchison Gorge and Red Hills. From this work it appears that the Central Volcanic Complex feldspar-phyric rocks represent a magma/facies variation rather than an older stratigraphic unit.

ANDESITIC-BASALTIC VOLCANIC ROCKS

Large lenses of andesite and basalt, dominated by hyaloclastic breccias and pillow lavas in most areas, occur between and partly interfingering with the Central Volcanics Complex–western volcano-sedimentary sequences and younger Southwell Subgroup–Tyndall Group at a number of places, e.g. Que–Hellyer, Pinnacles, Anthony Road, Comstock (Mt Lyell) and Lynchford. They are either plagioclase-pyroxene-phyric or plagioclase-hornblende-phyric, and their relationship to the majority of VHMS deposits in Tasmania is well documented. However, in the Rosebery–Hercules area they are absent, perhaps as a result of faulting, although they could be represented by the nearby, little known Curtin-Davis basalts.

Corbett (1990, 1992) has postulated that this widespread phase of volcanism coincided with a period of tensional tectonics associated with major faults and splay faults (e.g. Henty Fault, Mt Charter Fault, North and South Henty Faults and the Great Lyell Fault). Within the Henty Fault wedge, a large lens of calc-alkaline andesite with affinities to the other andesites crops out. A sequence of tholeiitic pillow basalts and dolerites, which also crop out, are geochemically identical (high TiO_2, low Nb and low P_2O_5/ TiO_2) to a suite of mafic dykes ('Henty dyke swarm') which intrude throughout the northern Central Volcanic Complex, but are concentrated along the North Henty and Henty Faults. There are tantalising similarities between these Henty tholeiites and the basalts at Sock Creek, which are along strike from the Que–Hellyer volcanics (Crawford *et al.*, 1992). This suggests that the Sock Creek basalts could be transitional between the tholeiites and the Que–Hellyer shoshonites, and that all are related to the same rifting episode.

The highly sheared and altered Miners Ridge Basalt has a distinctive tholeiitic chemistry, with low K_2O and depleted LREE patterns plus both low and high TiO_2 values (Crawford *et al.*, 1992). The basalt appears to be interbedded with the Miners Ridge Sandstone (a micaceous quartzwacke). A tentative correlation with the Double Cove basalts south of Macquarie Harbour is made by Crawford *et al.* (1992) who suggest that the basalts are rift tholeiites related to the passive margin basement onto which the Mount Read Volcanics were erupted. Corbett (1992), on the other hand, states that the available evidence could also support an early phase of tholeiitic volcanism associated with the *in situ* evolution of the belt. The Miners Ridge Basalt is fault bounded and probably tectonically emplaced.

VOLCANO-SEDIMENTARY SEQUENCES

From Elliott Bay to Beulah, marine volcano-sedimentary sequences flank the lava-dominated Central Volcanic Complex and Eastern quartz-phyric sequence (predominantly on the western side). The sequences typically consist of interbedded tuffaceous mass-flow deposits, turbiditic sandstone, shard-rich tuffaceous mudstone, micaceous siltstone and black shale. A local volcanic provenance is common, but interfingering with sediments derived from the Precambrian does occur. Extrusive andesitic and minor felsic volcanic rocks crop out, as do large intrusive porphyry bodies. The sedimentary units have provided a number of trilobite fossils giving dates from the early Middle Cambrian to early Late Cambrian (Corbett, 1992) (see fig. 8).

In the Queenstown area these rocks are known as the Yolande River sequence. At Lynchford a lens of Que–Hellyer type basalt, the Lynch Creek basalts, crops out within but close to the top of the sequence. Large sill-like quartz-feldspar ± biotite porphyries are intrusive and partly extrusive into this succession.

The term Dundas Group has been used widely to not only describe the volcano-sedimentary successions but to also include the Mount Read Volcanics in total (Carey and Banks, 1954). Recently Corbett (1992) redefined the rocks in the Que–Hellyer area as the Mt Charter Group, to replace the ill-defined term 'Dundas Group Correlates'. Brown (1986) used the term Huskisson Group to describe the rocks to the north of Renison, and Corbett and Lees (1987) used the term White Spur Formation at Hercules to describe a west-facing unit of volcaniclastic and mixed source sediments apparently overlying the Central Volcanic Complex. The White Spur Formation was included in the Dundas Group but recent work by McPhie and Allan (1992), using facies analysis, has suggested an alternative correlation (see later section on the Hercules–White Spur area). Fossil ages (Jago and Brown, 1989) from the Middle Cambrian are associated with sediments derived from the Mount Read Volcanics, while in the Late Cambrian upper Dundas Group, detritus derived from the volcanics is scarce and an offshore correlation with the Lower Owen Conglomerate is likely. From this discussion it would appear that the term Dundas Group will become less widely applied in the future.

TYNDALL GROUP

The Tyndall Group is a much battered and abused term since it was first used in 1974 (Corbett *et al.*, 1974). From its humble origin at Comstock Valley and the Tyndall Range, the term was extended to encompass all of the quartz-phyric rocks up the eastern side of the Mount Read belt (Corbett and McNeill, 1986), and even most of those at Elliott Bay (Large *et al.*, 1987). With the recent mapping it is now known that only part of the eastern succession is Tyndall Group, the larger part being older.

The Tyndall Group does, however, remain a valid stratigraphic unit, overlying the andesites at Comstock (also

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at Lynchford and Anthony Road), with late Middle Cambrian fossils in a basal limestone at Comstock. The group comprises distinctive banded pink and green crystal-rich sandstones and mass-flow deposits in the lower parts, passing up into mainly volcaniclastic conglomerate.

Primary volcanic rocks are not common, with quartz-phyric lava lenses intercalated within the group at Newton Creek and minor andesites in the equivalent Mt Cripps Subgroup on the Cradle Mountain Link Road. Welded tuffs occur within the upper volcaniclastic unit at Comstock (Corbett *et al.*, 1974), on the Cradle Mountain Link Road (Pemberton *et al.*, 1991), and as clasts in mass-flow deposits near the Tyndall Range (J. McPhie, pers. comm., *in* Corbett, 1992). The presence of granite and quartz-feldspar ± biotite porphyry clasts is common, and suggests the unroofing of the Darwin–Murchison granites and Bonds Range Porphyry during this time (Pemberton *et al.*, 1991; McNeill and Corbett, 1992). It is interesting to note that the Winterbrook volcanics and Black Bluff Range Cambrian windows have volcaniclastic conglomerates with granite and porphyry clasts, welded tuffs and dacites (with geochemistry that does not match the Que–Hellyer Volcanics) (Vicary and Pemberton, in prep.). The nearby fossil locality at Native Track Tier (Baillie and Jago, 1985) gives a late Middle Cambrian age, as does that on the Cradle Mountain Link Road (Pemberton *et al.*, 1991) and also at Paradise near Beulah (J. B. Jago, pers. comm.). Considering these criteria, it is likely that the Black Bluff Range windows and Winterbrook volcanics are Tyndall Group equivalents.

The Tyndall Group appears to be the final erosional phase of the Mount Read Volcanics pile, with mixing of basaltic-andesitic debris with felsic-quartz rich material in a shallow water to subaerial environment prior to deposition of the Owen Conglomerate.

GRANITES AND QUARTZ-FELDSPAR ± BIOTITE PORPHYRY

The period prior to the deposition of the Tyndall Group and its correlates appears to have been one of intense intrusive activity, not only of andesite-basaltic magma but also of granites (Murchison, Darwin and Low Rocky Point) and quartz-feldspar ± biotite porphyries (Bonds Range, Elliott Point and others). A majority of these intrusive rocks occur in the Eastern quartz-phyric sequence and could be responsible for the widespread episode of activity recognised by McPhie and Allen (1992) at the base of the Southwell Subgroup and in the White Spur Formation. It is also possible that they may have provided heat to the VHMS producing hydrothermal cells.

DIAGRAMMATIC CROSS-SECTIONS OF THE RELATIONSHIPS BETWEEN THE MAJOR UNITS

These simplified cartoon cross-sections have been drawn to illustrate our presently perceived understanding of the stratigraphic-facies relationships and positions of the various ore bodies and prospects. For a more detailed overview and in-depth discussion the reader is referred to Corbett (1992).

MT JUKES–MT DARWIN AREA (see fig. 2)

Recent mapping in the Jukes–Darwin area has shown that the feldspar-phyric Central Volcanic Complex interfingers with the Eastern quartz-phyric sequence, both to the east and west (Corbett *et al.*, in press). Parallel bands of quartz-phyric and feldspar-phyric lavas crop out on the western side at Slate Spur, while on the eastern side there are lenses of feldspar-phyric lava within the more abundant quartz-phyric rocks (at Lake Jukes, Allans Creek and east of Mt Huxley).

The Darwin Granite intrudes this mixed succession of quartz-phyric and feldspar-phyric rocks. A wedge of younger conglomerate containing clasts of the granite lies unconformably on the granite at South Darwin Peak. This was originally interpreted by Corbett (1979) as being part of the 'Eastern Sequence' and thus a Tyndall Group equivalent. Although our recent detailed mapping did not reach this area, work done to the north indicates that the volcaniclastic conglomerates of the Eastern quartz-phyric sequence and those of the Tyndall Group are indistinguishable. Rocks previously referred to as the 'Tyndall Group' (Corbett, 1979) in this area include older rocks which obviously interfinger with the Central Volcanic Complex. In many places it is quite difficult to distinguish between the two groups of similar rocks, so for mapping purposes an 'undifferentiated' category is retained. This difficulty appears to be due, in part, to the younger conglomerates being deposited on an originally irregular surface and, in part, to later folding and faulting. As noted earlier the occurrence of volcaniclastic sediments with granite or porphyry clasts overlain by the Owen Conglomerate is recognised as Tyndall Group. Considering this the relationships of these rock types at

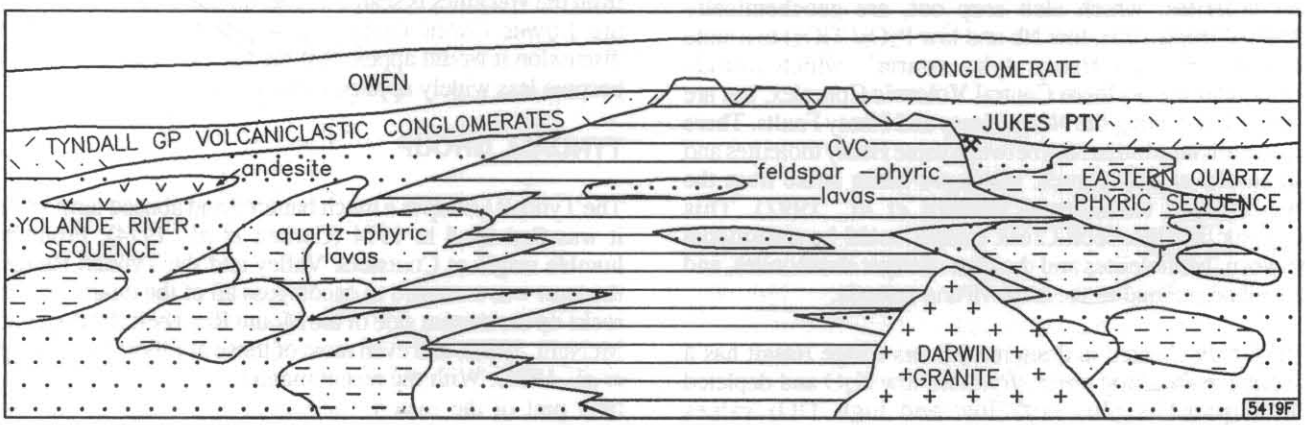


Figure 2

Schematic cross-section of the geology of the Mt Jukes–Mt Darwin area.

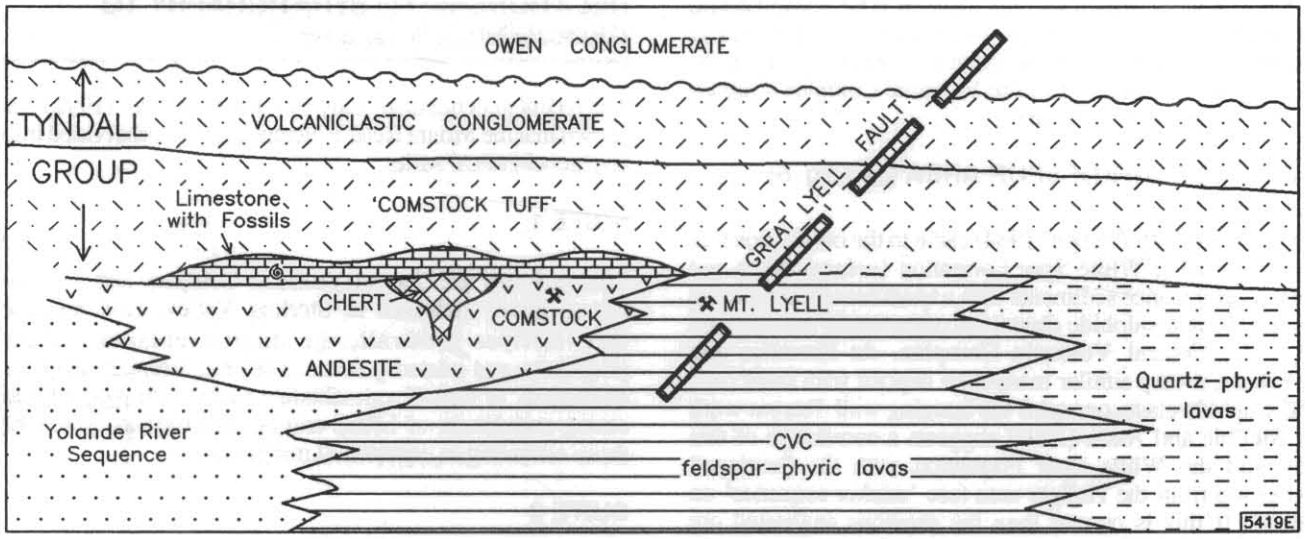


Figure 3

Schematic cross-section of the geology of the Comstock–Mt Lyell area.

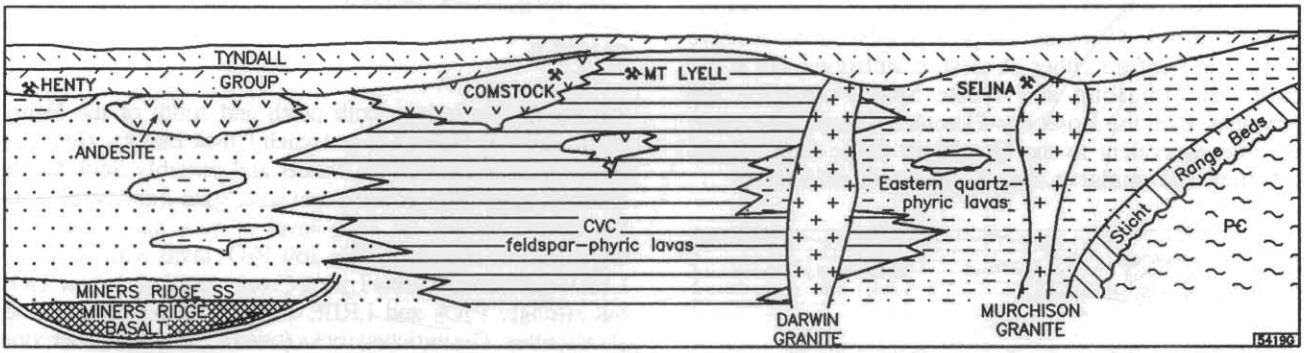


Figure 4

Summary diagram of facies relationships southeast of the the Henty Fault.

South Darwin Peak needs to be re-examined in the light of our present understanding to determine whether the contact with the Eastern quartz-phyric sequence is tectonically affected or depositional.

Mineralisation in this area is related to the contact (probably faulted) of the Eastern quartz-phyric sequence and the Central Volcanic Complex at East Darwin and close to it at Jukes Proprietary, with large alteration zones of K-feldspar, chlorite, magnetite, hematite, sericite and pyrite with minor chalcopyrite and gold.

COMSTOCK–MT LYELL AREA (see fig. 3)

The mineralisation at Mt Lyell–North Lyell–Prince Lyell etc. appears to be along strike and related to the nearby Comstock massive sulphide, which is associated with altered andesites of the Lynch Creek and Que–Hellyer type. Interfingering of the andesite with the Central Volcanic Complex and with the overlying fossiliferous limestone of the basal Tyndall Group (late Middle Cambrian) suggests a lateral and vertical facies relationship in a limited time scale. A similar succession is seen at the Anthony Road, with a major andesite accumulation immediately underlying Tyndall Group rocks.

SUMMARY DIAGRAM OF FACIES RELATIONSHIPS SOUTHEAST OF THE HENTY FAULT (see fig. 4)

From the diagram the suggested relationships from the oldest to youngest are:

(1) Faulted in Miners Ridge sequence

(2) A time equivalent Yolande River sequence–Central Volcanic Complex–Eastern quartz-phyric sequence

(3) A partly equivalent (to the above) but late andesite phase in the west, and granites and porphyries in the east (mainly). VHMS mineralisation at about this time.

(4) Tyndall Group

NORTH OF THE HENTY FAULT

A large block of feldspar-phyric and pumiceous volcaniclastic rocks (Central Volcanic Complex) is bounded to the east by the Henty Fault (see fig. 1); to the north is the Que–Hellyer volcanics (Mt Charter Group); to the northwest

is the Pinnacles area with Que–Hellyer type volcanics and Central Volcanic Complex rocks; and to the west is Rosebery–Hercules with the enigmatic relationship of the White Spur Formation–Central Volcanic Complex–Dundas Group sedimentary sequence.

HERCULES–WHITE SPUR AREA (see fig. 5)

Previous work by Corbett (1984) came to the conclusion that the west-facing White Spur Formation (volcaniclastic and mixed-provenance sediments with a basal breccia containing shale rafts and sulphide clasts) unconformably transgressed over the Central Volcanic Complex. At Hercules and Rosebery, a very similar mass-flow deposit with shale rafts and sulphide clasts occupies the hanging wall. Recent work by McPhie and Allen (1992) suggests a correlation of this unit and the White Spur Formation with the Southwell Subgroup from the Hellyer area (see 'marker sequence' on fig. 1). If this is correct then the previous suggested ore position of Rosebery–Hercules within the Central Volcanic Complex, and therefore older than Que–Hellyer, is reversed with a slightly younger age than Que–Hellyer.

Corbett (1992) suggests another possible correlation with the Black Harry Beds (rich in mass-flow deposits) which are basal to the Mt Charter Group and interfinger or overlie the Central Volcanic Complex. At present there is no decisive evidence to confirm either of these correlations, but if the Southwell Subgroup and White Spur Formation are equivalent, then the Rosebery–Hercules mineralising event was time equivalent to the Que River Shale (late Middle Cambrian) and similar to that of Que River and Hellyer.

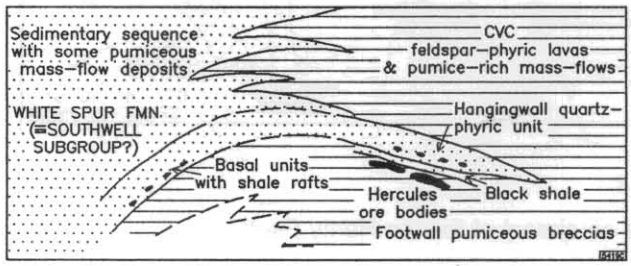


Figure 5

Schematic cross-section of one interpretation of the geology of the Hercules–White Spur area.

HELLYER–PINNACLES AREA (see fig. 6)

The relationship between the Central Volcanic Complex and the Que–Hellyer volcanics is difficult to decipher because of the faulted contact at Mt Charter. However, correlates of the Que–Hellyer volcanics extend along strike through Sock Creek to Pinnacles, and here the stratigraphic relationships can be more easily inferred. The Hollway andesite lies within feldspar-phyric lavas of Central Volcanic Complex type, overlain by correlates of the Que River Shale and Southwell Subgroup. Feldspar-phyric lavas interfinger up to the level, probably, of the lower part of the Southwell Subgroup.

From this correlation it would appear that the Que–Hellyer volcanics are laterally equivalent to the Central Volcanic Complex, and possibly to have formed as a result of a significant period of rifting which produced basalts and andesites at many places along the Mount Read belt.

RELATIONSHIP OF STRATIGRAPHY TO GEOCHEMISTRY (see fig. 7)

The recent geochemical study by Crawford *et al.* (1992) has shown that the Mount Read Volcanics can be subdivided into five geochemical suites.

SUITE 1

This includes the Central Volcanic Complex and Tyndall Group lavas, andesites at Sterling Valley, Hollway, the Que–Hellyer footwall, the quartz-feldspar ± biotite porphyries and related granites. They are 'normal' orogenic medium-K to high-K calc-alkaline rocks with moderate to strong enrichment of LREE and are regarded as typical of those occurring in continental margin arcs.

SUITE 2

The hornblende-phyric andesites occurring mainly as intrusives within the upper part of the southern Central Volcanic Complex (e.g. Crown Hill, Anthony Road and Reservoir andesites) have lower TiO_2 and higher P_2O_5 than Suite 1, and are slightly more enriched in LREE. They are regarded as high K andesites.

SUITE 3

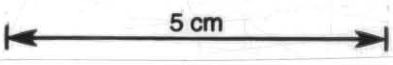
Basalts and andesites, both north and south of the Henty Fault, fall into Suite 3 (e.g. Lynch Creek basalts, Howards Plains intrusives, Hellyer basalts and possibly Sock Creek basalts). They form a continuum with Suite 2 andesites, with the cut-off mainly on SiO_2 level at 57% and a range of compositions from low TiO_2, low P_2O_5 lavas with moderate LREE enrichment (some Lynch Creek samples), to low TiO_2 but strongly P_2O_5 and LREE enriched lavas classified as shoshonites. The enriched rocks (two from Lynch Creek, one from Swan Creek and one from Hellyer) have no compositional equivalents in the Andes or in modern arc systems, and are correlated with 'post-collisional' lavas.

SUITE 4

The Henty Fault wedge tholeiites and Henty dyke swarm have the geochemical characteristics of rift tholeiites (with slightly low TiO_2 and definitely low Nb). The low Nb is seen in basalt erupted above subduction zones during early phases of rifting of magmatic arc, back-arc basin opening. Field relationships show this to have been post-Central Volcanic Complex but pre-Tyndall Group time. It is noted by Crawford *et al.* (1992) that it is difficult to relate this to a post-collisional setting of the Mount Read Volcanics.

SUITE 5

The Miners Ridge Basalt, with its depleted LREE pattern, is unrelated geochemically to any others in the Mount Read Volcanics. Its closest correlate would be some of the tholeiites of the Crimson Creek Formation (older and to the west of the Mount Read belt). Stolz and Large (1992) have suggested that the relatively gold-enriched Crimson Creek Formation could be the reason why Mount Read Volcanic VHMS deposits are gold enriched, and point to the recent tectonic models of Green (1984), Corbett and Lees (1987), Corbett and Turner (1989), and Berry and Crawford (1988), which all have the Crimson Creek Formation as basement to the Mount Read Volcanics. Recent work by Dower (1991) and Corbett *et al.* (in press) show the Miners Ridge



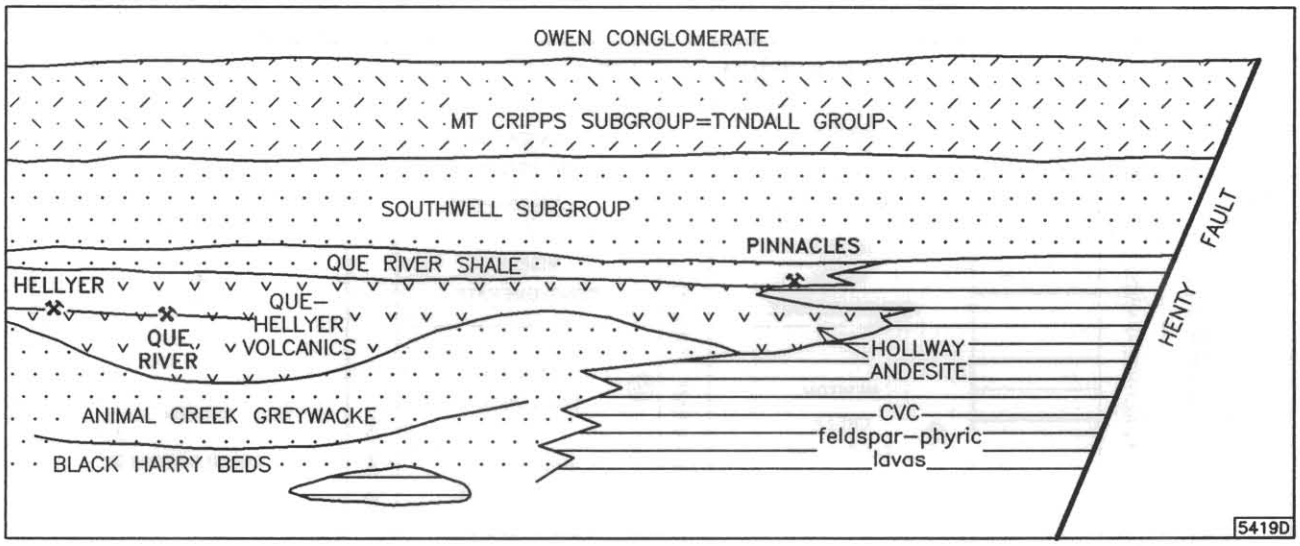


Figure 6

Schematic cross-section of the geology of the Hellyer–Pinnacles area.

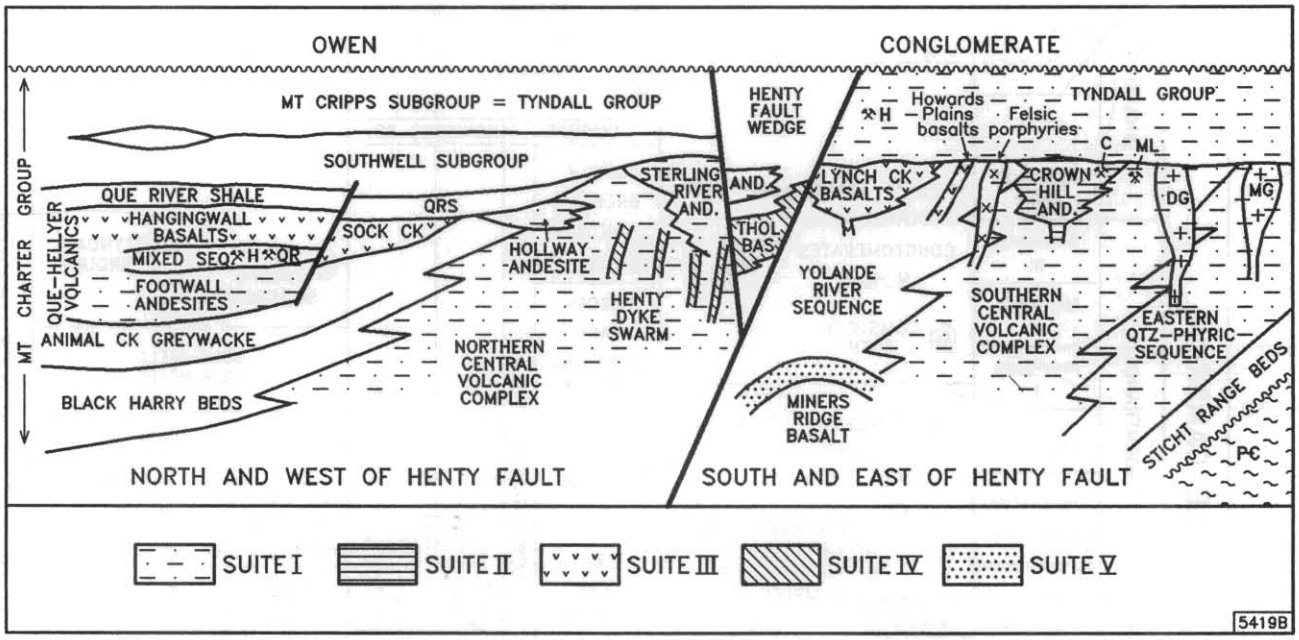


Figure 7

Summary of the stratigraphic relationships of the different geochemical suites (modified after Crawford *et al.*, 1992).

Sandstone and basalt to be fault enclosed, suggesting tectonic emplacement.

RELATIONSHIP BETWEEN STRATIGRAPHY AND MINERALISATION

MAJOR VHMS DEPOSITS (see fig. 1)

Hellyer and Que River

These occur within an andesite-basalt succession at the change between Suite 1 and Suite 3 (shoshonitic) rocks. They probably formed during a rifting episode associated with the development of the Henty and Mt Charter Faults. The Que River Shale (late Middle Cambrian) and Southwell Subgroup (the 'marker sequence' at its base) immediately overlie the Que–Hellyer volcanics.

Rosebery–Hercules

These are found in a felsic sequence with no andesites known in the immediate vicinity. There is a possible connection with the ancestral Rosebery Fault. Recent correlations (McPhie and Allen, 1992) of the hanging wall quartz-phyric unit with the basal Southwell Subgroup suggests an ore position just below the Que River Shale and perhaps of similar age to Que–Hellyer.

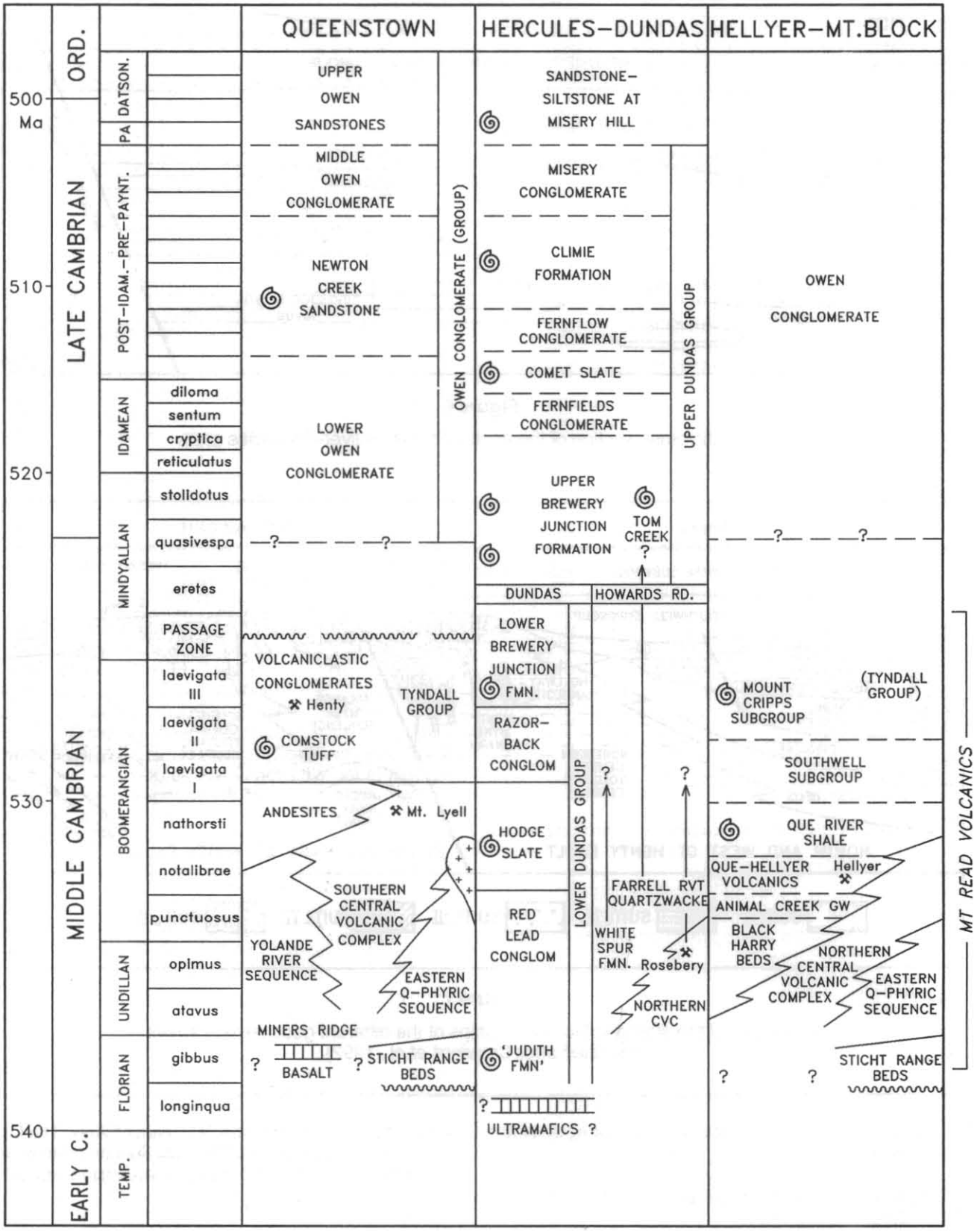


Figure 8

Comparative stratigraphic columns for Queenstown, Hercules–Dundas and Hellyer–Mt Block areas (from Corbett, 1992).

5 cm

Comstock–Mt Lyell

These occur partly in andesite and partly in felsic volcanic rocks adjacent to andesite. Preliminary data suggest the andesites may be Suite 3 type. The Tyndall Group (possibly includes Southwell Subgroup equivalents) immediately overlies Comstock. There is a strong inferred relationship to the Great Lyell Fault, which appears to have been the locus for large hydrothermal systems (e.g. the chert-sinter exhalites such as the Comstock Chert).

Conclusion

The evidence for a stratigraphic correlation at the pre-Tyndall Group–Southwell Subgroup position with the 'andesite connection' and 'marker sequence' for the major VHMS deposits is now gaining strength.

OTHER VHMS-RELATED DEPOSITS (see fig. 1)

Henty

The Henty mineralisation occurs at or near the contact between lavas below and volcaniclastic mass-flow rocks above, and has traditionally been assigned to the 'Tyndall Group'. With the recent refinement of the term Tyndall Group, it is possible that the lower lavas are equivalent to felsic lavas and andesites elsewhere, and that the VHMS mineralisation is in a similar position to that of the large VHMS deposits. The immediate footwall position of the deposit to the Henty Fault also suggests a tectonic and perhaps genetic influence from the fault. As the gold is hosted in large zones of intense silicification, McNeill and Corbett (1992) suggests an epigenetic-epithermal origin, and parallels could be drawn with the silicification seen in the Comstock–Mt Lyell area.

Pinnacles

There is strong evidence that the Pinnacles mineralisation is at or about the Que River Shale stratigraphic level (Reid, 1991; Coutts, 1990). Once again there is the andesite connection with the Hollway andesite, and a possible influence from the Rosebery Fault or its precursor. Therefore Pinnacles could fit the same general pattern as the large VHMS deposits.

Wart Hill

Large massive sulphide clasts (± 5 m) occur as rafts in a mass-flow deposit near the western margin of a quartz-phyric-rich lava sequence where interfingering with a volcano-sedimentary sequence takes place. This unit has similarities to the Rosebery hanging wall unit, which has large sulphide clasts at the Bastyan Dam. However the original deposit may have been some distance from the present prospect and in a different stratigraphic position.

GRANITE-RELATED DEPOSITS

Copper-gold-pyrite-hematite-magnetite deposits, usually associated with chlorite-K feldspar (± tourmaline) alteration, are common along the Jukes–Darwin Range, in the Dora–Selina–Murchison area, at Mt Remus, and to a lesser extent in the Elliott Bay area. There is an obvious geographic association with Cambrian granite bodies and with quartz-feldspar ± biotite porphyry bodies. Other lines of evidence (S isotopes, Zn ratio, presence of tourmaline, etc.) indicate a genetic link to the granites.

POST-CAMBRIAN MINERALISATION

Two styles are commonly recognised with Devonian granite-related mineralisation (lead, zinc and silver; e.g. Farrell and Lakeside) and gold occurrences associated with fault zones in the Lynchford–King River areas (e.g. Coupon, Harris Reward, Lynch Creek, Sailor Jack and perhaps the source for the alluvials at Flannigans Flats).

CONCLUSION

The recent mapping of the Mount Read Volcanics Project and other detailed work (e.g. McPhie and Allen, 1992; Crawford *et al.*, 1992) has refined and altered our definitions of some of the established Mount Read Volcanic stratigraphic groupings. It is now apparent that the western volcano-sedimentary sequences, Central Volcanic Complex and Eastern quartz-phyric sequence are facies variations of time equivalent units. The andesitic-basaltic volcanism associated with the mineralising event of Que–Hellyer was widespread, and interfingers with the upper part of the Central Volcanic Complex, and if coupled with the 'marker sequence' of McPhie and Allen (1992) suggests a stratigraphic correlation with the major VHMS deposits at this period.

Mapping at Jukes–Darwin has clearly shown the interfingering relationship between the Central Volcanic Complex and Eastern quartz-phyric sequence, and that the Tyndall Group should be confined to later volcaniclastic sediments with granite and quartz-feldspar porphyry clasts. Minor volcanism (andesitic to rhyolitic) and welded tuffs are present to the north (Comstock, Newton Creek and Link Road), plus granite and porphyry clasts. All of these features are seen in the Winterbrook volcanics, and it is suggested that they are correlates of the Tyndall Group / Mt Cripps Subgroup.

Although the 1:25 000 mapping of the Mount Read Volcanics is not complete the coverage achieved during the Mount Read Volcanics Project has rapidly advanced our understanding of the stratigraphic-facies relationship and stimulated a great deal of study by others, which has been of benefit to all those working on these rocks.

ACKNOWLEDGEMENTS

This paper draws from the contributions of MRVP co-workers P. Komyshan, A. McNeill, J. Jackson, M. Vicary and J. Bradbury. The recent detailed facies analysis of Jocelyn McPhie, and geochemical studies of Tony Crawford, have greatly assisted this overview. Support staff at the Department of Mines are thanked with the work of J. Ladaniwskyj and A. Hollick on the diagrams being singled out for special mention.

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New perspectives on Tasmanian geology

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ABSTRACT

New information about the structure and sedimentary basin configuration in the southern Tasman Fold Belt confirms that the eastern Tasmania terrane is the on-strike continuation of the Melbourne Zone of Victoria. It represents a passive-margin to back-arc basin which was deformed and amalgamated with the western Tasmania terrane in the late Middle Devonian. The western Tasmania terrane has characteristics of both the western Lachlan Fold Belt and the Kanmantoo Fold Belt, and could be a largely exotic block lying across the junction between the two fold belts. The Precambrian "basement" of Tasmania, regarded for so long as firmly rooted to its mantle lithosphere, could be composed of thrust-bounded slices accreted to the Tasman Fold Belt initially in the Middle Cambrian during westward thrusting of the Kanmantoo Fold Belt over the platform margin in the Adelaide region. Renewed contraction in the Middle Devonian formed many of the present thrust contacts. These new ideas make it imperative that existing exploration philosophies and models are re-examined to take into account the thrust-fault geometry and the possible allochthonous nature of much of Tasmania.

INTRODUCTION

Tasmania occupies an important place in the geological framework of Australia, lying at the southern extension of the 1000-km wide Tasman Fold Belt, which occupies the eastern third of the continent (fig. 1). The Tasman Fold Belt is a largely Phanerozoic fold belt, with a history extending from the latest Precambrian, or beginning of the Cambrian, until the mid-Cretaceous, when the magmatic arc which lay along its eastern border for much of its history was rotated eastwards to its current position in the Tonga-Kermadec volcanic islands. The Tasman Sea grew in its wake.

Within the Tasman Fold Belt, there are three separate fold belts, each with a distinctive geological history, overlapping in time (fig. 2). The westernmost of these is the Kanmantoo Fold Belt, which began in the latest Precambrian or earliest Cambrian with deposition of quartzose clastics, mainly in deep-marine conditions. The Kanmantoo Fold Belt was deformed, intruded by granite, uplifted, and thrust westward onto the Australian craton from the Middle Cambrian to the earliest Ordovician (Preiss, 1987). The Lachlan Fold Belt, immediately to the east, contains marine sediments and volcanics of oceanic affinity, from at least the Middle Cambrian, and had a lively tectonic history until its stabilization in the mid-Carboniferous.

The Lachlan Fold Belt can be divided into two parts by a line running NNW from near Sale in Victoria, along the Mt Wellington fault zone, and thence along the western edge of the Wagga Metamorphic Belt (Powell *et al.*, 1990). To the west of this line, quartzose clastics deposited in mainly deep-marine conditions prograded from the south-west from the Early Ordovician to the Early Devonian. During the Ordovician, quartzose clastics derived from the south-west spread across the entire Lachlan Fold Belt as a submarine turbidite apron, but in the earliest Silurian the tectonic setting in the east changed dramatically. The mid-Silurian to mid-Devonian of the eastern Lachlan Fold Belt is dominated by massive outbursts of silicic volcanics, with underlying granitoid intrusives, abrupt facies changes caused by deposition in and adjacent to northerly-trending grabens, and local areas of contractional deformation (Powell, 1983, 1984*a*). The whole eastern Lachlan Fold Belt appears to have been a zone of transcurrence with local areas of transtension and transpression. The eastern and western Lachlan Fold Belt were reunited in the Middle Devonian when contractional deformation affected both parts, and the region rose above sea level. The final deformation in the mid-Carboniferous extended throughout Australia (Powell, 1984*a, b*), and was part of the world-wide deformation associated with the collision of Gondwanaland and Laurasia to form Pangea.

The easternmost fold belt, the New England Fold Belt, began in the Siluro-Devonian and was dominated by magmatic arcs which episodically stepped eastward throughout the next 300 million years. The final magmatic arc, which was active along the present coast of Queensland until the mid-Cretaceous, was extinguished when rifting began in the Tasman Sea about 95 million years ago (Veevers *et al.*, 1991). The New England Fold Belt contains most of the forearc asssemblages preserved in the Tasman Fold Belt, whereas the Lachlan and Kanmantoo fold belts have rock successions more typical of marginal-sea or back-arc settings.

Within this regional setting, Tasmania occupies a crucial position. First, it lies athwart the projected southern extension of the join between the Kanmantoo and Lachlan fold belts (fig. 1). This junction, postulated variously to lie along the Woorndoo fault zone adjacent to the eastern side of the Grampians in western Victoria (Baillie, 1985; Scheibner, 1985), or further east along the Avoca fault zone (Glen *et al.*, 1992), separates complexly multiply-deformed Cambrian rocks to the west from relatively simple, upright to locally overturned Devonian folds to the east (VandenBerg and Gray, 1992). Depending on where the tectonic boundary is placed, the Stawell gold mine lies either in the eastern Kanmantoo or the westernmost Lachlan Fold Belt.

Secondly, there is no known Precambrian exposed in the Tasman Fold Belt on mainland Australia, even though the presence of Precambrian sources at depth in some parts of the eastern Lachlan Fold Belt has been inferred from isotopic

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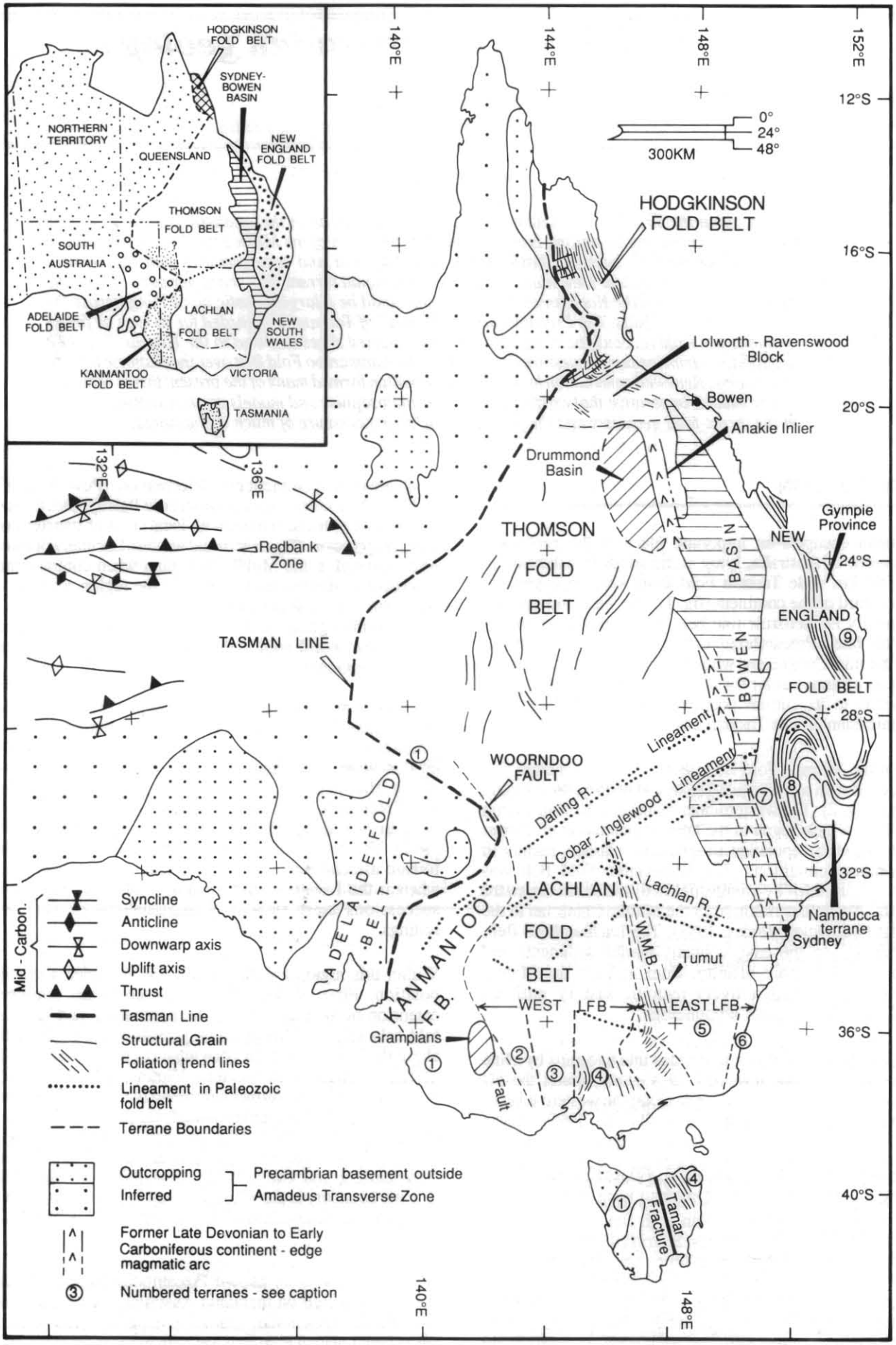


Figure 1

Tectonic sketch of eastern half of Australia showing the broad tectonic divisions of Tasman Fold Belt; modified from Powell *et al.* (1990, fig. 1).

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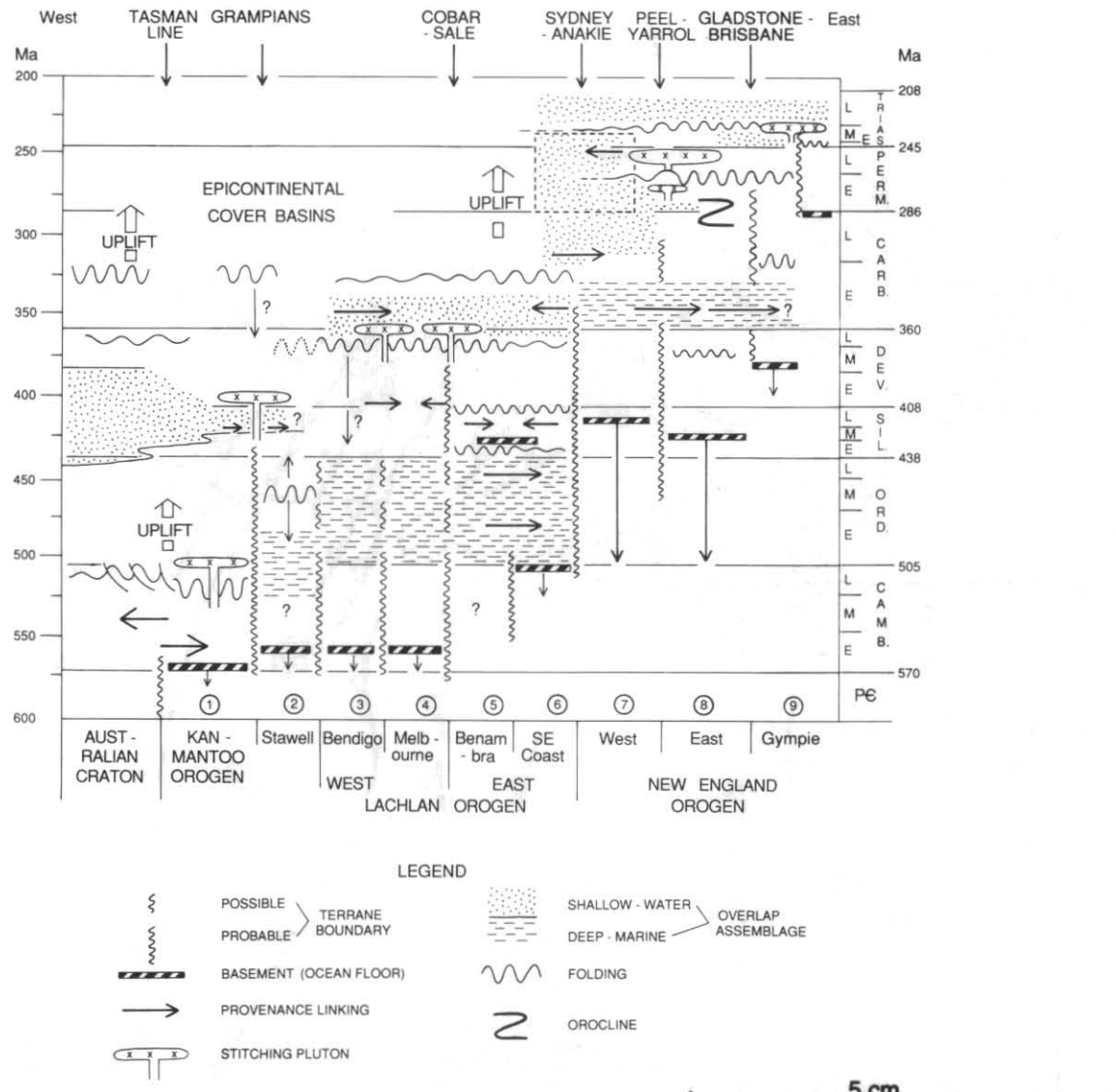


Figure 2

Time-space diagram for the southern Tasman Fold Belt (updated from Powell *et al.* 1990, fig. 2).

studies. The question thus arises of whether Tasmania is a window to the deeper levels of the Tasman Fold Belt.

In this paper, I outline some recent work in the southern Tasman Fold Belt, including growing recognition that thrust faults have played an important part in the tectonics, and raise the possibility that long-held ideas about Tasmania being cored by Precambrian rocks rooted to the Earth's mantle, may have to be revised. The implications for mineral prospectivity are profound.

TASMANIA'S GEOLOGICAL FRAMEWORK

Tasmania lies in the western half of the Tasman Fold Belt, with the western two-thirds of the island comprising Late to Upper Precambrian to mid-Palaeozoic rocks deposited in very varied tectonic settings. In contrast, the north-eastern third of the island comprises a remarkably uniform early Ordovician to Lower Devonian quartzose turbidite apron. These two parts, named the western and eastern Tasmania terranes (Banks and Baillie, 1989), have no clear connection until the Middle Devonian, when they are linked by deformation common to the whole of the southern Lachlan Fold Belt. Immediately afterwards, both eastern and western Tasmania were intruded by Upper Devonian to Lower Carboniferous granites (fig. 3–4).

The western Tasmania terrane comprises, from west to east (fig. 3), the relatively gently-deformed Upper Precambrian to Cambrian quartzose clastics, carbonates and mafic volcanics of the Smithton Basin and Rocky Cape region, bounded on the east by a highly deformed and metamorphosed linear zone, the Arthur Lineament. This passes eastward into Upper Precambrian quarztose turbidites of the Burnie region and Lower Cambrian turbidites, shales and mafic volcanics of the Crimson Creek Group. The latter succession is overlain by Middle and Upper Cambrian felsic, andesitic and minor mafic volcanics, and associated clastics of the Mt Read Volcanics, which passes up into Cambro-Ordovician clastics followed by Ordovician carbonates. Farther east, the central part of the island is occupied by multiply-deformed, mostly medium- to low-grade regional metamorphic Precambrian rocks of the Tyennan region. The Cambrian volcanic belt wraps around the northern end of this region, and there are two smaller areas of Precambrian rocks outcropping in the Forth and Badger Head regions (fig. 3). The eastern half of the western

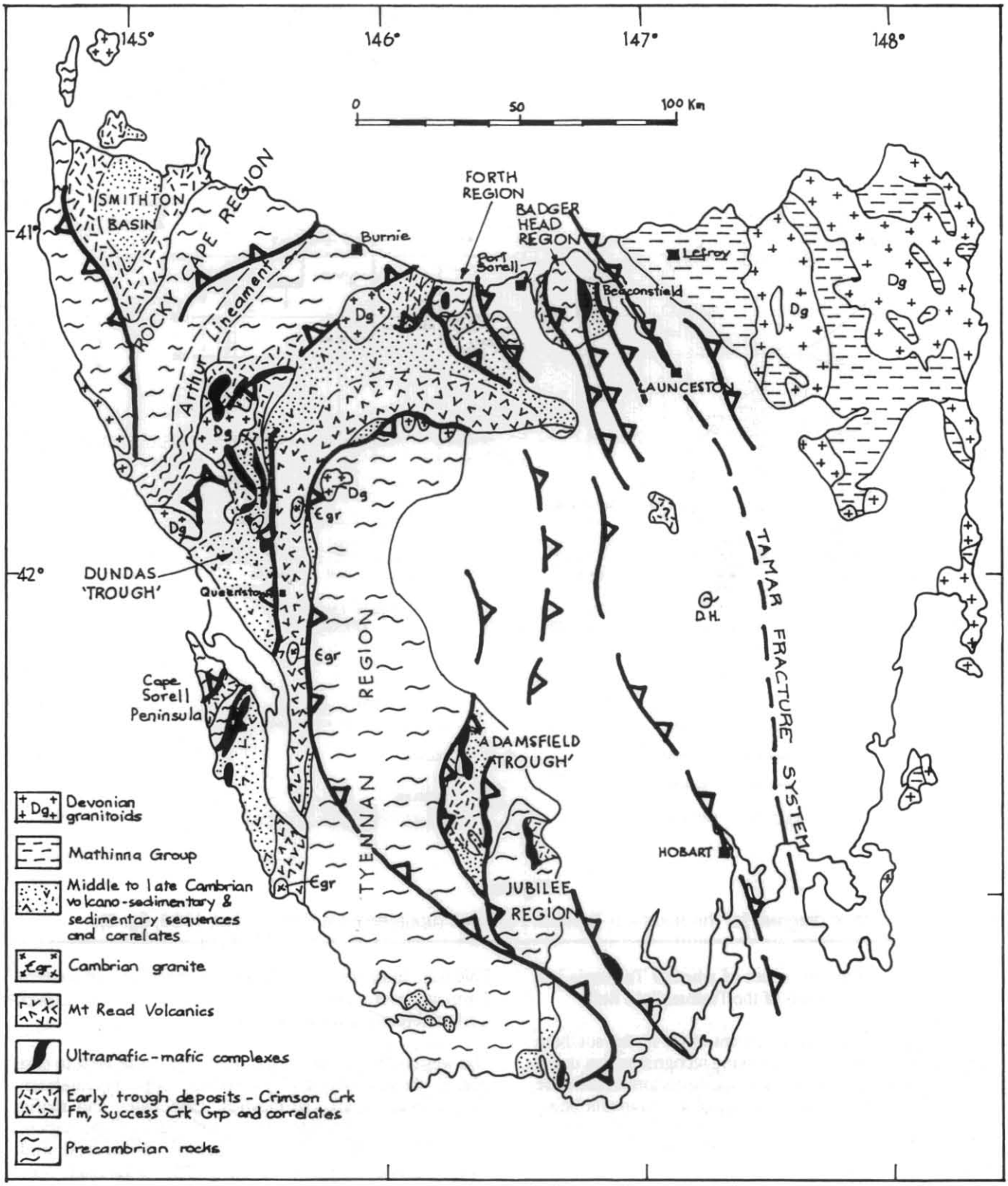


Figure 3

Simplified geological map of Tasmania showing tectonic elements, based on Corbett and Turner (1989, fig. 5.1) and Leaman *et al.*(1992, fig 2).

5 cm

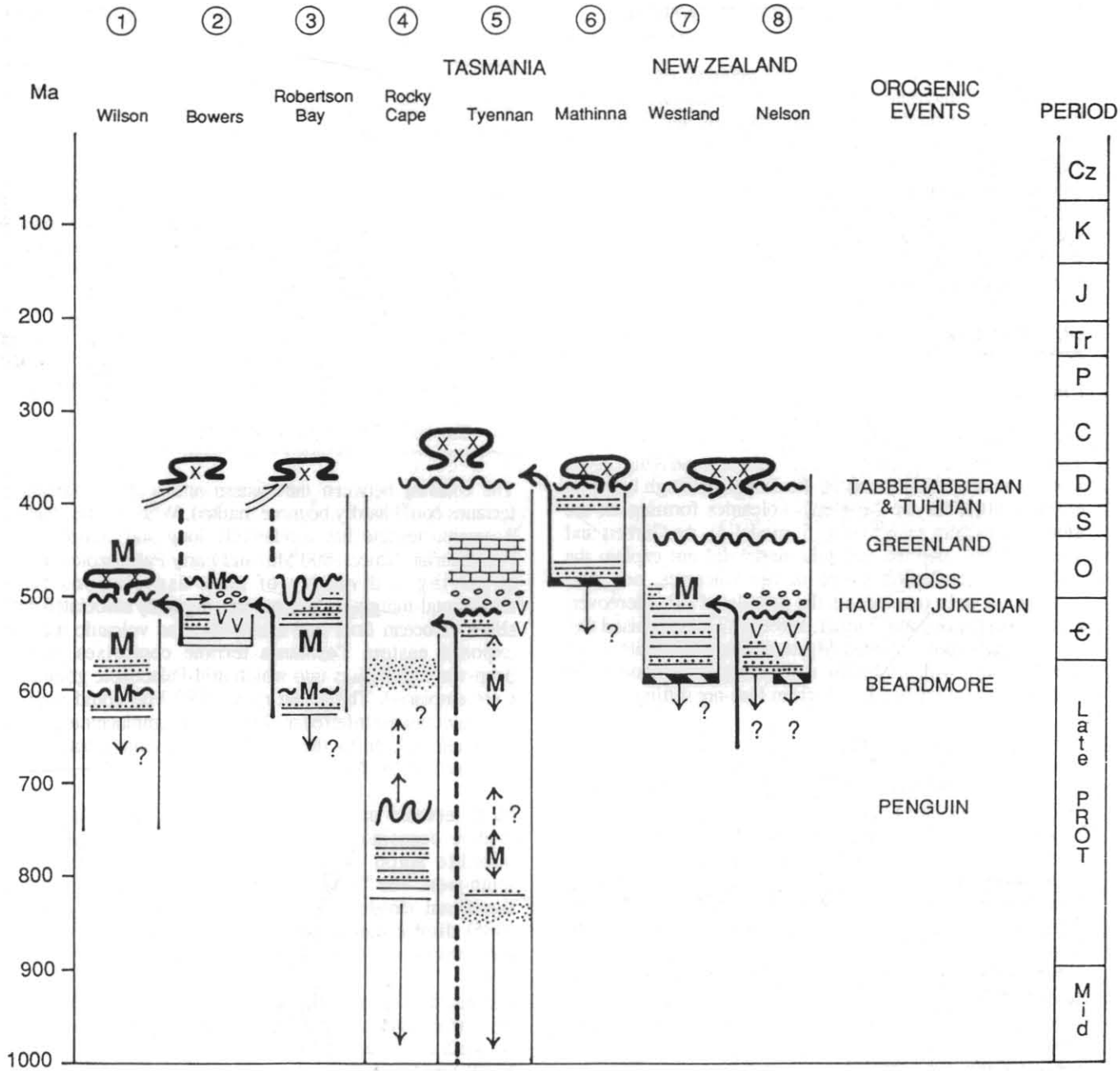


Figure 4

Terrane chart of the southern extension of the Tasman Fold Belt, from North Victoria land (terranes 1 to 3) through Tasmania (terranes 4 to 6) to New Zealand (terranes 7 and 8). Note that the western Tasmania terrane of Banks and Baillie (1989) is considered as two separate terranes, divided along the Arthur lineament, because of different tectonic histories prior to the end of the Cambrian. Most symbols as in Figure 2. Additionally, horizontal brick pattern = platform carbonate, **M** = age of metamorphism, v = volcanics.

Tasmania terrane is largely covered by flat-lying Permo-Triassic sediments and Jurassic dolerite, but there are some Cambrian rocks, with associated ultramafics, in the Adamsfield and Beaconsfield regions (fig. 3).

The eastern Tasmania terrane (fig. 3) contains a small area north-east of Launceston where a 1-km thick quartzose turbidite sheet is overlain by a thick black pelite, in part Lower Ordovician, which passes upward into widespread quartzose turbidites of the main part of the Mathinna Group (Powell *et al.* 1992*a*). The upper Mathinna Group, occupying much of north-eastern Tasmania, is Lower Devonian, and was deformed into NNW-trending folds and intruded by silicic melts in the late Early Devonian. The subsequent main granodioritic batholiths were emplaced in the Middle Devonian, prior to a south-westward-directed thrusting which amalgamated the eastern and western Tasmania terranes in the late Middle Devonian. Younger, in places stanniferous, granites were emplaced in the Late Devonian or Early Carboniferous, when granites were intruded throughout many parts of the island. Since the Early Carboniferous, the two terranes have remained welded together, and the only deformation has been mild extension along the Tamar Fracture System, and other faults, associated with emplacement of the Jurassic dolerite and subsequent stages of extension during Australia's breakup from Gondwanaland.

5 cm

PREVIOUS TECTONIC INTERPRETATIONS

Most earlier interpretations of the geology of Tasmania envisaged the tectonic setting of Lower Palaeozoic to have been narrow troughs developed between and within an extensive Precambrian basement (e.g. Williams, 1978, 1989). Williams (1978) considered the Precambrian to have formed "geanticlines" between adjacent troughs, the margins of which localised subsequent deformation. Precambrian regions were regarded as rigid blocks, implicitly rooted to the underlying mantle, which controlled the folding of the sediments caught between.

(a) Western Tasmania terrane

Considerable debate concerned the nature of the Mt Read volcanic belt and associated Dundas Group sediments, as outlined in the summary below precised from Corbett and Turner (1989). Early models (e.g. Campana and King, 1963; Corbett *et al.*, 1972) favoured the Dundas Trough being an ensialic rift, with the Mt Read Volcanics forming an arc along the eastern margin (fig. 5, model 1). As Corbett and Turner (1989) pointed out, this model did not explain the andesitic calc-alkaline nature of the volcanics, nor their location on only one side of the postulated rift. Moreover, Corbett (in Corbett and Turner, 1989, p.177) recognised that "... the association of high-Mg andesites (bonninites) and low-Ti basalts with ultramafic-mafic complexes [beneath the Dundas Group] is known only from fore-arc settings".

The second group of models tried to overcome these short-comings by postulating either a W-dipping (Solomon and Griffiths, 1972) or E-dipping (Solomon and Griffiths, 1974; Crook, 1980; Green 1984; Corbett and Lees, 1987) subduction zone in the Dundas 'Trough' (fig. 5, model 2). Problems associated with these models are the implied width of at least a few hundred kilometres for the ocean basin necessary to generate the Mt Read Volcanics by subduction, difficulty in locating the highly deformed subduction complex which would have developed in the trench, and the chemistry of the basalts (see above). Moreover, the models do not account for the presence of ultramafic rocks in the Adamsfield 'Trough' on the eastern side of the Tyennan block. A variant on the subduction model (fig. 5, model 3) suggested that the subduction zone lay east of the Tyennan block and dipped west, so that the Dundas 'Trough' formed during back-arc extension behind the Mt Read Volcanics (Solomon and Griffiths, 1974; Corbett, 1981; Varne and Foden, 1987). A perceived problem with this model is that it does not appear to account for why the Mt Read Volcanics are located so precisely along the western margin of the Tyennan block (Corbett in Corbett and Turner, 1989, p.179).

The third class of models regarded the ultramafics as part of a single ophiolite sheet thrust over the autochthonous Precambrian continental crust of Tasmania, and later down-faulted to its present position (fig. 5, model 4; Berry and Crawford, 1988). In this model, based loosely on analogy with the end-Cretaceous emplacement of the Oman ophiolite sheet on to the Arabian shield, the whole of the western Tasmania terrane is regarded as a single continental block which was thrust, in the Middle Cambrian, beneath an oceanic island arc along an eastward-dipping subduction zone. Post-collisional extension is postulated to have formed grabens in which the Dundas Group accumulated, while at the same time the Mt Read Volcanics were erupted. Perceived difficulties with this model are the intercalation of low-Ti basalts, considered to be part of the allochthonous sheet, with the basal Dundas Group sediments, which contain quartzose detritus derived from the underlying autochthon, the lack of evidence in coeval sediments for detritus derived from the allochthonous sheet, and the lack of a reason for the apparent restriction of the Mt Read Volcanics to the western and northern margin of the Tyennian region.

A separate important problem is to determine whether the arcuate shape of the Dundas-Fossey structure, and thus by association, the Mt Read Volcanics, is a primary palaeogeographic feature or whether it has been produced by bending of an originally more linear trend. Corbett (in Corbett and Turner, 1989, p.168) suggested that the parallelism of trends in the Dundas-Fossey arc with lithological trends in the underlying Precambrian Tyennan block indicate strongly that the bend is a superimposed tectonic feature, possibly formed during the Devonian.

(b) Eastern Tasmania terrane

The contrast between the eastern and western Tasmania terranes could hardly be more marked. Whereas the western Tasmania terrane has a relatively long and complex late Precambrian (since ~800 Ma) and Early Palaeozoic history, involving a diversity of rock associations from continental-margin to deep-marine, arguably associated with slices of ocean floor and a calc-alkaline volcanic arc, the exposed eastern Tasmania terrane comprises simply deep-water turbidites into which mid-Palaeozoic granitoids were emplaced. The oldest rocks (480 Ma) could well be younger than the inferred mid-Cambrian emplacement of the ultramafic sheet in the western Tasmania terrane, and younger than the Mt Read Volcanics.

Most tectonic models for the eastern Tasmania terrane involve deposition of quartzose clastics in a submarine turbidite apron derived from cratonic sources to the south-west. The Tamar fracture system is seen as a zone of significant sinistral (Williams, 1978) or dextral (Baillie, 1985) displacement, and thus the source of the turbidite apron may not have been the western Tasmania terrane.

The junction between the two terranes lies along the line of the Tamar River, where there is an abrupt change in rock type as well as structural style and symmetry. The main NNW-trending folds in the eastern Tasmania terrane verge eastwards, whereas those in the adjacent western Tasmania terrane verge WSW. Some people (e.g. Williams, 1989, p.489) consider that there is a sedimentary linkage between the eastern and western terranes in the Early Devonian, but this was discounted by Powell and Baillie (1992) on re-examination of the outcrops. There is thus no proven linkage between the two terranes until the later phase of WSW-verging deformation in the Middle Devonian (Williams, 1989; Powell and Baillie, 1992).

An important, but not widely publicised feature of the eastern Tasmania terrane is the widespread presence of megakinks in the regional NNW-trending structure (Goscombe and Findlay, 1989). These megakinks, known in the mainland continuation of the Lachlan Fold Belt from the work of Powell *et al.* (1985), involve sharp swings in the strikes of steeply-dipping axial-plane cleavage through angles of 12° to 43°, with angles of 16° to 18° being most common. Goscombe and Findlay (1989) estimate that the megakinks represent a NNW-SSE crustal shortening of 3 to 8 per cent, with compensatory ENE-WSW crustal extension, and no crustal thickening. The megakinks postdate the first generation of folds and intrusion of the Middle to Upper

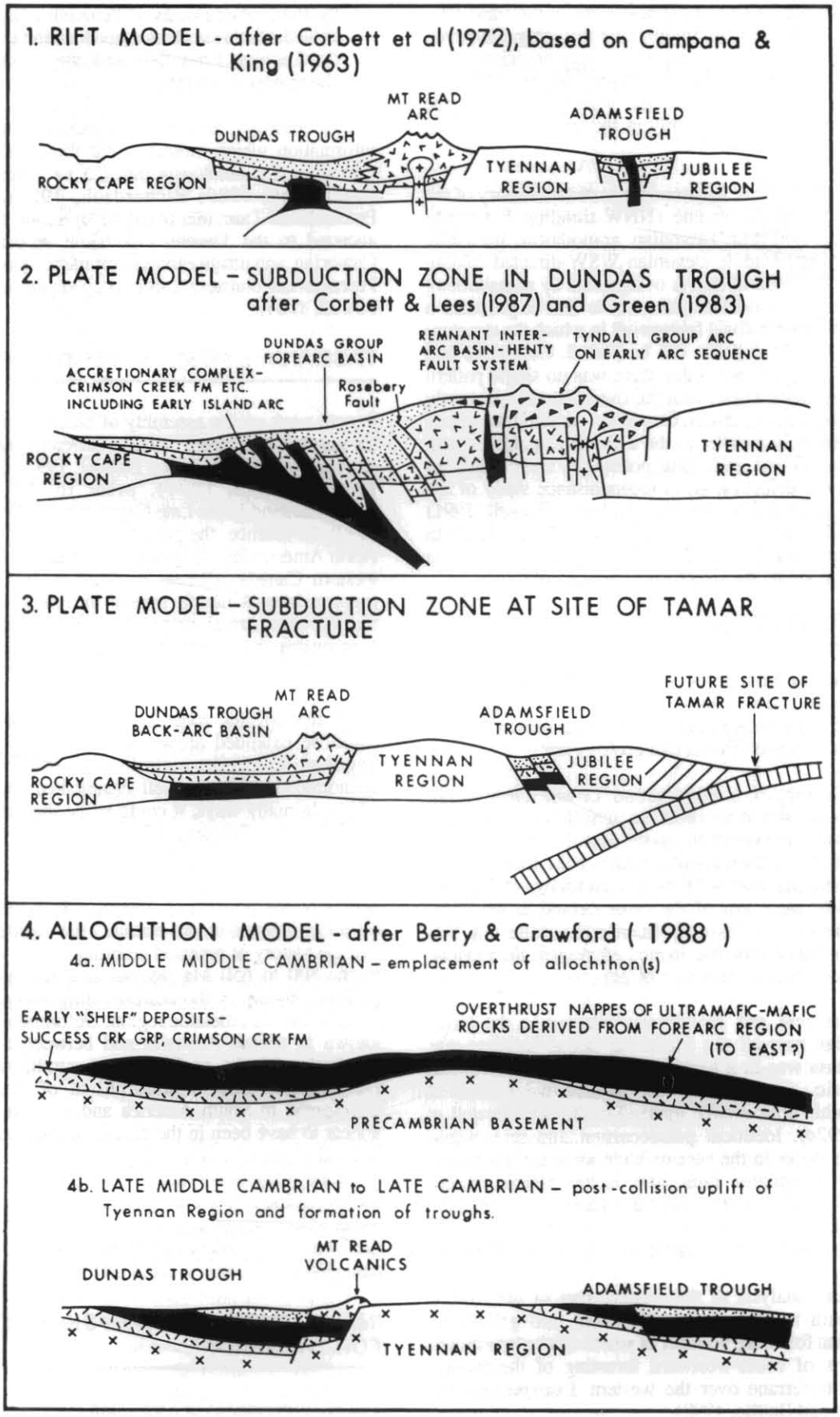


Figure 5

Schematic tectonic models for the western Tasmania terrane (from Corbett and Turner, 1989, p. 176).

5 cm

Devonian granodiorites, and appear to fit in the same time gap as the WSW-directed folding and thrusting. However, the kinks appear to postdate the S_2 cleavage associated with the WSW-directed thrusting (Powell and Baillie, 1992), and are thus probably formed in the waning stages of the thrusting, or afterward, possibly in the mid-Carboniferous (Powell, 1984*b*).

The importance of this 3-phase deformational history of the north-east Tasmania terrane (NNW-trending E-verging folding before Middle Devonian granodiorite intrusion, followed by late Middle Devonian WSW-directed folding and thrusting, which in turn is overprinted by megakinking which could be mid-Carboniferous) is that it provides a temporal and orientational framework in which the structure of individual gold deposits can be placed. Goscombe and Findlay (1989, p.19) noted that there was no single pattern to the gold-bearing veins, with the overall trend apparently not rotated by the megakinks. One of the common directions (032°) is precisely parallel to the sinistral megakink trend. They concluded that gold veins potentially were emplaced throughout the deformation. A reconnaisance study of the gold veins in the Lefroy-Beaconsfield area (Powell, 1991) suggested that the gold veins there could be related to WSW-directed folding and thrusting. Clearly, more work is required to evaluate the structural relations fully.

NEW INFORMATION

Recent structural and stratigraphic studies in Victoria and Tasmania have clarified relationships between some units, and opened up possible relationships with others. The most important of these for Tasmanian geology are:

1. Recognition of a widespread Lower Ordovician quartzose turbidite sheet in which palaeocurrent directions are consistently to the east or north-east. This apron extends throughout Lachlan Fold Belt, thereby demonstrating that both eastern and western Lachlan Fold Belt were part of the same terrane in the Early Ordovician. The eastern Tasmania terrane has this tectonostratigraphic unit in the Lefroy area (Stony Head Sandstone of Powell *et al.*, 1992*a*).

2. Palaeocurrent and provenance patterns in the Early Devonian part of the Mathinna Group indicate that deposition was in a basin elongate to the NNW, with cratonic sources to the south-west and a feldspathic/lithic source inferred to the east (Powell *et al.*, 1992*a*). Identical palaeocurrent and provenance patterns occur in the eastern Melbourne trough, where the Mt Wellington fault zone is the eastern margin (Powell *et al.*, 1992*b*). This connection across the Bass Strait ties the tectonic position of the eastern Tasmania terrane to the western Lachlan Fold Belt in the Devonian.

3. Structural analysis of the western part of the eastern Tasmania terrane shows there are two groups of Devonian folds, the younger of which can be interpreted in terms of south-westward thrusting of the eastern Tasmania terrane over the western Tasmania terrane (Powell and Baillie, 1992).

4. Recognition of the thrust-faulted nature of the contact between Precambrian rocks of the Badger Head block and Cambrian rocks of the Port Sorell region (Leaman *et al.* 1973; Elliot *et al.* 1992), and similar relationships in many other parts of Tasmania (Leaman 1986*a*, *b*; 1990) led Leaman *et al.* (1992) to postulate that most of the Precambrian rocks of Tasmania comprise a series of Palaeozoic thrust slices embedded in the western part of the Lachlan Fold Belt and the eastern part of the Kanmantoo Fold Belt.

These findings, taken in conjunction with published information which indicates that the crustal thickness in Tasmania is anomalously thin (23 to 27 km, Leaman and Richardson, 1989; Richardson, 1989), suggest that Precambrian Tasmania could be an exotic block or blocks accreted to the Tasman Fold Belt, probably during the Cambrian, and not an eastward promontory of the Australian Precambrian craton as previously depicted (Veevers and Powell, 1984).

TASMANIA'S POSITION IN GONDWANALAND

Recent work on the assembly of Gondwanaland has raised the possibility of some radically different palaeogeographic reconstructions (fig. 6; see Dalziel, 1991, 1992; Hoffman, 1991: Moores, 1991), prior to the assembly of Gondwanaland in the Late Cambrian (fig. 7; Li and Powell, 1992). In essence, the postulate is that the western part of North America lay alongside Australia and Antarctica, with western Canada adjacent to south-eastern Australia. My purpose here is not to review the merits of the various possible reconstructions, but to point out the importance such a reconstruction could have once the best fit has been determined.

First, metallogenic zones known to exist in one continent could be extended along strike into another continental fragment. Lineament control on the distribution of major economic deposits is well established (e.g. O'Driscoll, 1985). In many ways, it could be be the matching of such now-disjunct features which will fine-tune the most acceptable fit.

Secondly, the position of Tasmania in the pre-Gondwanan assembly is by no means certain. I have already pointed out that the history of repeated deformation and metamorphism in the 800 to 650 Ma interval is quite unlike the stable platform history of the nearest contiguous part of cratonic Australia in the Adelaide region. Deformation of this age is known in central Australia and between the Pilbara and Kimberley blocks of Western Australia (Myers, 1990). Deformation and metamorphism of this age is also widespread in South America and western Africa, which appear to have been in the process of amalgamation in this interval (Ramos, 1988). It is possible that either or both of the Rocky Cape and Tyennan regions could have come from the Argentine region during the early Cambrian breakup of the pre-Gondwanan supercontinent, and become welded to the Tasman Fold Belt during the Late Cambrian. Careful palaeomagnetic study is required to test this hypothesis.

IMPLICATIONS OF A THIN-SKINNED MODEL FOR TASMANIA

The full implications of a thin-skinned model for the crustal structure of Tasmania have yet to be worked through, but some preliminary comments can be made.

1. The stratigraphic order and/or tectonic zonation of economic deposits could be attenuated, duplicated or reversed, depending on the geometry of the thrust faults present.

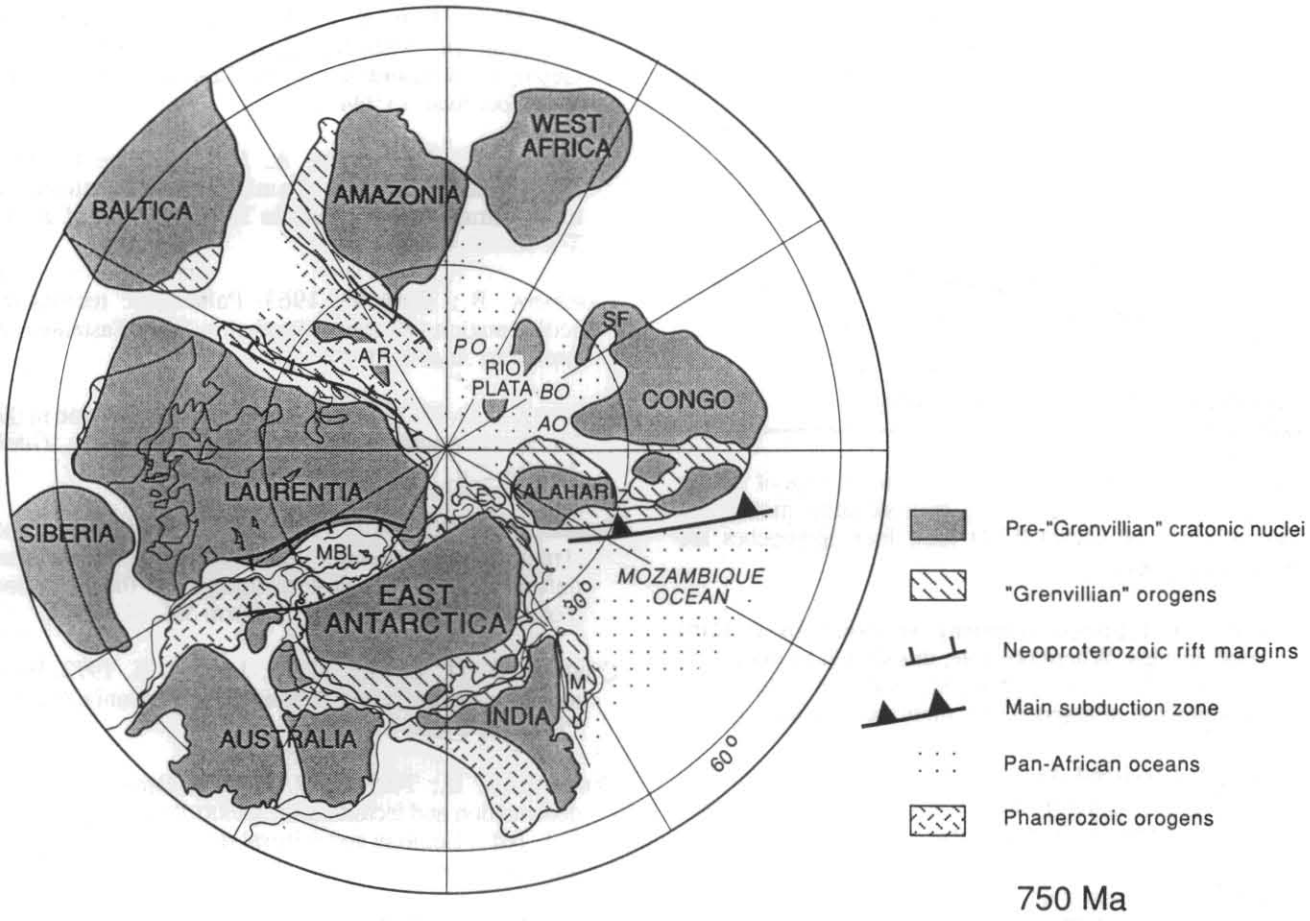


Figure 6

Late Precambrian supercontinent reconstruction from Dalziel (1991, 1992). Note Tasmania's position within the Neoproterozoic rift.



Figure 7

End-Cambrian Gondwanaland reconstruction from Dalziel (1991, 1992).

5 cm

2. Exploration models based on assumptions about a normal stratigraphic order for the rock successions will need re-evaluation to determine if thrust repetitions could have occurred.

3. Exploration strategies based on rift models may have to be re-evaluated if the target host rocks are shown to be slices of a now-dismembered terrane.

4. It may be worth exploring beneath Precambrian slices if the right kinds of deposit and structural geometry present themselves.

WHERE DO WE GO FROM HERE?

Like all novel hypotheses, there needs to be a lot of testing of the framework before the thin-skinned model for Tasmania can be accepted. At least four approaches are worthy of support.

1. Further detailed mapping in areas of crucial relationships. Where possible, this should be done with full geophysical support so that the subsurface continuation of mapped structures can be constrained.

2. Selected diamond-drilling should be carried out in areas of potential economic interest to delineate the shapes of possible thrust-fault structures.

3. More palaeomagnetic studies should be carried out to determine when the Rocky Cape and Tyennan regions became welded to the Australian craton, and whether the arcuate shape of the Mt Read Volcanics is primary, or a result of later deformation.

4. There should be an integrated approach by Industry, Government and academic organisations to obtain funding for one or more deep seismic profiles across structures of major interest.

It is salutary to note in this regard the recent revolution in geological thought about classical fold belts such as the Appalachians of North America, which has come about in the last 10 years solely from the results of the COCORP seismic reflection profiles. The short deep-crustal profile in central Victoria (Gray *et al.*, 1991) raises possibilities that there could be wholesale mid-crustal detachment in the western Lachlan Fold Belt.

ACKNOWLEDGEMENTS

This work is derived from almost two decades of field work in the south-eastern Tasman Fold Belt, supported mainly by the Australian Research Council and its precursors, Macquarie University and the University of Western Australia. Field work supported by ARC grants E83 15504 and A38831488 is especially acknowledged, as well as the collaboration with P. W. Baillie of the Tasmania Mines Department, which has been particularly useful. Mrs D. Baillie drafted one of the diagrams at very short notice.

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Changes in the Earth Sciences

S. M. RICHARDS
Managing Director, Aberfoyle Limited

Changes in attitudes to funding and organisation of earth sciences research and research training in Australia reflect world wide changes in attitudes to research of any kind.

From a company point of view, to stay competitive it is essential to develop a culture of continuous improvement. Technology, research and development, and business strategy must be integrated across the whole corporation. Outcomes are being measured against business and technological objectives. Partnerships need to be developed between the researchers and their customers.

In the public sector, the CSIRO Priorities exercise, the Key Centres of Excellence and the Cooperative Research Centres are all manifestations of the same trend.

In earth science in particular, there will be increasing emphasis on research in particularly Australian problems - for example, the regolith with particular attention to soil and water quality for agricultural purposes, and to its overall character insofar as it impedes successful exploration.

Many explorers are no longer satisfied with conventional "recipe" search models, but want site specific models capable of change and evolution as new information is obtained. To develop such models, explorers need to be part of the research process, not separate from it. The kind of research explorers are most likely to support is that which fits most closely with business objectives.

Earth sciences also have a crucial emerging role in reconciling the development and conservation approaches to sustainable development. The clients will be either industry or "national interest", insofar as the whole community, including industry, is expecting well informed land use decisions.

RICHARDS, S. M. 1992. Changes in the Earth Sciences. *Bull. geol. Surv. Tasm.* 70:188.

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Geology and geophysics of the Lisle–Golconda goldfield, northeast Tasmania

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ABSTRACT

The Lisle–Golconda goldfield contains a number of different styles of gold mineralisation. The majority of gold production came from alluvial workings in the Lisle valley. No obvious hard rock source for this alluvial gold has been found.

Studies of gold-grain morphology and internal structure support the contention that much of the gold at Lisle is of secondary origin. Gold appears to have been precipitated within the unconsolidated sediments from groundwater containing low concentrations of gold by the action of humic compounds and biological agents.

Many of the gold occurrences within the goldfield are closely spatially associated with cupolas of granodiorite. Regional geophysical data has been used to attempt to constrain the subsurface distribution of granitic rocks within the study area.

GEOLOGY

The Lisle–Golconda goldfield is situated approximately 30 km northeast of Launceston in northeastern Tasmania (fig. 1). The goldfield was the site of considerable mining activity in the latter half of the 19th century, and contains a variety of different styles of gold mineralisation. A number of historical gold mining areas occur within the boundaries of the region here referred to as the Lisle–Golconda goldfield. These include the Lisle, Cradle Creek, Lone Star, Golconda, Panama, Denison and Lebrina goldfields. Detailed descriptions of each of these fields are provided by Thureau (1882), Twelvetrees (1909) and Reid (1926). The geology of the region is shown in Figure 2.

The study area lies to the west of the bulk of the Devonian Scottsdale Batholith which intruded the Mathinna Beds, a thick, poorly-documented succession of regionally metamorphosed turbiditic sediments of presumed Siluro-Devonian age. The Mathinna Beds crop out over much of the study area, where they consist of steeply-dipping, NW-trending beds of quartzite with minor finer-grained interbeds. The topography in the northern portion of the region is subdued, and outcrop is poor or obscured by widespread Tertiary sediments and Quaternary alluvium. To the south, the land surface rises abruptly towards a deeply-dissected plateau approximately 600 m above sea level. In the far southwest of the area the Jurassic dolerite-capped peak of Mount Arthur rises above the plateau to a height of over 1100 metres. Tertiary basalt flows are present, both on the plateau and at a number of isolated locations at lower levels to the north.

Many of the known sites of gold mineralisation show a close spatial association with small cupolas of granodiorite which have intruded the Mathinna Beds up to 10 km west of the main boundary of the Scottsdale Batholith. The granodiorite is highly weathered at the surface, and its outcrop is often obscured by surficial sediments. Granodiorite was exposed by mining activities in the Lisle, Golconda, Panama and Lone Star goldfields. The outcropping areas of granodiorite are interpreted to be the apical regions of a larger subsurface body, the extent of which is roughly delineated by the extent of the mapped area of hornfelsed sediments.

A particularly prominent feature of the intrusions is their surface expression. Marked topographic depressions occur in all areas where the granodiorite is exposed. The strongly-hornfelsed sediments within the contact aureole of the intrusion are resistant to both chemical and mechanical weathering, while the granodiorite appears to be particularly susceptible to chemical breakdown, and is consequently eroded. The largest of these features is associated with the intrusion at Lisle (fig. 3). Here the resultant crater-like feature has dimensions of approximately 4×5 km and a depth of up to 350 metres. The slopes on the flanks of the depression are steep, and considerable thicknesses of talus have been shed from the enclosing ridges into the basin, the floor of which is flat or gently undulating. The single hydrological outlet from the Lisle valley is to the north through a narrow, deeply incised gully. The smaller intrusions, such as at Panama or Golconda, display the same basic form as the intrusion at Lisle (fig. 3).

MINERALISATION

The Lisle–Golconda goldfield is unusual for mining districts in northeast Tasmania in that in excess of 95% of all the gold recovered was won from alluvial workings. The vast majority of this production came from the Lisle goldfield, which has produced an estimated 250,000 ounces of gold. Despite the high alluvial production no obvious source of the alluvial gold was found.

Gold was first discovered at Lisle in 1879 by Charles Bessell. Initial returns from claims on the floor of the valley of Lisle Creek were very high and a gold rush ensued. By the end of 1879 3000 miners were working claims within the field (Twelvetrees, 1909). By 1885 most of the highly productive ground had been worked over, and the majority of claims

ROACH, M. J. 1992. Geology and geophysics of the Lisle–Golconda goldfield, northeast Tasmania. *Bull. geol. Surv. Tasm.* 70:189–198.

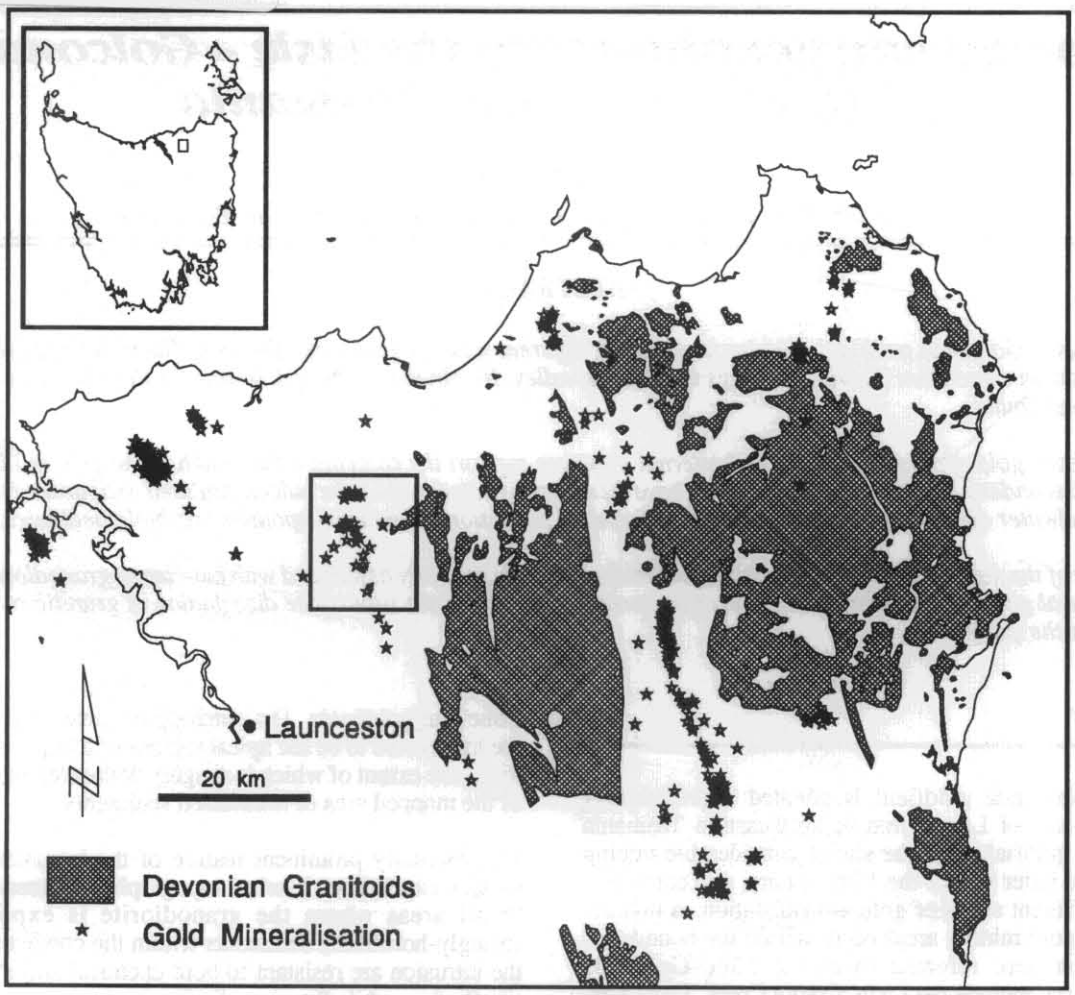


Figure 1

Locality diagram showing the boundaries of the Lisle–Golconda Goldfield, the distribution of Devonian granitic rocks, and gold mineralisation locations from the Tasmania Department of Mines MIRLOCH database.

were abandoned. By 1900 the field as a whole was largely abandoned. A large amount of prospecting work was carried out by miners in the 1880s with the aim of finding the source of the gold at Lisle. With the exception of a few thin quartz veins, both within the granodiorite and the adjacent Mathinna Beds, no source of detrital gold was discovered.

The gold mined at Lisle had a number of unusual characteristics. These were recorded by both Twelvetrees (1909) and Reid (1926):

- The gold was extremely fine in grainsize, generally less than 0.4 mm in diameter. Nuggets were rare.
- Gold was rarely found with vein quartz attached.
- The gold was generally of very high fineness.
- Gold concentrations were highest in wash material immediately overlying the weathered granodiorite surface.
- Gold was often concentrated within sediments with either a high organic carbon content or with wash material stained with manganese oxides.

Production from the Lone Star valley was small, with almost all of the production from alluvial workings. The mineralisation at Lone Star displayed many of the features characteristic of the deposits at Lisle. In contrast, at Golconda and Panama where the underlying intrusion is only just exposed, almost all of the gold came from quartz veins within the granodiorite. Very little alluvial gold was recovered from these fields.

Gold production from the region of Cradle and Tobacco Creeks was from a combination of alluvial workings, thin quartz veins hosted by the Mathinna Beds, and from material referred to by Reid (1926) as "gold impregnated sandstones". Here there is no exposed granodiorite, however many of the mineralised sites lie close to the mapped contact aureole, suggesting the presence of granodiorite at relatively shallow depths.

The majority of the historical production from the Denison and Lebrina goldfields came from well-defined, roughly east-west trending quartz veins within the Mathinna Beds. These vein deposits are remote from the mapped contact aureole of the granodiorite. Minor amounts of alluvial gold were also recovered from Denison; these deposits were clearly sourced from the adjacent quartz veins.

ALLUVIAL GOLD

Samples of alluvial gold from the Lisle and Denison goldfields were obtained by panning. The morphology of the

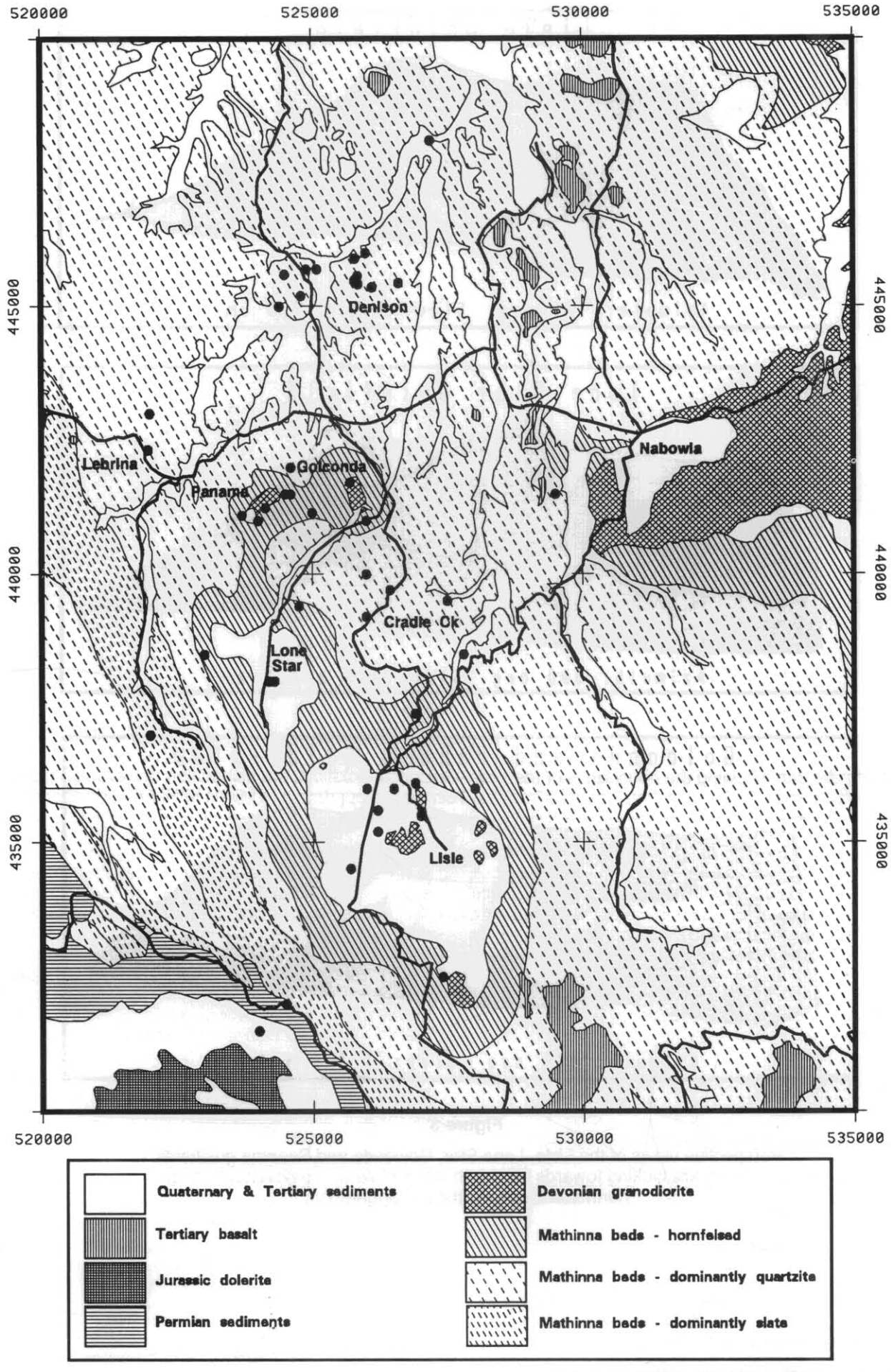


Figure 2. Geology of the Lisle–Golconda Goldfield. Mineralised locations from the MIRLOCH database are shown as black dots. (1:100 000, AMG grid).

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4/11

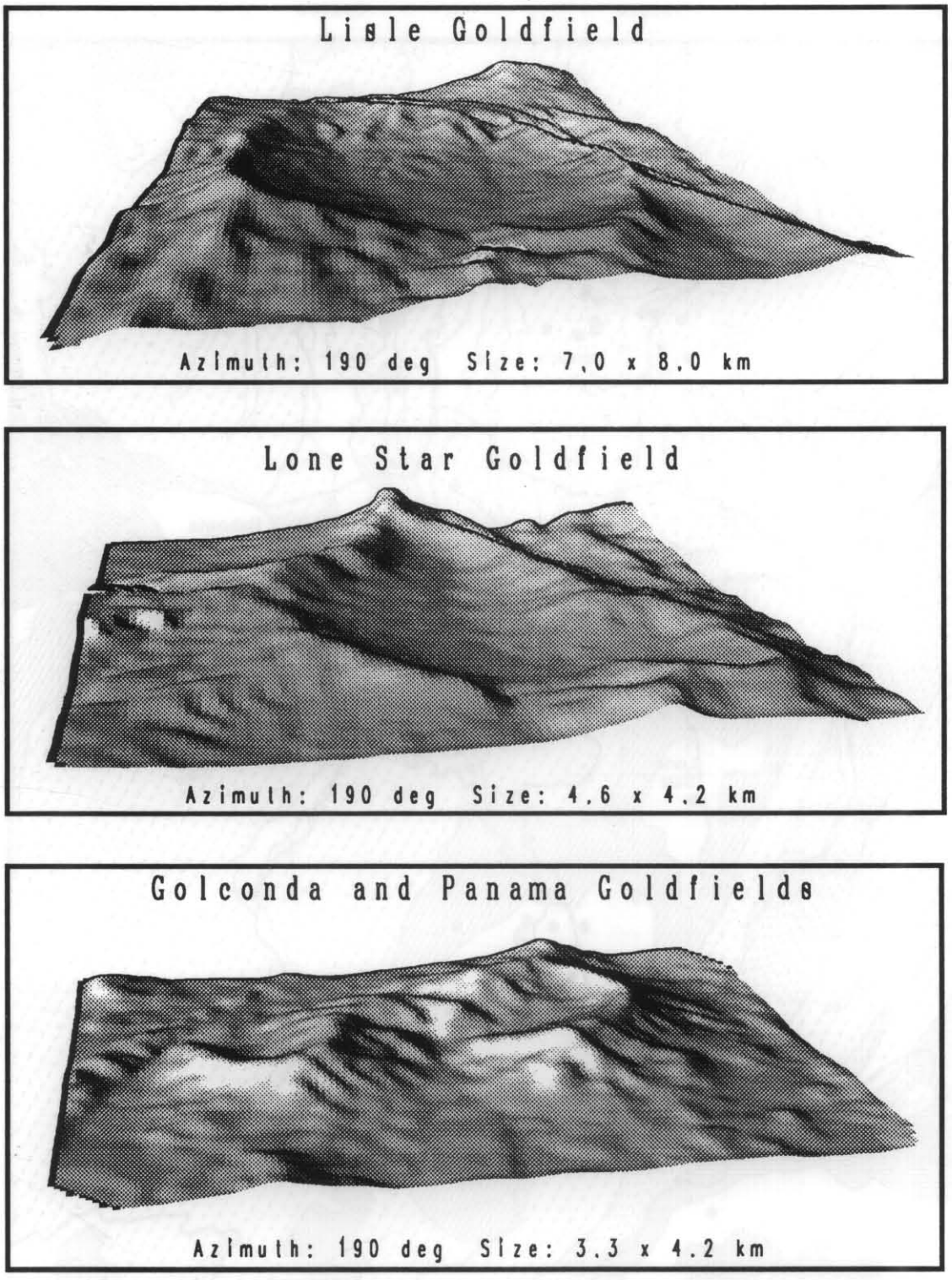


Figure 3

Perspective views of the Lisle, Lone Star, Golconda and Panama goldfields. All views are looking towards the south with simulated illumination from the northeast and no vertical exaggeration.

5 cm

gold grains obtained in this way was recorded using both optical and scanning electron microscopy. Alluvial grains from Denison were clearly derived from the adjacent quartz veins.

Gold grains from Denison were typically larger than those recovered from Lisle, however there was a wide variation within each sample set. The overall morphology of grains from both locations was similar, with grains ranging from sub-rounded to well rounded in both samples. A number of the grains from Denison had pieces of vein quartz embedded within them, but this was not observed in the samples from Lisle. Several grains from Lisle had partial black coatings of oxides; this feature was not observed in the samples from Denison. In detail the grains from Lisle had an irregular or rough surface texture while the majority of those from Denison had a smooth surface. These characteristics support the contention that the mode of formation of the alluvial deposits at the two locations was different.

The gold grains from both locations were mounted in resin and polished to reveal their internal structure. Many of the grains from both localities displayed the thin gold-rich rims discussed by Groen, Graig and Rimstidt (1990). At Denison all of the gold grains were solid and displayed no internal structure. In contrast, many grains from Lisle showed evidence for complicated internal structures. This feature was best developed in a sample from the Tasmanian Alluvials lease at Lisle, supplied by R. S. Bottrill from the Tasmania Department of Mines. In this sample, the majority of grains showed evidence of complicated internal structures. Examples of some of the more spectacular textures are shown in Plate 1. There is a clear gradation between textures such as these and apparently solid grains. The fineness of most of this gold is very high, in excess of 980. The regions between the gold layers are now voids and, consistent with the observations of Twelvetrees (1909) and Reid (1926), may have originally been layers of organic material. Baker (1978) suggested the importance of humic compounds in the transportation and deposition of gold at Lisle. The extremely fine textures may also be suggestive of biological involvement in gold deposition (Mineyev, 1976).

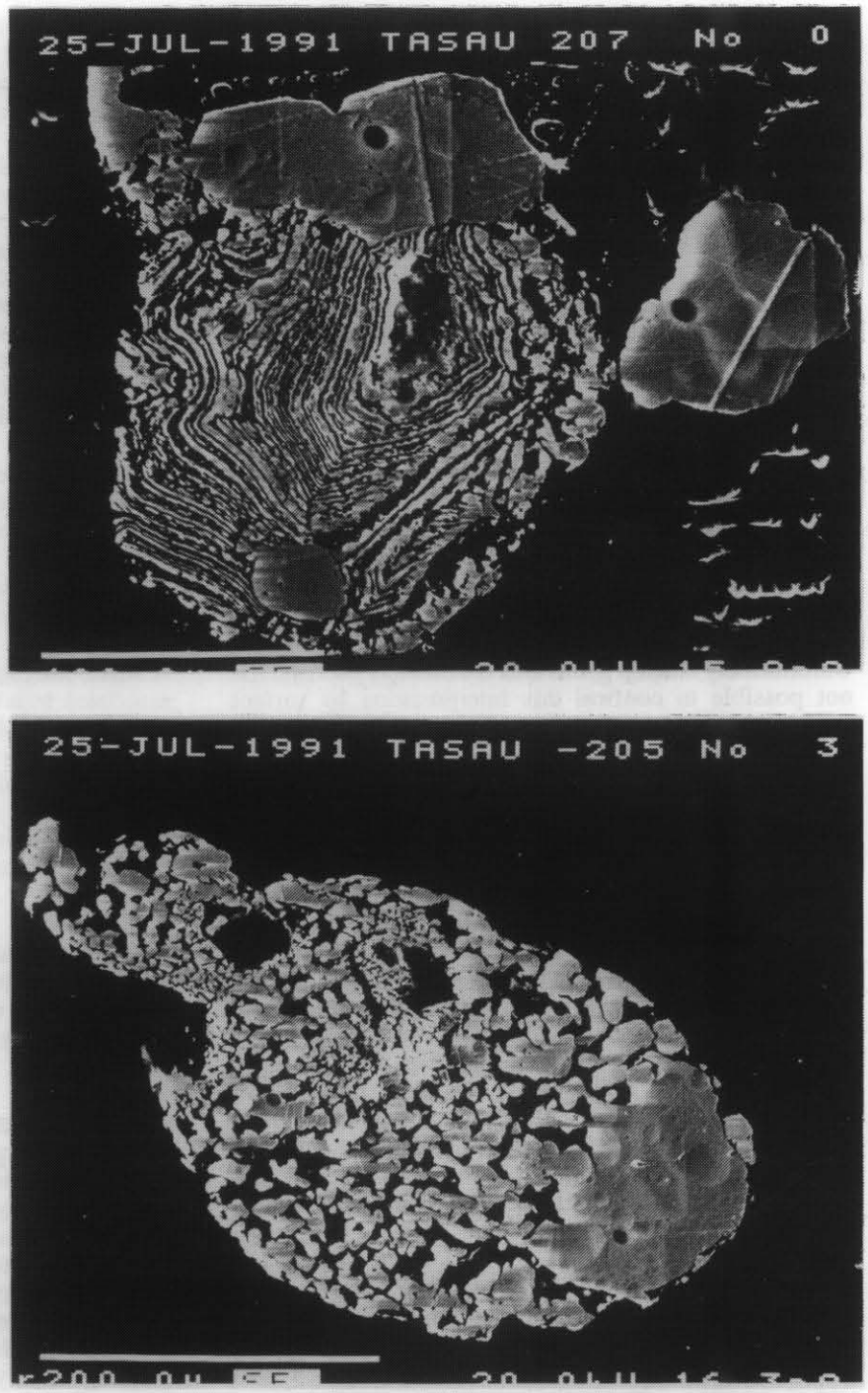


Plate 1

SEM photomicrographs of sections through two gold grains from the Lisle goldfield. Sample from the Tasmanian Alluvials lease at Lisle, courtesy R. S. Bottrill. Scale bar is 200 µm.

The textural evidence supports the contention of Reid (1926) that "all the gold won from detrital and alluvial deposits is of secondary origin". At this stage the primary source of the gold is unknown. Work is in progress to measure the background gold concentrations of the granodiorite and the adjacent Mathinna Beds to determine whether the volume of material eroded from the valley could account for the inferred gold resource. The geomorphology of the valley, with its thick layer of sediments and largely enclosed hydrology, is almost certain to have strongly influenced the process of secondary enrichment of gold in the placer.

GEOPHYSICS

Regional geophysical data was used to provide some constraints on the gross structure of the goldfield, in particular the form of the associated granitic intrusions and

6/11

their relationship to known mineralisation. In addition the geophysical data also provided important information on the composition of the exposed granitic rocks.

An aeromagnetic survey covering the entire region was conducted in 1983 by Seltrust Minerals (Storer, 1985). An image of this dataset is shown in Figure 4*, together with an overlay of geology and gold mineralisation locations from the Tasmania Department of Mines MIRLOCH database.

The isolated high-frequency negative magnetic anomalies closely correspond to the mapped outcrop of Tertiary basalt flows, and indicate a strong reverse remanent magnetisation.

The linear NW-trending anomalies occur above areas of Mathinna Beds outcrop. The trend of these anomalies is parallel to the regional strike, and they are inferred to result from magnetic units within the Mathinna Beds. Highly weathered samples of these units have magnetic susceptibilities ranging from 2 to 8×10^{-3} SI. Many of these linear anomalies are abruptly truncated along an irregular boundary trending roughly NE. This is suggestive of the presence of a major structural feature with this orientation. Unfortunately outcrop in this area is extremely poor and it is not possible to confirm this interpretation by surface mapping.

An irregular magnetic anomaly is associated with a portion of the Lisle goldfield. This anomaly results from a magnetic component of the exposed granodiorite. Clearly, however, the granodiorite is not uniformly magnetic, the strong anomaly being restricted mainly to the northeastern corner of the valley. Outcrop within the Lisle basin is extremely poor and there is only one location in the south where it is possible to sample granodiorite which is not totally weathered. Here it consists of a uniform grey, medium to fine-grained hornblende, biotite granodiorite. Both highly magnetic and effectively non-magnetic samples were obtained from this location. The two rock types appear identical in hand specimen. Many measurements were taken on the available outcrop, yielding susceptibility values of either less than 0.3×10^{-3} SI or between 4 and 12×10^{-3} SI. The average measured density of both rock types was 2.71 t/m^3.

A zone of magnetic anomalies resulting from the magnetic granodiorite stretches north from the Lisle valley to Panama. A small anomaly is associated with the outcropping granodiorite at Panama but no anomaly is directly associated with the intrusion at Golconda. Samples of granodiorite from the dump of the Enterprise mine at Golconda, and from the Department of Mines Lisle DDH 1 and 2 near Golconda, confirm the bimodal distribution of magnetic susceptibility. From a magnetic perspective there are clearly two different types of granodiorite within the Lisle–Golconda area. The differences in magnetic responses are not simply the result of either weathering or alteration.

The magnetic survey extends east to the western margin of the Scottsdale Batholith near Nabowla. The granodiorite exposed at Nabowla is very similar in hand specimen to the Lisle granodiorite. It has a magnetic susceptibility of approximately 0.2×10^{-3} SI and a density of 2.71 t/m^3.

A low amplitude, very long wavelength anomaly is apparent in the north of the survey. This represents the southern margin of a major regional magnetic anomaly delineated by the Bureau of Mineral Resources regional magnetic coverage. Its amplitude and wavelength are indicative of a deep, highly magnetic source beneath the Mathinna Beds.

A semi-regional gravity survey was conducted in order to attempt to further constrain the distribution of granodiorite. Existing data from the Department of Mines gravity database was infilled to a density of approximately one station per square kilometre over the majority of the area. A grey-scale image of residual Bouguer anomaly is shown in Figure 5. The residual Bouguer anomaly map was derived using the 1991 version of the Tasmanian regional gravity field of Leaman and Richardson (1989). Bouguer corrections were made for a density of 2.67 t/m^3.

A large negative anomaly is associated with the Scottsdale Batholith. The minimum of this anomaly, to the east of the study area, is consistent with a thickness of approximately 8 km of granite with a density of 2.62 t/m^3. The effective boundary of this large anomaly extends well beyond the mapped outcrop of the batholith.

A small, irregular minima in residual Bouguer anomaly is associated with the bulk of the Lisle granodiorite. This is consistent with the low density contrast (-0.04 t/m^3) between the granodiorite and the enclosing Mathinna Beds, which have a measured density of 2.75 t/m^3. A more pronounced local minimum in the gravity field is located to the north beneath the Denison goldfield. This anomaly occurs in an area of Mathinna Beds outcrop, remote from exposures of granodiorite.

Two dimensional forward modelling of gravity and magnetic data was conducted for a series of sections oriented approximately east-west. An example of one of these sections, passing through the Lisle valley, is shown in Figure 6.

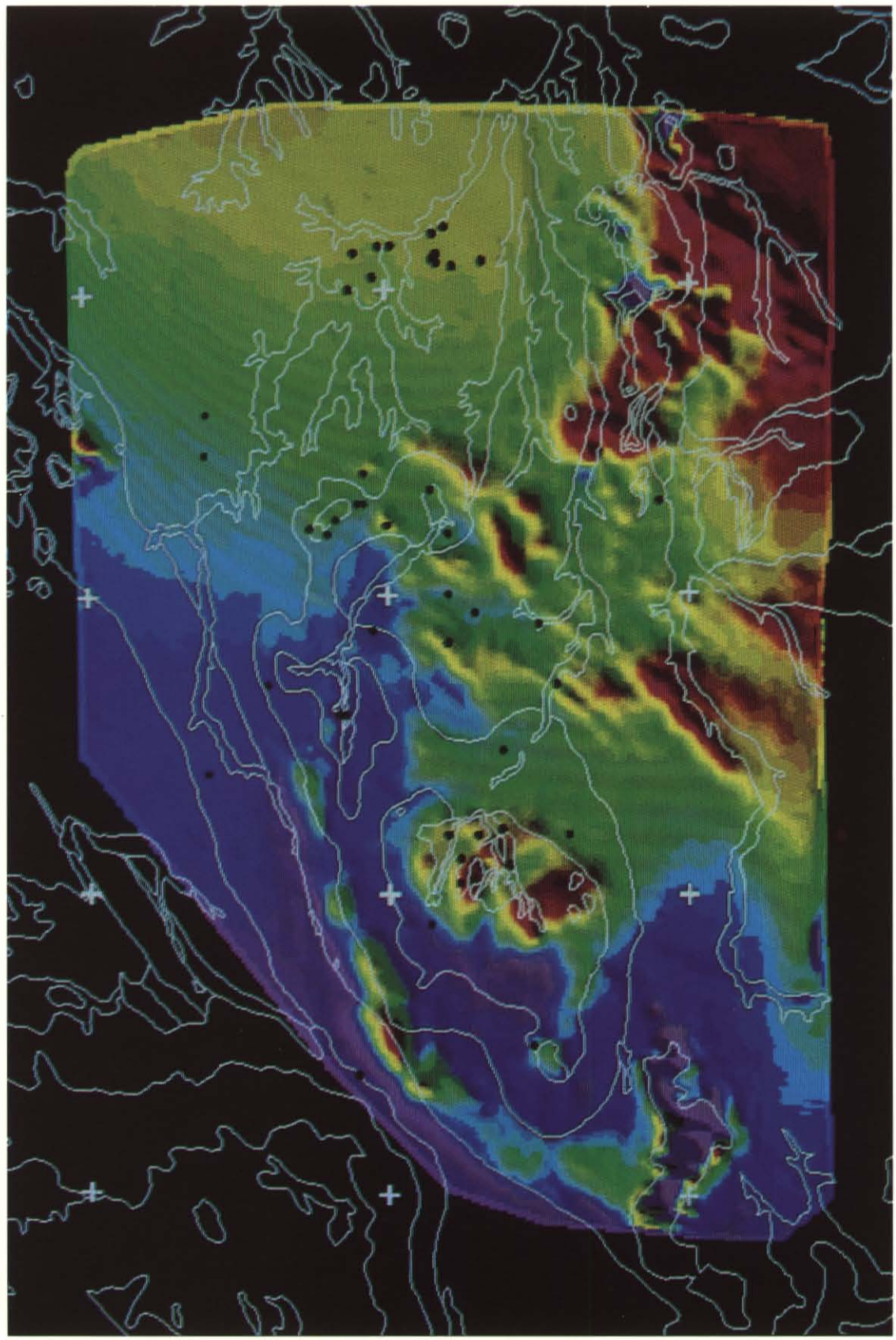
The measured density of the granodiorite which crops out on the western margin of the Scottsdale Batholith is 2.71t/m^3. The magnitude and gradient of the gravity anomaly in this area immediately implies that this granodiorite is relatively thin and that it is underlain by large volumes of low density granite, presumed to be similar in properties to the granite exposed near Scottsdale. The thickness of the corridor of Mathinna Beds sediments separating the Lisle granodiorite and the Scottsdale Batholith is poorly constrained because of the low density contrast between the Mathinna Beds sediments and the granodiorite. For the section shown in Figure 6, the thickness of Mathinna Beds lies between 3 and 4 kilometres.

The flattening of the gravity profile associated with the Lisle intrusion implies the presence of large volumes of granodiorite in the subsurface. The magnetic data acts to further constrain the model. The sharp peaks in the observed magnetic field at Lisle result from the geometry of the upper surface of the magnetic granodiorite. The wavelength and amplitude of the overall anomaly, however, provides an indication of the total volume of the magnetic component, suggesting a thickness of up to 2.5 kilometres.

The gravity low in the area of the Denison goldfield has no associated magnetic anomaly. The anomaly runs across the regional Mathinna Beds strike. Approximately ten gravity

* Figure 4 is located in the pocket at the rear of this bulletin.

7/11



5 cm

Figure 4.
(M. J. ROACH — *Lisle–Golconda goldfield)*

Lisle–Golconda aeromagnetics with geology and gold occurrence locations overlayed. Magnetic data from Seltrust Minerals 1984 aeromagnetic survey. Gold mineralisation data from Tasmania Department of Mines MIRLOCH data base. Geological boundaries digitised from the Pipers River and Launceston 1:63 360 scale geological maps. The image is approximately 12.7 × 18.8 km with a 5 km grid.

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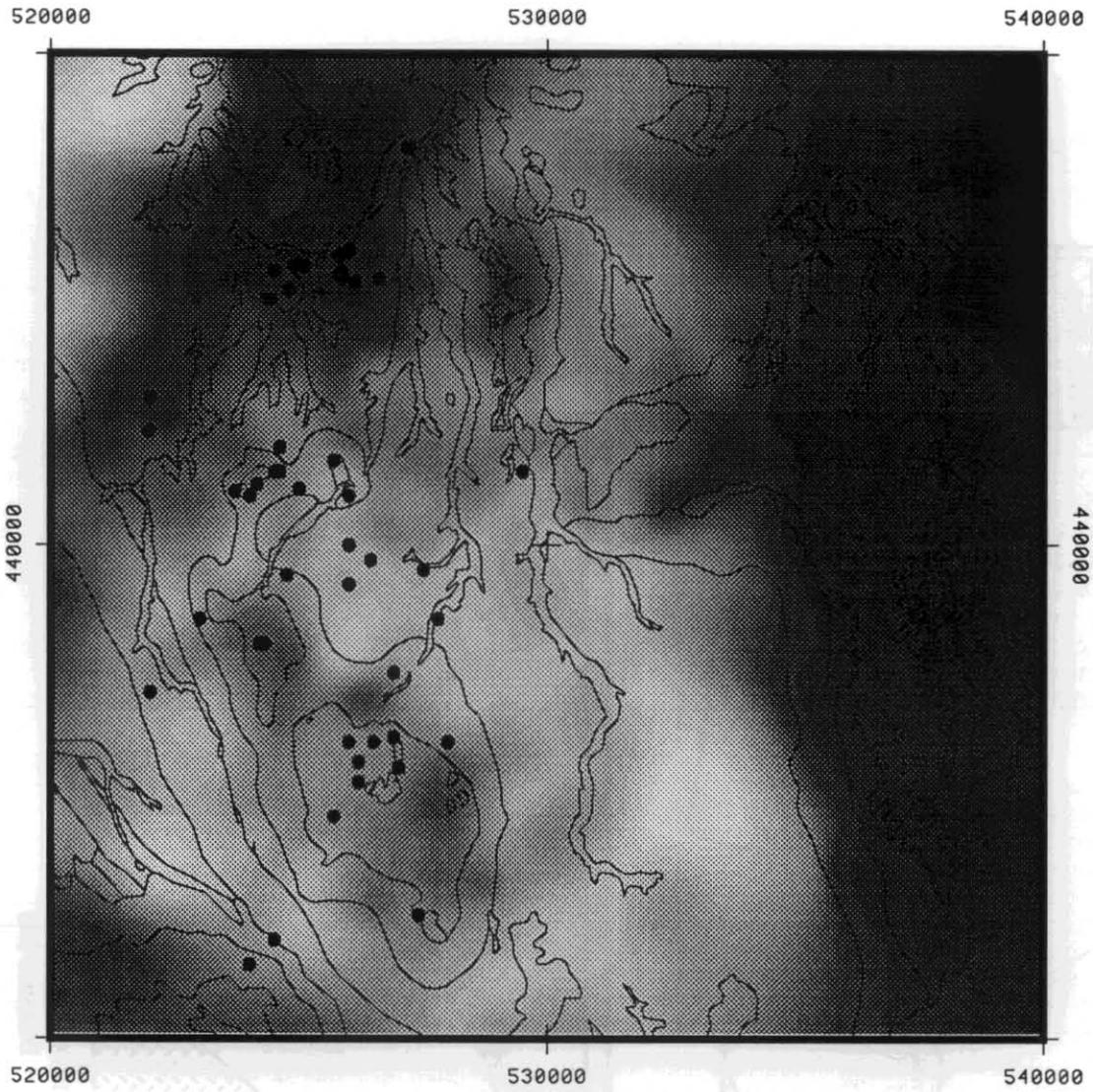


Figure 5

Grey-scale image of residual Bouguer anomaly with geology and gold occurrence locations overlaid. Bouguer reduction density 2.67 t/ m^3, Mantle91 regional field removed (Leaman and Richardson, 1989) (1:150 000, AMG grid).

stations fall within its boundary. The anomaly does not correlate with the mapped distribution of Tertiary and Quaternary sediments.

The most likely explanation for this anomaly is the presence of a subsurface granitic intrusion. The Mathinna Beds are exposed across the entire area and there is no additional outcrop information with which to constrain the gravity model. As a result, the geometry of the inferred body is determined principally by the chosen density contrast. It is possible, however, to place an upper limit on the body's density due to the fact that no contact aureole has been mapped at the surface. This results in an upper estimate of 2.65 t/m^3 and implies that the pluton beneath the Denison goldfield has a different composition to the granodiorite exposed at Lisle and Golconda, where the measured density is 2.71 t/m^3.

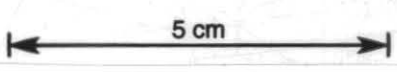
GRANITE CHEMISTRY AND PETROLOGY

The marked variations in the magnetic susceptibility of the various granodiorite units suggested that the these units may also be distinctive geochemically. A suite of 15 samples from Lisle, Golconda, Panama and the western margin of the Scottsdale Batholith, known as the Diddleum pluton (McClenaghan, 1989), were analysed for major and trace elements. Plots of Sr vs Rb and K_20 vs Al_20_3 are shown in Figure 7.

There appears to be a fairly clear distinction between the rocks of the Scottsdale Batholith and the granodiorite from the Lisle area. There is also a possible geochemical difference between the magnetic and the non-magnetic rocks from Lisle.

Figure 8 shows a Sr vs Rb plot for selected Tasmanian granitoids, including the analyses from Lisle. The granodiorites from the Lisle area fall within a well-defined field. In terms of Rb and Sr, the Lisle granodiorite is the least fractionated of the Tasmanian granitoids.

Thin sections of the various granite samples were examined in an attempt to explain their variable magnetic properties. All the samples, including those from the Scottsdale Batholith, contain small amounts of finely disseminated magnetite and ilmenite. The strongly magnetic samples from Lisle and Golconda were distinguished by the presence of



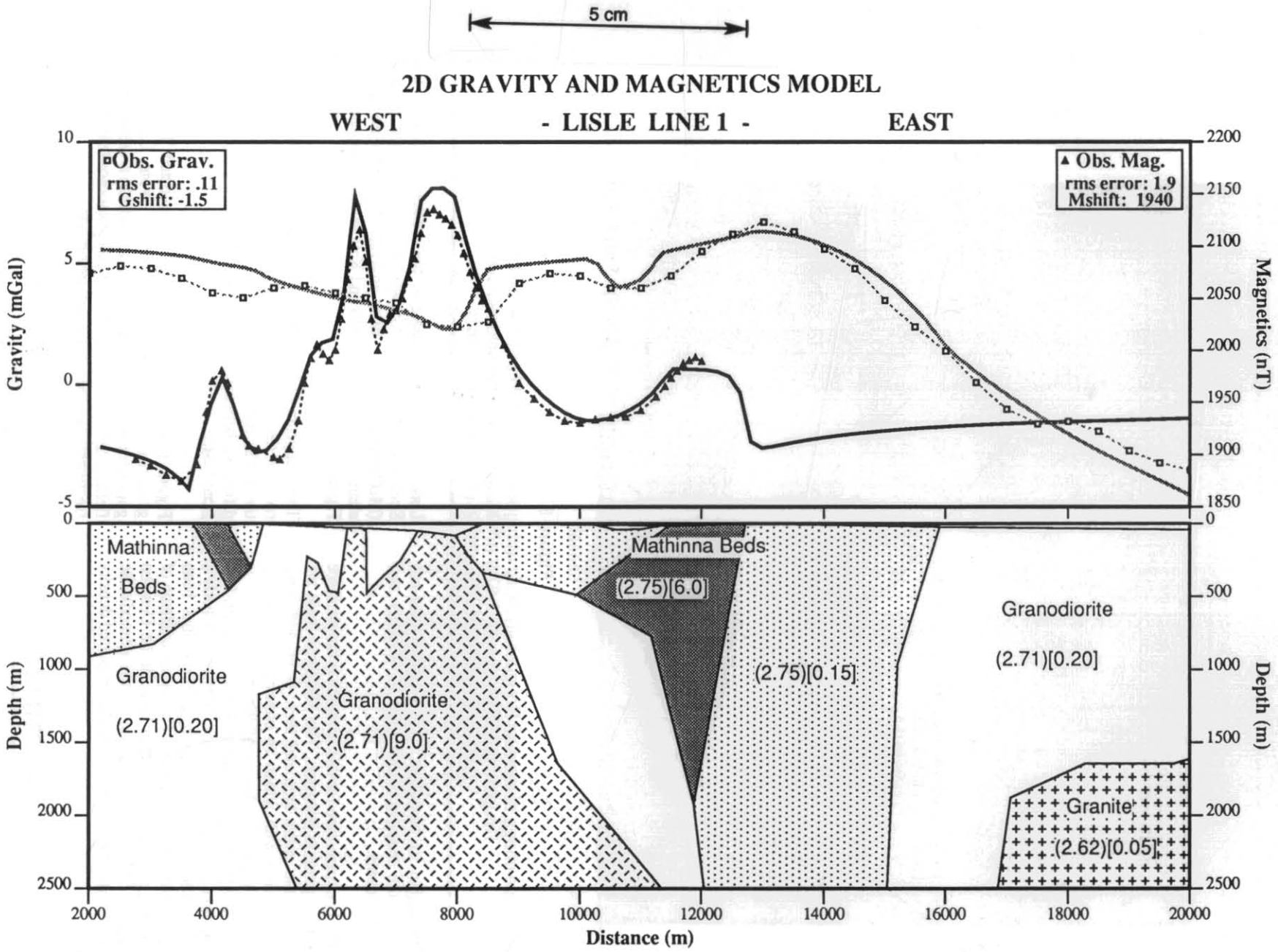


Figure 6. Two-dimensional gravity and magnetics model section crossing the Lisle valley. Values in curved brackets are densities (t/ m^3), values in square brackets are magnetic susceptibilities [$\times 10^{-3}$ SI].

aggregates of magnetite associated with clots of hornblende and biotite.

SUMMARY AND CONCLUSIONS

1. Gold grain textures and the features of the alluvial deposits suggest that a significant proportion of the alluvial gold recovered from the Lisle goldfield is of secondary origin, precipitated from gold-rich groundwaters through a combination of chemical and biochemical processes.

2. The geomorphology of the Lisle basin is a significant factor in the development of the alluvial deposit. The thick layers of sediment, and the restricted hydrology within the valley, have led to an environment which is favourable for the secondary remobilisation and precipitation of gold.

3. Geophysical and geochemical data indicate that the granodiorite exposed at Lisle is different in physical properties and composition from the western portion of the Scottsdale Batholith. The Lisle granodiorite is a separate and distinct intrusion.

4. The Lisle granodiorite may be subdivided into a magnetic and a non-magnetic phase. There are slight geochemical differences between the two lithologies. The distribution of the two phases, and field relationships between them, is complex. The relative importance of either phase as a potential source of gold is unknown.

5. Gravity data suggests that a subsurface granitic intrusion underlies the Denison goldfield. Geophysical modelling is poorly constrained, however the implied maximum density of the intrusive rocks suggests that the composition of this pluton is different to the composition of the granodiorite exposed at Lisle.

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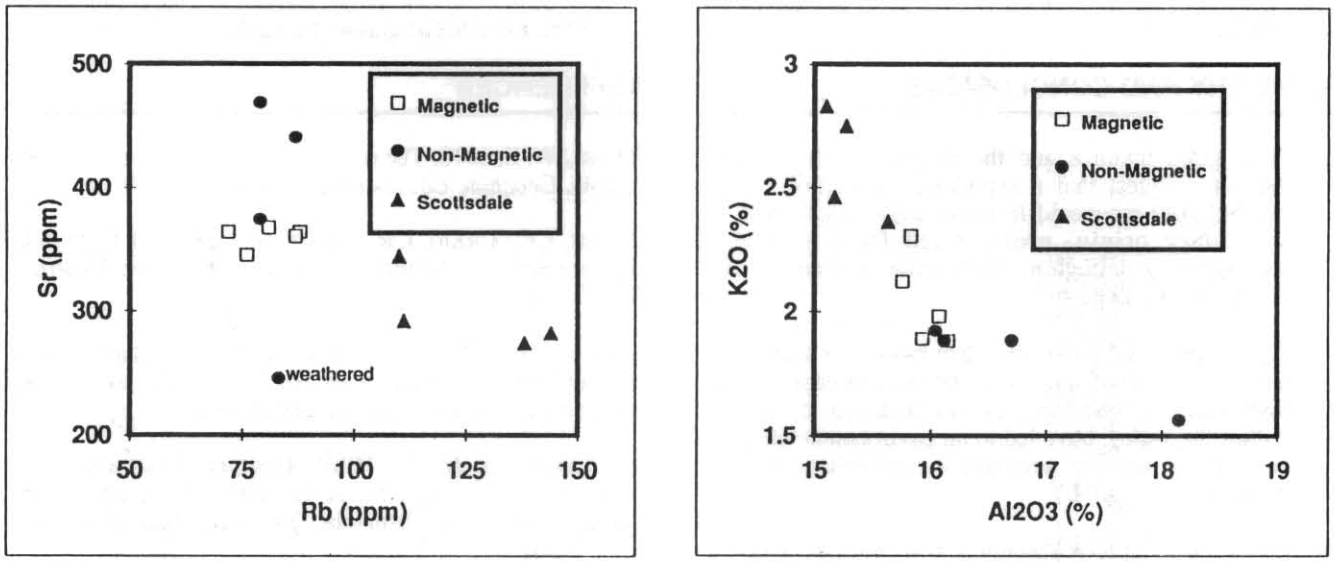


Figure 7

Plots of Sr vs Rb and K vs Al for the Lisle granodiorite and the western portion of the Scottsdale Batholith.

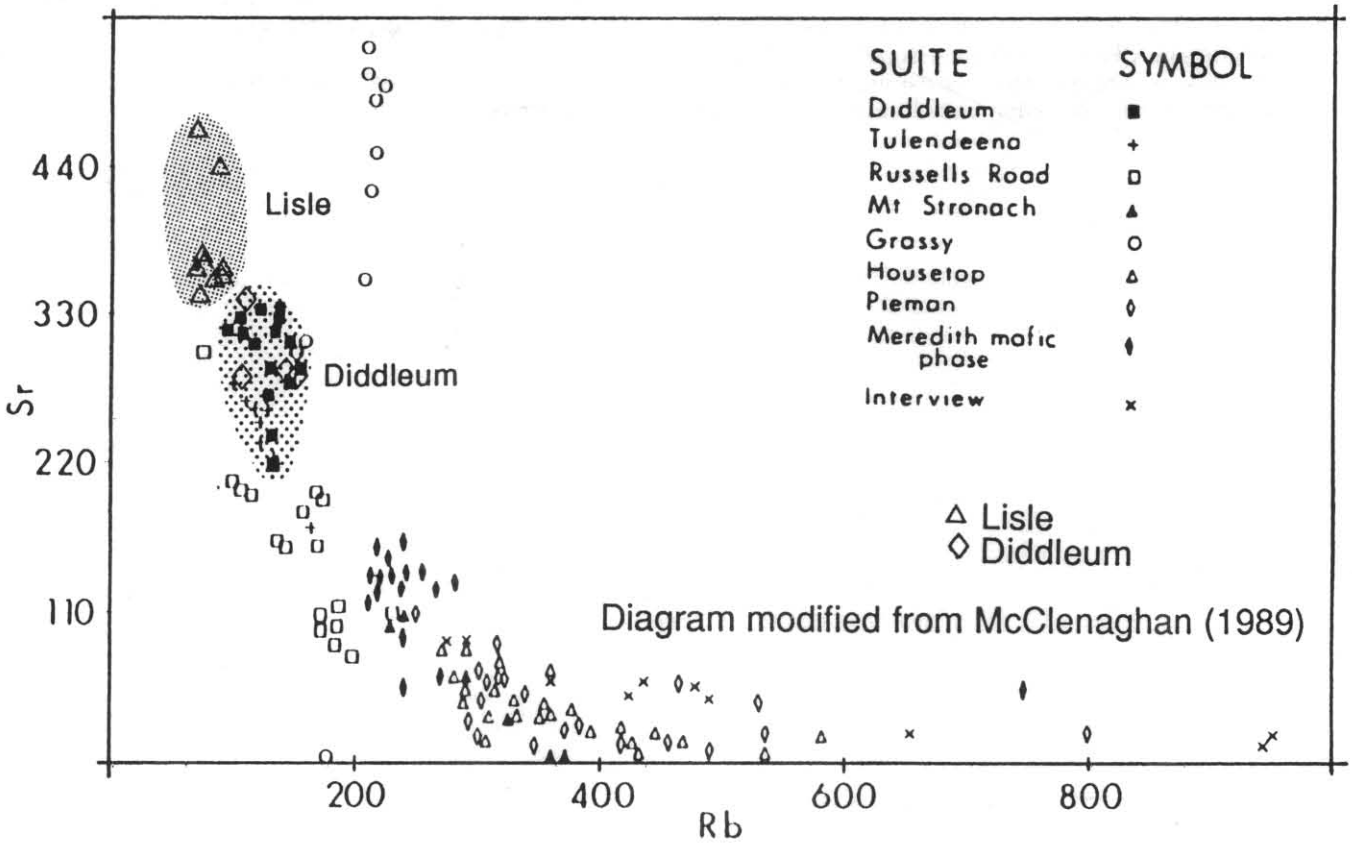


Figure 8

Plot of Sr vs Rb for the Lisle granodiorite compared to other Tasmanian granitoids. Modified from McClenaghan (1989).

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Regional geophysics of the Alberton – Mangana goldfield, northeast Tasmania

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ABSTRACT

Gold mineralisation in the Alberton–Mangana goldfield occurs within quartz veins hosted by the Siluro-Devonian Mathinna Beds. The distribution of gold occurrences defines a clear NNW-trending lineation which passes through the centre of a corridor of Mathinna Beds sediments separating the Devonian Scottsdale and Blue Tier batholiths. Regional geophysical data has been used to define the gross structure of the goldfield, in particular the form of the adjacent granitoid intrusions and their relationship to gold occurrences.

GEOLOGY

The Alberton–Mangana goldfield is situated in northeast Tasmania approximately 60 km east of Launceston (fig. 1). The geology of the region is shown in Figure 2.

Gold mineralisation is hosted by the Mathinna Beds, a thick succession of regionally metamorphosed sandy turbidites. Structural and stratigraphic relationships within the succession are poorly defined. Deformation in the Early Devonian produced moderate to tight folding with fold axes trending NNW.

Large-scale granitic intrusions closely followed the regional deformation. The Alberton–Mangana goldfield lies within a corridor of Mathinna Beds which separates the Scottsdale and Blue Tier batholiths. The batholiths are composite bodies, each consisting of a number of discrete plutons with characteristic mineralogy, geochemistry and physical properties. The timing of the mineralisation with respect to the regional deformation and the granitic intrusions is unknown.

Thin sequences of flat-lying Permo-Triassic sediments unconformably overlie the Mathinna Beds. These are intruded by Jurassic dolerite sills which form the resistant caps of the isolated topographic high points. The topography is rugged, rising to in excess of 1500 m on the Ben Lomond plateau. Tertiary basalt flows are present in the north of the area around Alberton and Ringarooma.

The Alberton–Mangana Goldfield here refers to the general region comprising, from north to south, the Alberton, Mt Victoria, Dans Rivulet, Mathinna, Tower Hill and Mangana Goldfields. These areas are discussed separately in reports by Twelvetrees (1900, 1904, 1907*a*, 1907*b*), Finucane (1935), and Nye and Blake (1938). A synthesis of the geology of the region was carried out by Threader (1967).

MINERALISATION

Gold mining in the region commenced with the discovery of alluvial gold near Mangana in 1852 and reached a peak of activity in the early 1870s, rapidly declining thereafter. By 1900 the majority of mines in the area were closed. Little mining activity has taken place since the 1930s.

Gold mineralisation occurs within discrete quartz veins, silicified shear zones and faults which range from less than one centimetre up to several metres in thickness. Low-grade disseminated mineralisation is uncommon. Mineralised quartz veins are generally steeply dipping and may be locally either concordant or discordant to bedding and cleavage within the regionally metamorphosed Mathinna Beds sedimentary rocks. On a regional scale, the locations of known gold occurrences form a prominent NNW-trending lineation, sub-parallel to the regional bedding trend. This alignment of prospects is suggestive of a major controlling structural feature, which is thought to be a dextral wrench fault system (Taheri and Findlay, 1992). Over much of its length the lineation has a pronounced negative topographic expression. The concentration of prospects around Mathinna and Alberton are inferred to fall within dilatational regions within this shear.

Gold occurs both free and in close association with arsenopyrite, pyrite, galena and sphalerite. The total sulphide content of the quartz reefs is low, typically less than 3%. Gold grades are highest in vein samples which contain several sulphide phases. The majority of veins, while rich in gold, were limited in strike and depth extent, and as a result are not readily suited to modern mining methods. Little modern systematic exploration has been conducted within the goldfield.

The largest mine in the goldfield was the New Golden Gate Mine at Mathinna, which worked a quartz reef system to a depth of 600 m and produced 7895 kg of gold from ore with an average grade of 25 g/t (Williams *et al.*, 1989).

GEOPHYSICS

Regional magnetic and gravity datasets were used to provide some constraints on the gross structure of the goldfield. Measurements of the physical properties of rocks from the study area were made both in the field and from available drill core samples. These results are shown in Table 1.

From a geophysical perspective the Devonian granitic rocks may be subdivided into three main classes:

ROACH, M. J. 1992. Geology and geophysics of the Alberton – Mangana goldfield, northeast Tasmania. *Bull. geol. Surv. Tasm.* 70:199–207.

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- Low density, non-magnetic granites and adamellites typical of the bulk of the Blue Tier and Scottsdale batholiths;
- Medium density, non-magnetic granodiorites such as the southern portion of the Blue Tier batholith and zones within the Pyengana Granodiorite;
- High density, strongly magnetic hornblende granodiorite represented by the bulk of the Pyengana pluton.

The Mathinna Beds in the study area are effectively non-magnetic and have a density similar to the magnetic component of the Pyengana pluton. The Mathinna Beds, the granites and adamellites are all non-magnetic, and it is not possible to distinguish between these lithologies based on regional magnetic data alone. An interpretation involving a synthesis of magnetic and gravity data is required in order to confidently predict the subsurface distribution of the various lithologies. The gravity and magnetic data in this case are clearly complimentary.

An aeromagnetic survey of the entire Alberton–Mangana goldfield was conducted in 1989 by the Tasmania Department of Mines (Richardson, 1989). An image of this dataset is shown in Figure 3*. A qualitative interpretation of the features shown in this image is presented as Figure 4.

High-frequency, high-amplitude anomalies result from Tertiary basalt flows (Tb) and from Jurassic dolerite sills (Jd). The low-amplitude linear anomalies in the southeast portion of the survey area are inferred to be caused by thin flows of Tertiary basalt beneath a cover of Quaternary alluvium. Portions of the exposed Pyengana pluton are strongly magnetic, however other zones within the pluton's mapped boundaries are apparently non-magnetic. The differences in physical properties between these two components of the Pyengana pluton have been confirmed by the mapping of Capp (1991).

The long-wavelength, low-amplitude, rounded magnetic anomalies in areas of Mathinna Beds outcrop are interpreted to result from subsurface bodies of granodiorite with physical properties similar to the magnetic portion of the exposed Pyengana pluton. These bodies flank both the Scottsdale and Blue Tier Batholiths. There is no systematic relationship between the distribution of magnetic granodiorite and the sites of known gold mineralisation.

Granodiorite in the Alberton area appears to directly underlie the gold deposits, at a depth of less than one kilometre. This interpretation is supported by the presence of thick porphyry dykes in the workings of a number of mines in the Alberton goldfield (Twelvetrees, 1904). The proximity of underlying granodiorite may also account for the predominance of arsenopyrite within mineralised veins at Alberton, compared to veins at Mathinna and Mangana which are dominated by pyrite and galena (Nye and Blake, 1938).

Gravity stations are sparsely and irregularly distributed throughout the goldfield. Two lines of closely-spaced stations were measured to supplement the existing data. One line passes through Mathinna and the other to the south of Mt Victoria. Topography is rugged and access limited to much of the area. Terrain corrections are high, ranging from 0.5 to 8.1 mGal.

A residual Bouguer anomaly map of the Alberton–Mangana area is shown in Figure 5. The map was derived using the modified MANTLE91 version of the Tasmanian regional gravity field (Leaman and Richardson, 1989). Large negative anomalies are associated with the Scottsdale and Blue Tier batholiths. The magnitude of these anomalies (-25 mGal) is consistent with a thickness of 8–9 km of granite with a density of 2.61 t/m^3. A relative positive anomaly of up to 10 mGal is associated with the Mathinna Beds corridor. The Mathinna Beds and the Pyengana pluton have the same density (2.75 t/m^3) and hence there is no gravimetric expression of the contact between these two units.

MODELLING

Two-dimensional forward modelling of gravity and magnetic data was carried out for a series of east-west sections crossing the goldfield. All modelling was conducted using magnetic data continued to a constant altitude of 1500 metres. This was necessary because of the large variation in terrain clearance in the raw magnetic data caused by the rugged topography. The important features of the major magnetic anomalies are preserved in the continued dataset.

The magnitude of the gravity anomaly associated with the Mathinna Beds corridor and the Pyengana pluton is low, given the relatively high density contrast with the surrounding granite (0.13 t/m^3). This immediately places constraints on the maximum thickness of the combined package of sediments and granodiorite. It implies that the entire goldfield must be underlain by a large volume of low-density granite. The maximum implied thickness of the Mathinna Beds, assuming the measured densities, is less than three kilometres.

Model sections for two lines are given in Figures 6 and 7. The locations of these sections are shown in Figure 4. Line 1 (fig. 6) extends from the Scottsdale batholith across the Mathinna Beds and Pyengana pluton to the Blue Tier batholith. The positive gravity anomaly on this line clearly results from the combination of the Mathinna Beds and the dense granodiorite. The magnetic anomaly reflects the irregular distribution of the magnetic granodiorite component. The modelled thickness of Mathinna Beds is 1.6 km, while the Pyengana pluton appears to have a maximum thickness of 2.5 kilometres.

Line 2 (fig. 7) passes from the Scottsdale batholith over Mathinna Beds outcrop, crossing two inferred granodiorite bodies. Detailed modelling of the eastern granodiorite suggests a minimum depth of approximately 200 m to the top of the body. Contact metamorphism of the Mathinna Beds is apparent on the surface above the anomaly maximum (Capp, 1991), however a 500 m hole drilled in 1991 by the Department of Mines on the western flank of the anomaly did not intersect granodiorite.

The granodiorite bodies appear to be less than one kilometre in thickness and roughly tabular in form. The upper surface of the granodiorite is constrained by the magnetic data, while the gravity profile determines the location of the contact with the underlying granite. It is probable that the granite has intruded and assimilated the granodiorite. This interpretation is consistent with the observed field relationships to the north, where the Pyengana pluton has been intruded by the younger Poimena granite.

* Figure 3 is located in the pocket at the rear of this bulletin.

3/10

SUMMARY AND CONCLUSIONS

Regional geophysical data has been used to place some constraints on the gross structure of the goldfield. The resolution of the data precludes an investigation of the local signature of individual deposits.

Gravity data implies that low-density granitic rocks underlie the entire goldfield. The maximum calculated thickness of Mathinna Beds is 2.6 kilometres. Magnetic data suggests the presence of a number of subsurface bodies of strongly magnetic hornblende granodiorite. There is no clear spatial relationship between these granodiorite bodies and the known gold occurrences.

Mineralisation is structurally controlled on both a regional and a local scale. The identification of favourable structural environments for mineralised vein development is the most important aspect of exploration for gold in the Alberton–Mangana area. The importance of the underlying granitoid intrusives in the formation of the gold deposits, either in the form of the direct input of fluid or as heat sources driving the hydrothermal systems, is as yet unknown.

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Table 1

Physical properties of the major rock types exposed within the Alberton–Mangana goldfield.

		Density (t/m^3)		Susceptibility (x10^{-3}SI)	
	Lithology	Range	Value	Range	Value
Tertiary	Basalt	2.80 - 2.90	2.85	Variable	>10
Jurassic	Dolerite	2.70 - 2.85	2.80	Variable	10
Permian	Sediments	2.25 - 2.50	2.40	0.00 - 0.02	0.00
Blue Tier Batholith	Granite	2.59 - 2.63	2.61	0.02 - 0.15	0.05
Scottsdale Batholith	Granite	2.59 - 2.65	2.62	0.02 - 0.20	0.12
Pyengana Pluton	Granodiorite	2.74 - 2.75	2.75	3.0 - 10.0	8.0
	Granodiorite	2.70 - 2.73	2.71	0.15 - 0.30	0.22
Mathinna Beds	Metasediments	2.55 - 2.80	2.74	0.06 - 0.32	0.15

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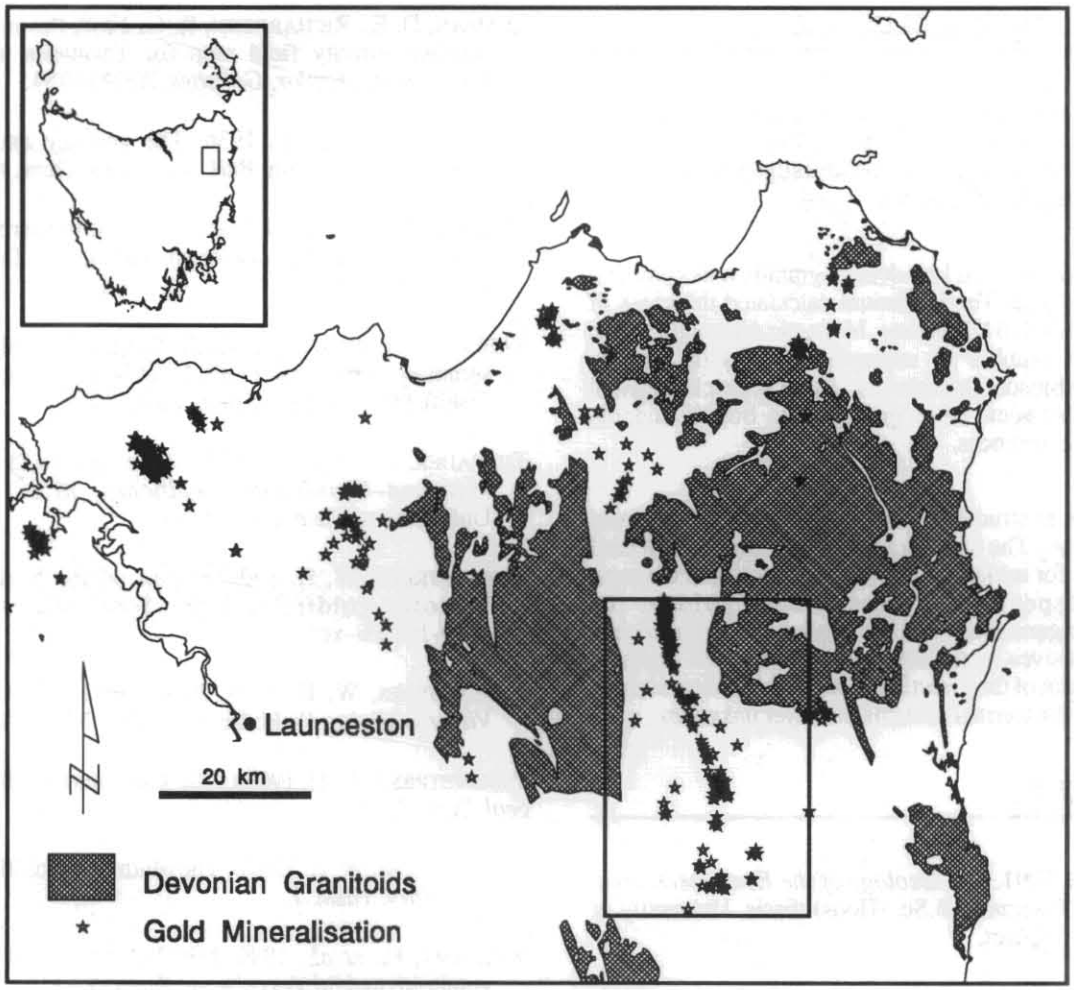


Figure 1

Locality diagram showing the boundaries of the Alberton–Mangana goldfield, the distribution of Devonian granitic rocks, and gold mineralisation locations from the Tasmania Department of Mines MIRLOCH database.

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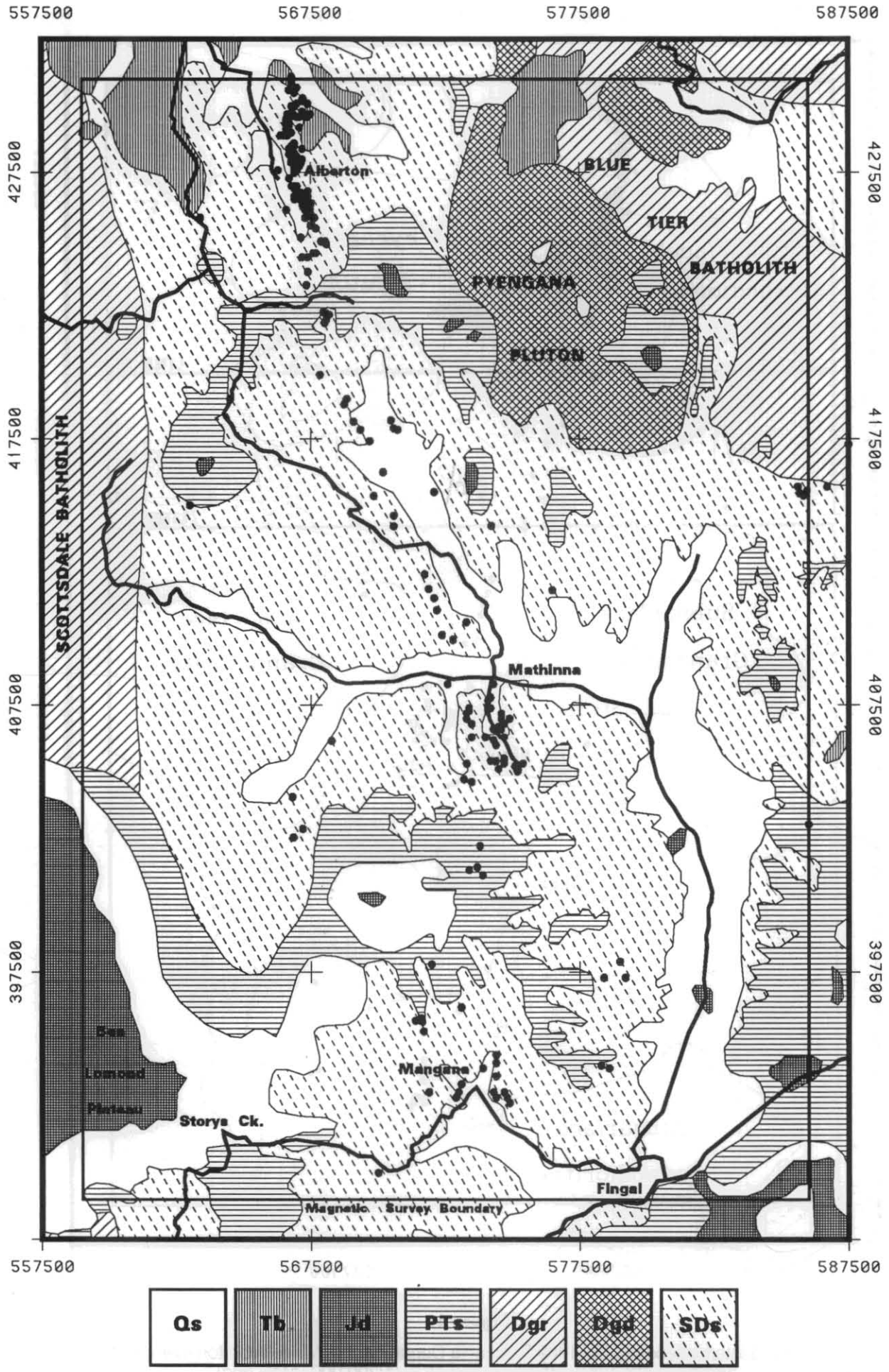
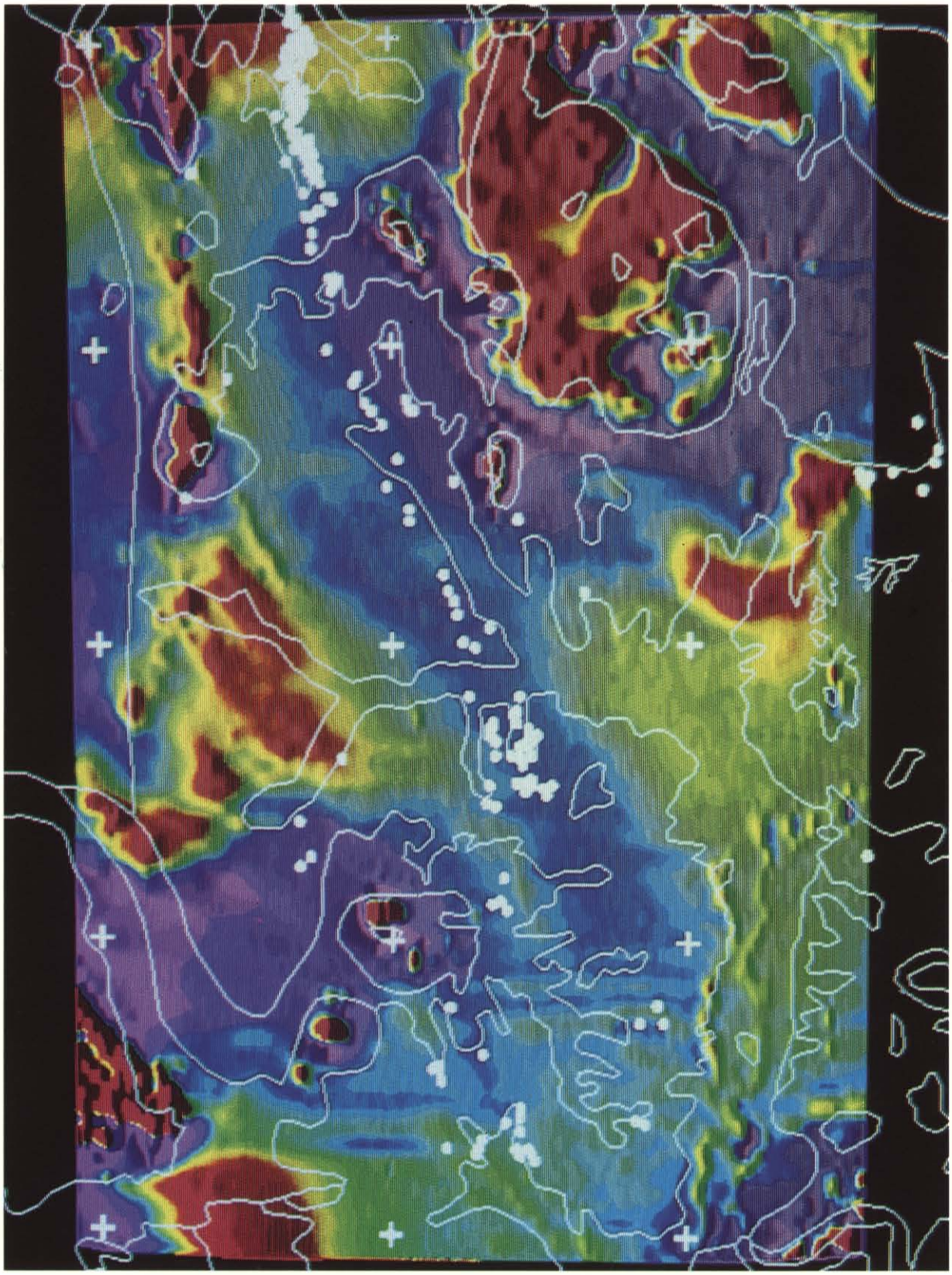


Figure 2. Geology of the Alberton–Mangana goldfield. Mineralised locations from the MIRLOCH database are shown as black dots. (1:200 000, AMG grid).

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Figure 3.
(M. J. ROACH — *Alberton–Mangana goldfield)*

1989 Tasmania Department of Mines Alberton–Mangana aeromagnetic survey, with geology and gold occurrence locations overlayed. Gold mineralisation data from Tasmania Department of Mines MIRLOCH data base. The image is approximately 27 × 42 km with a 10 km grid.

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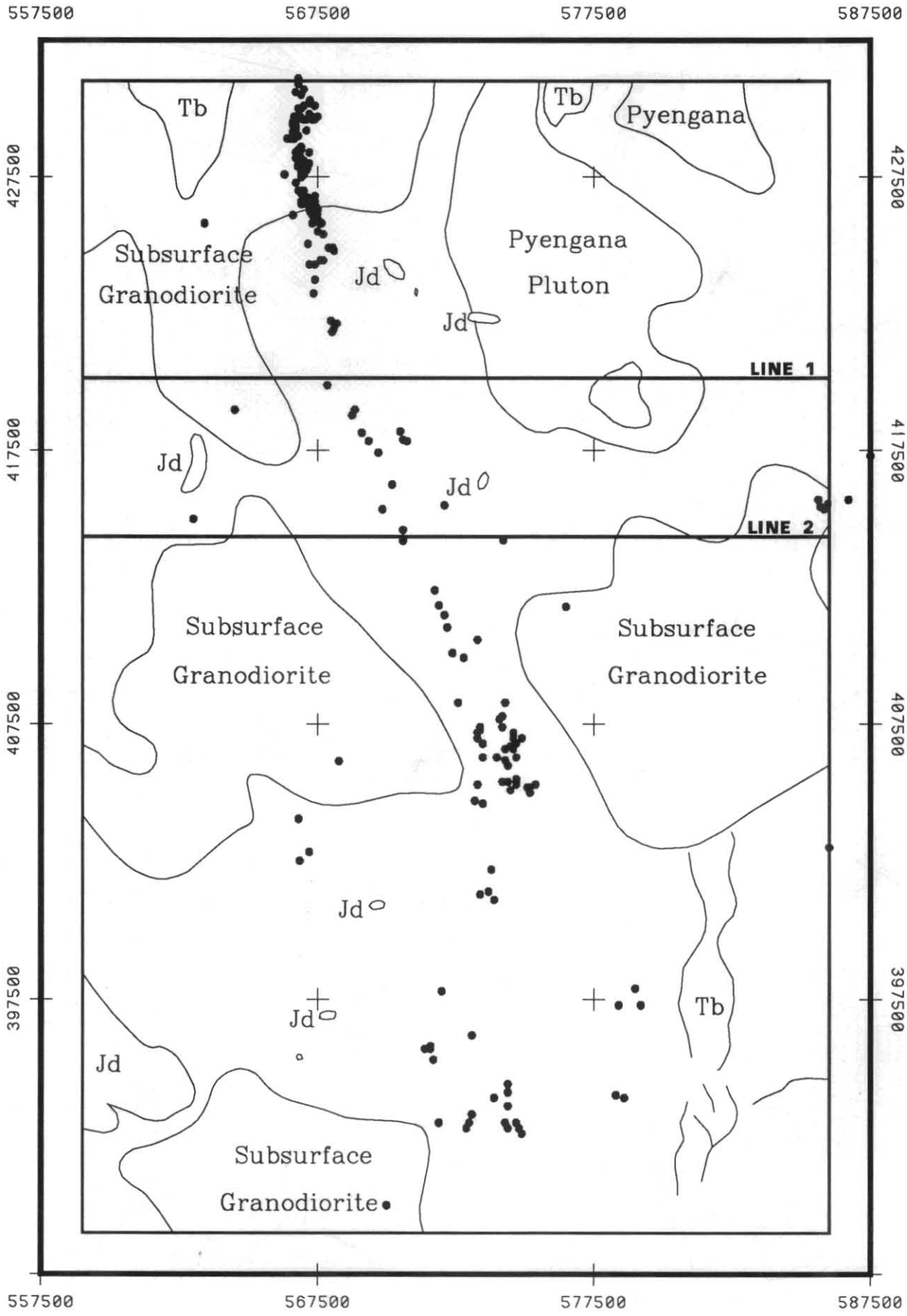


Figure 4

Qualitative interpretation of the 1989 Tasmania Department of Mines Alberton–Mangana aeromagnetic survey shown in Figure 3. (1:200 000, AMG grid).

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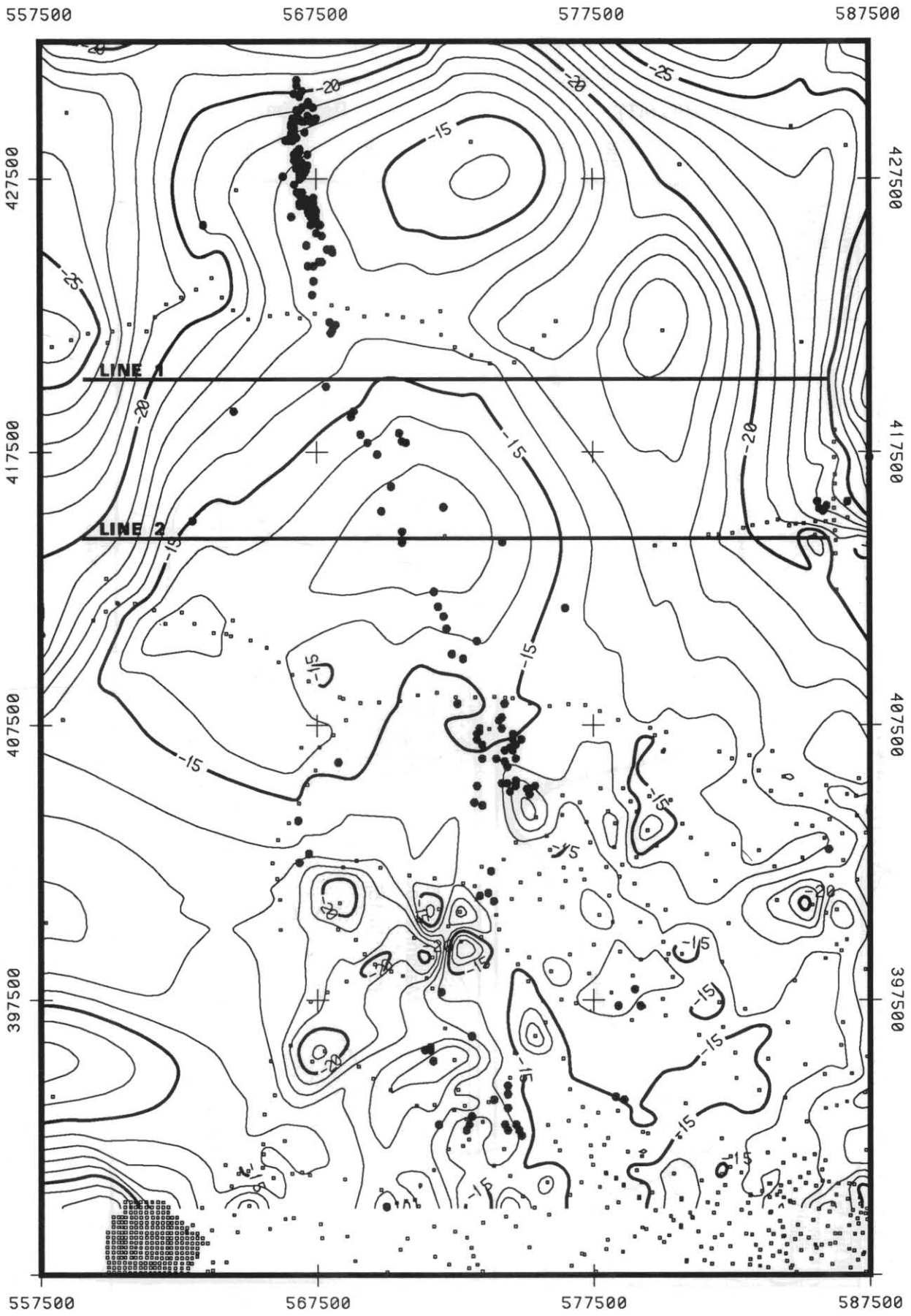


Figure 5

Residual Bouguer anomaly map of the Alberton–Mangana goldfield. Bouguer reduction density 2.67t/m^3, Mantle91 regional field removed (Leaman and Richardson, 1989). Small squares show the locations of gravity stations. (1:200 000, AMG grid).

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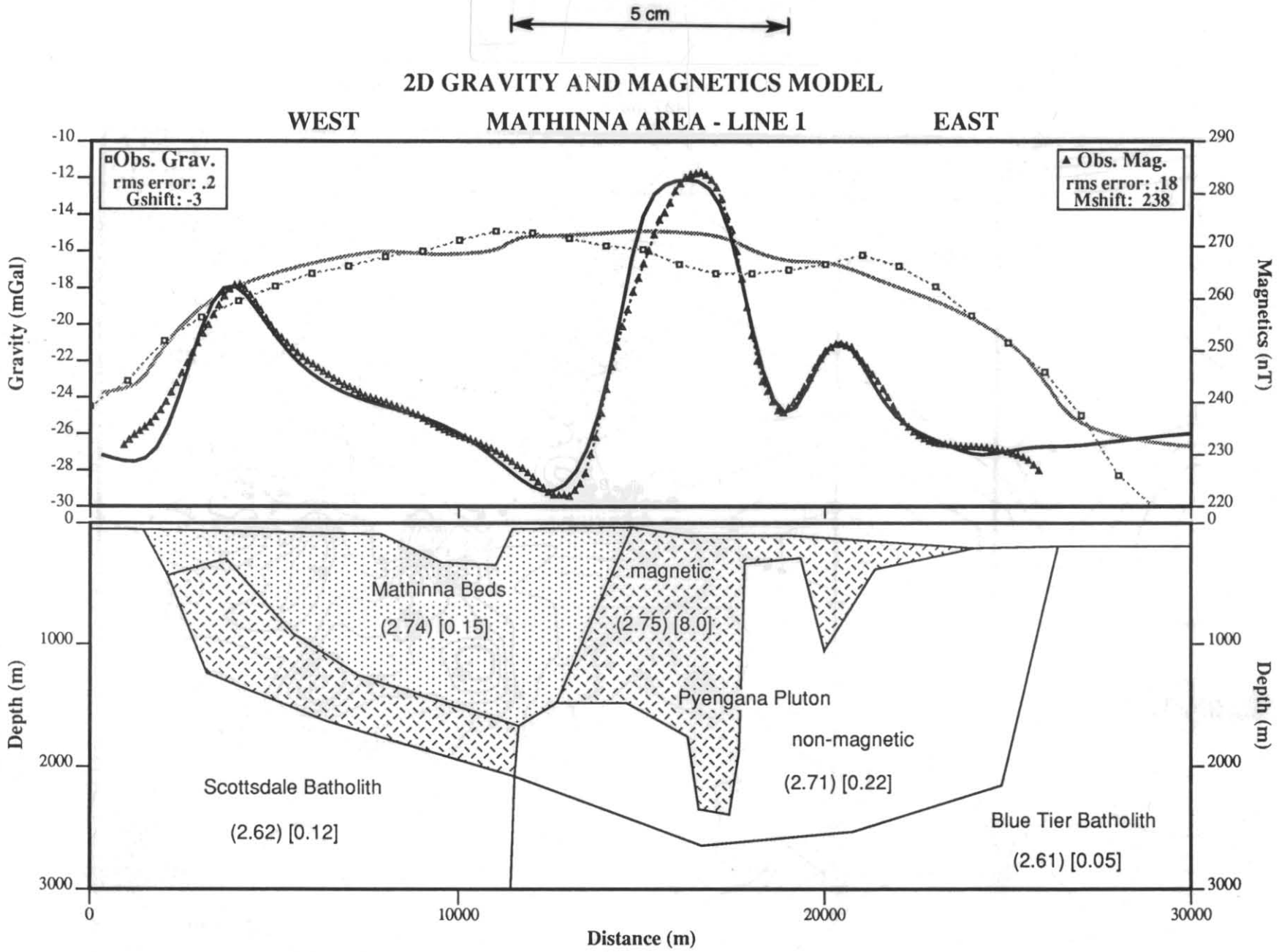


Figure 6. Two-dimensional gravity and magnetics model section crossing the Pyengana pluton. Values in curved brackets are densities (t/ m^3); values in square brackets are magnetic susceptibilities [$\times 10^{-3}$ SI]. Location of the section is shown in Figures 4 and 5.

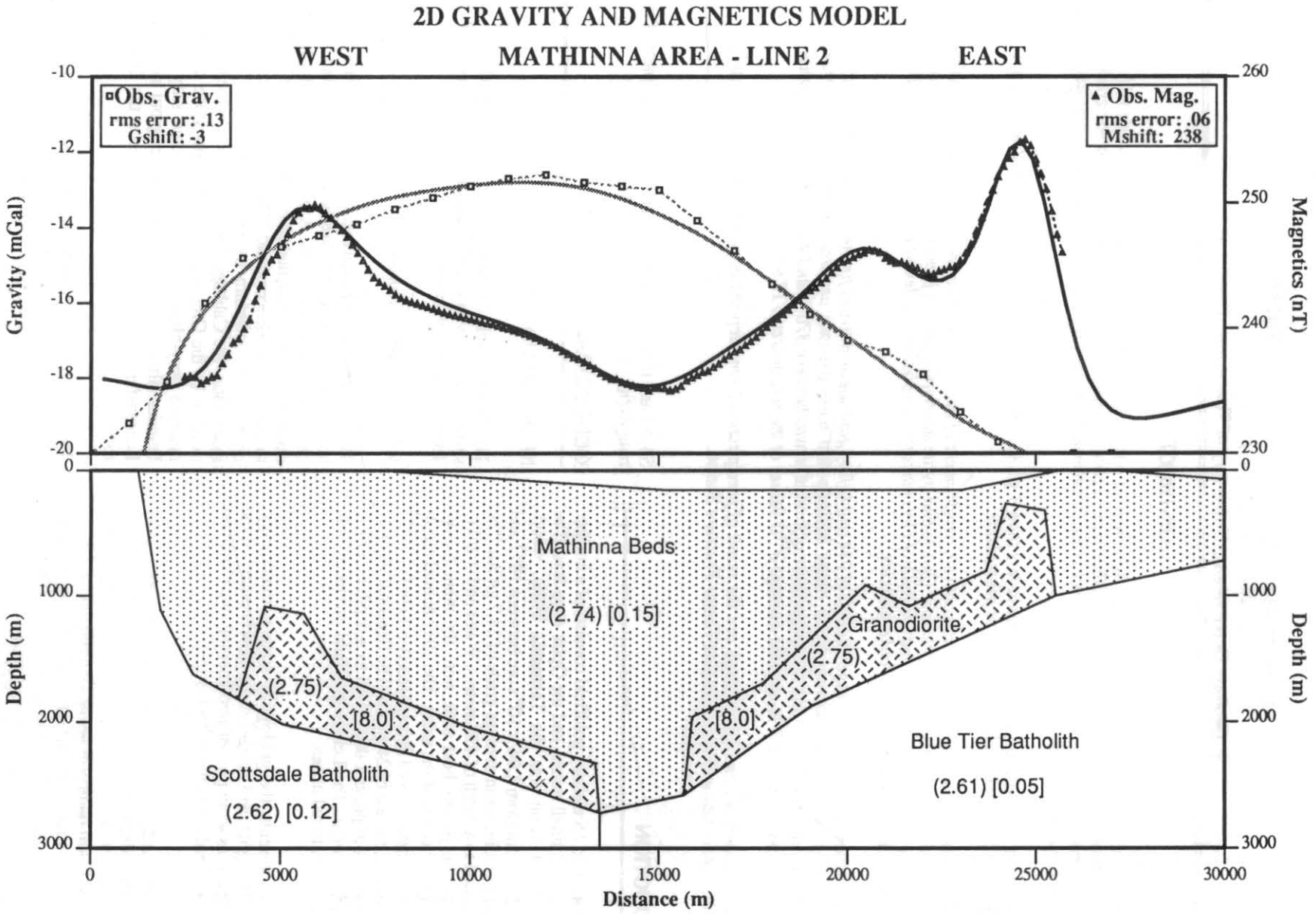


Figure 7. Two-dimensional gravity and magnetics model section showing the inferred geometry of subsurface granodiorite bodies. Values in curved brackets are densities (t/m^3); values in square brackets are magnetic susceptibilities [$\times 10^{-3}$ SI]. Location of the section is shown in Figures 4 and 5.

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

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ABSTRACT

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

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

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

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

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

INTRODUCTION

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

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

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

GEOLOGICAL SETTING

INTRODUCTION

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

West of the River Tamar

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

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

RUSSELL, D. W.; VAN MOORT, J. C. 1992. Mineralogy and stable isotope geochemistry of the Beaconsfield, Salisbury and Lefroy goldfields. *Bull. geol. Surv. Tasm.* 70:208–226.

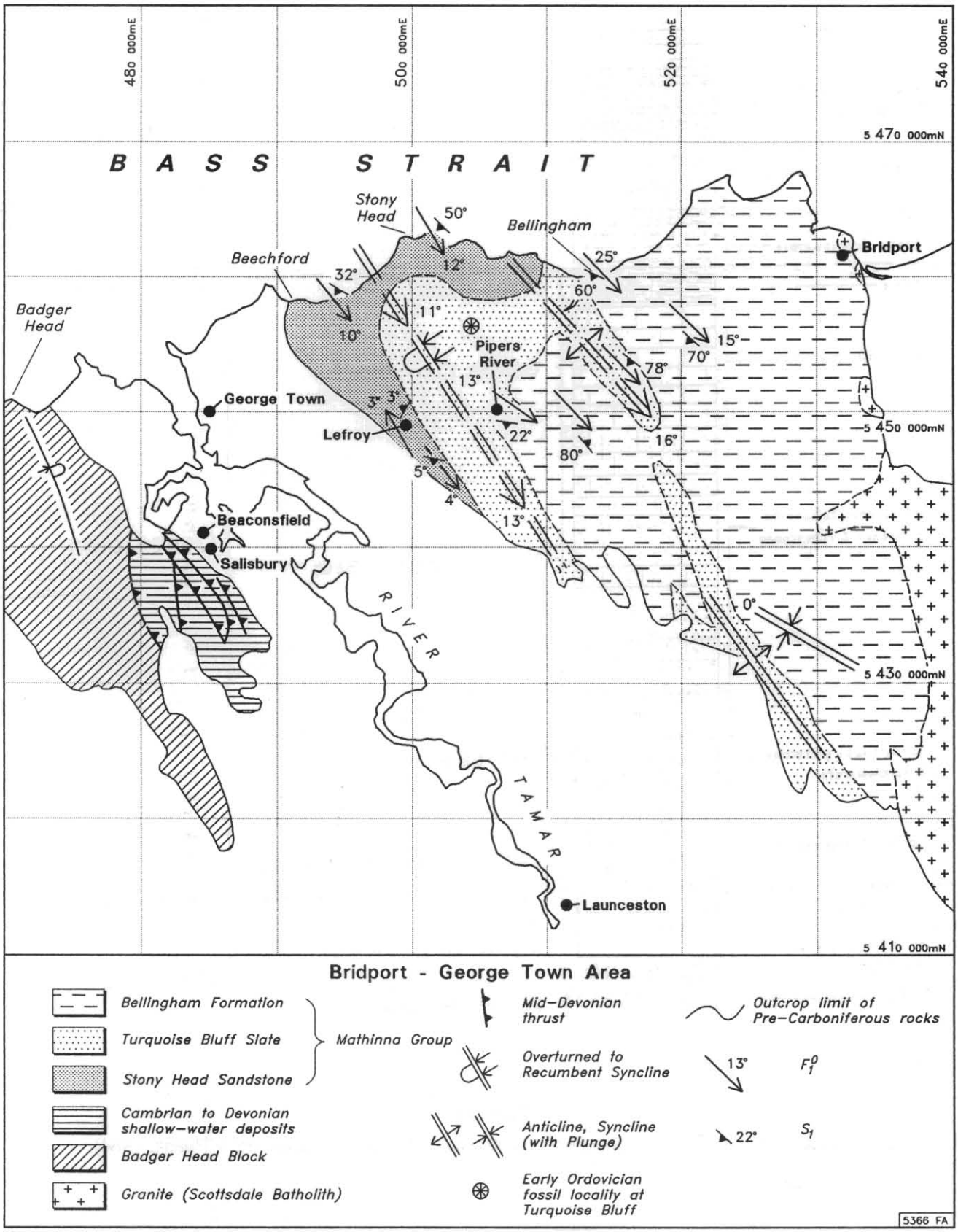


Figure 1

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

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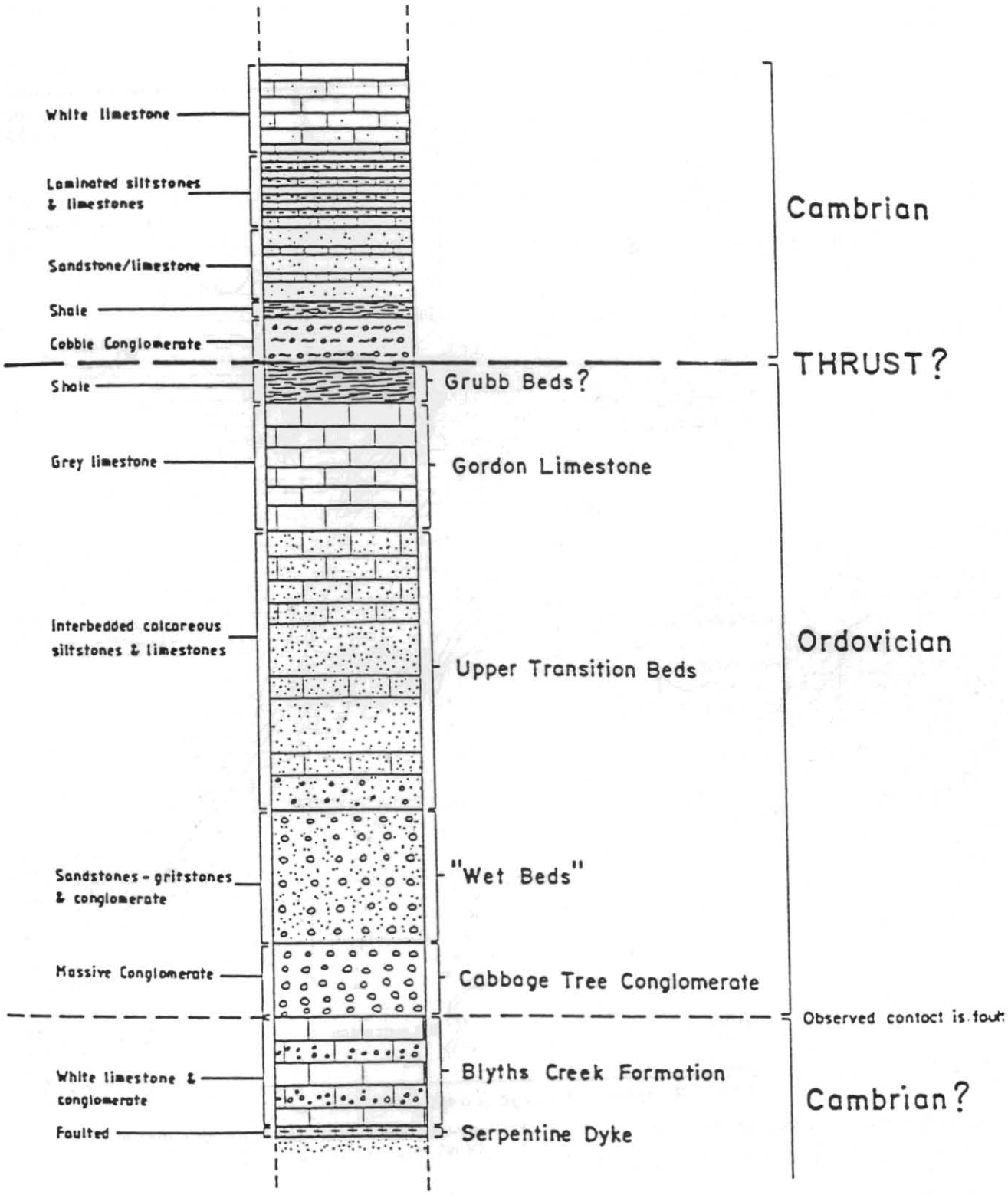


Figure 2

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

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

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

East of the River Tamar

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

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

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

MINE SEQUENCES

Beaconsfield Goldfield

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

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

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

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

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

Lefroy Goldfield

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

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

THE ORE BODIES

Beaconsfield Reef

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

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

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

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

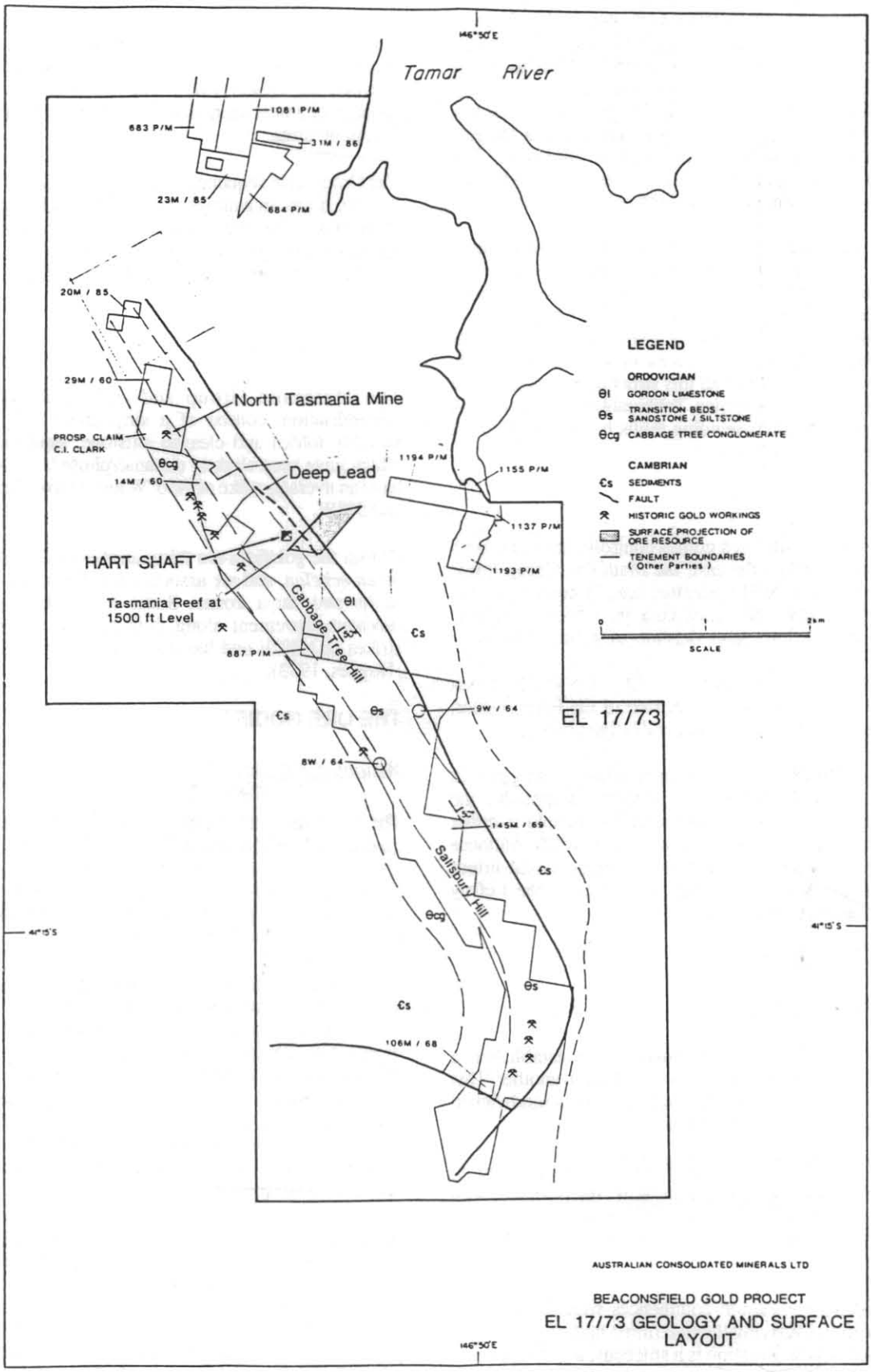


Figure 3

Regional geology of the Beaconsfield and Salisbury goldfields.

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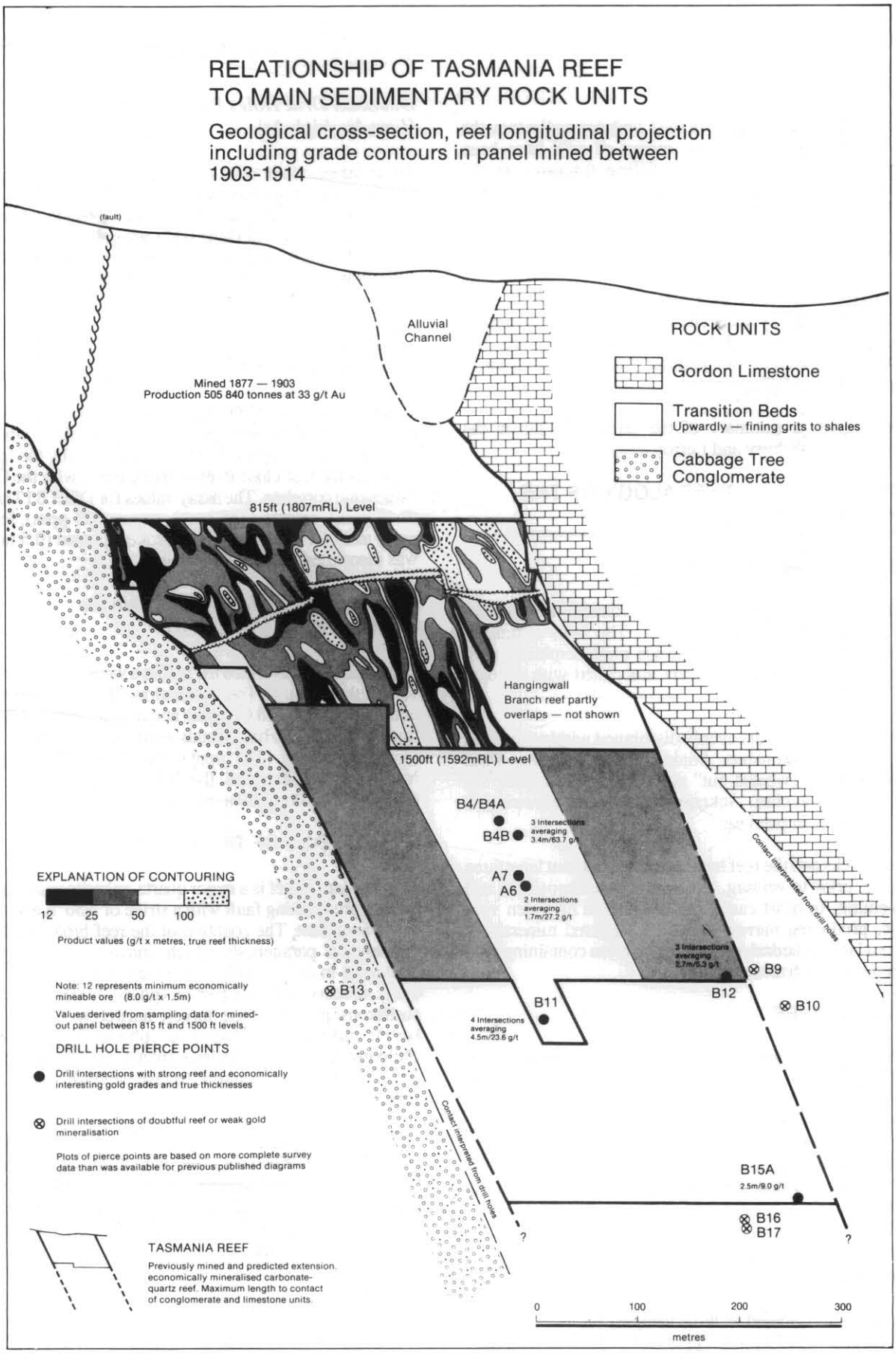


Figure 4

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

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

Salisbury Reef

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

Lefroy Reef

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

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

PETROLOGY AND MINERALOGY OF THE TASMANIA REEF

PETROLOGICAL DESCRIPTIONS

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

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

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

TASMANIA REEF

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

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

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

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

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

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

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

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

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

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

MINERALOGY OF THE TASMANIA REEF

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

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

Quartz

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

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

Figure 5

Summary of diamond-drill holes.

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

Carbonates

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

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

Pyrite

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

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

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

Gold

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

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

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

Other Sulphides

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

PARAGENESIS

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

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

Figure 6

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

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

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

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

MINERALOGY OF SALISBURY AND LEFROY

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

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

FINENESS OF GOLD

INTRODUCTION

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

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

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

The results of these analyses were used:

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

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

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

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

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

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

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

REEF GOLD

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

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

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

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

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

Figure 8

Gold fineness signatures of the Beaconsfield and Lefroy goldfields.

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

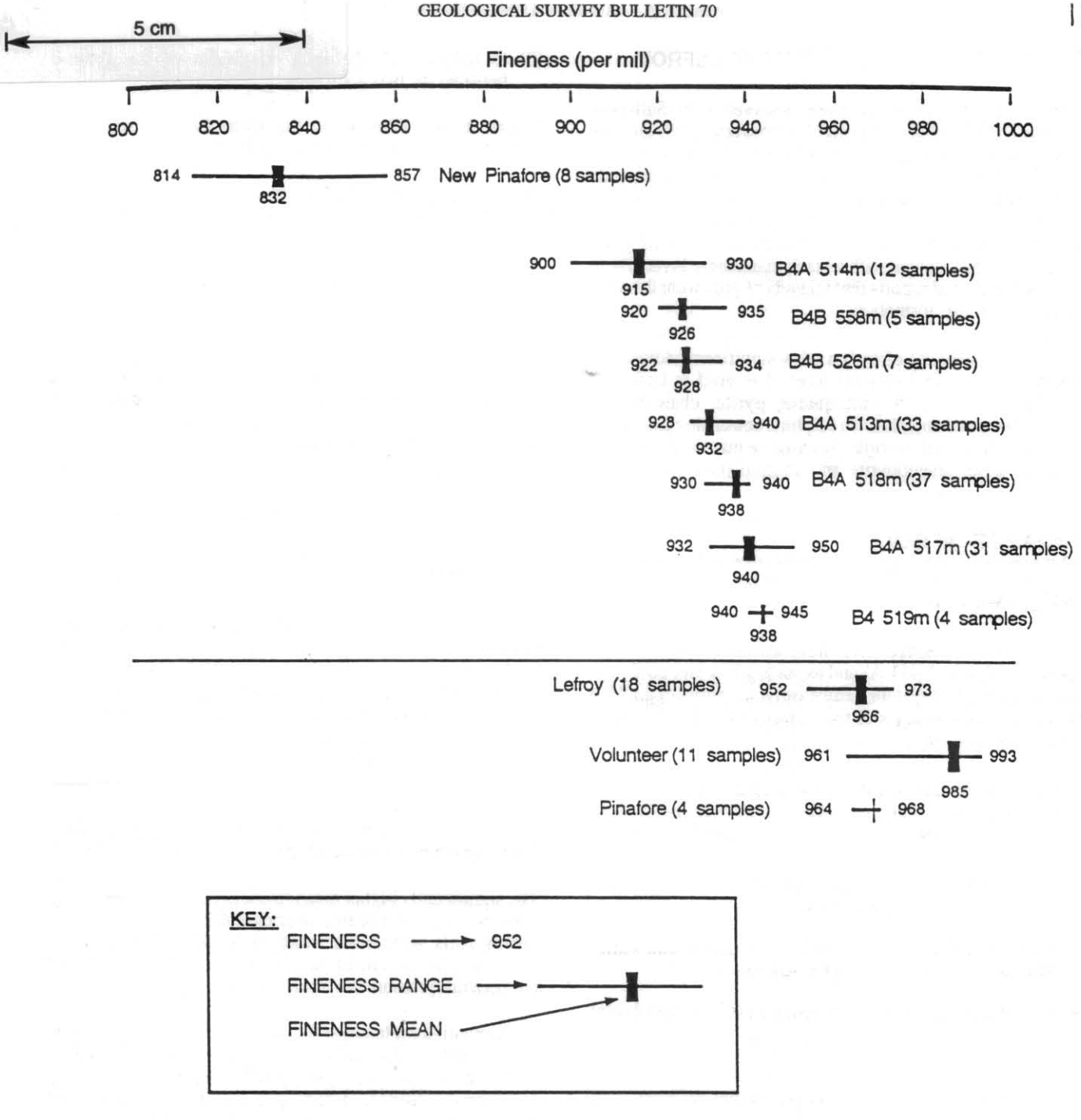


Figure 9

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

ALLUVIAL GOLD

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

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

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

12/20

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

Figure 10

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

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

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

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

SILVER DISTRIBUTION WITHIN GOLD GRAINS (REEF)

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

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

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

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

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

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

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

13/20

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

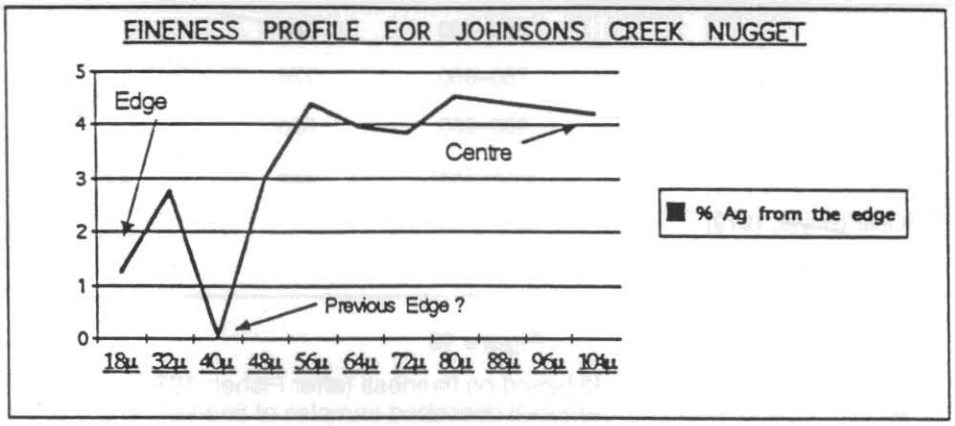


FIGURE 4e (i)

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

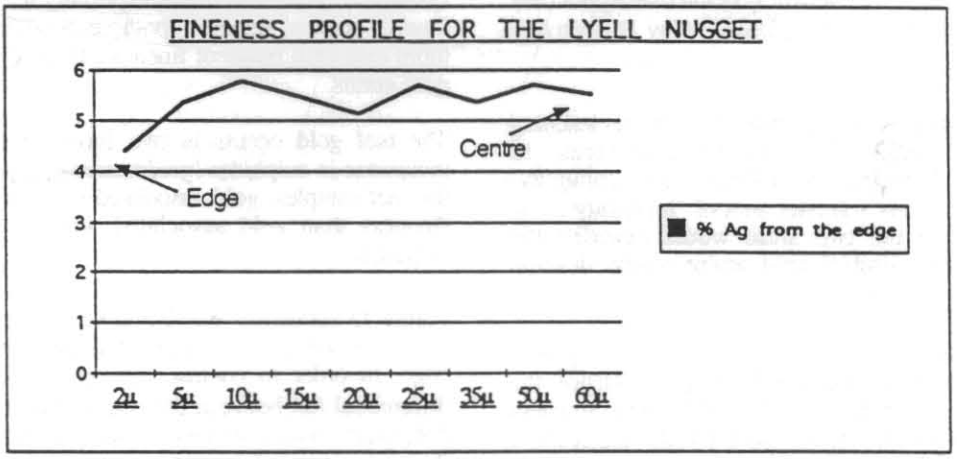


Figure 11

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

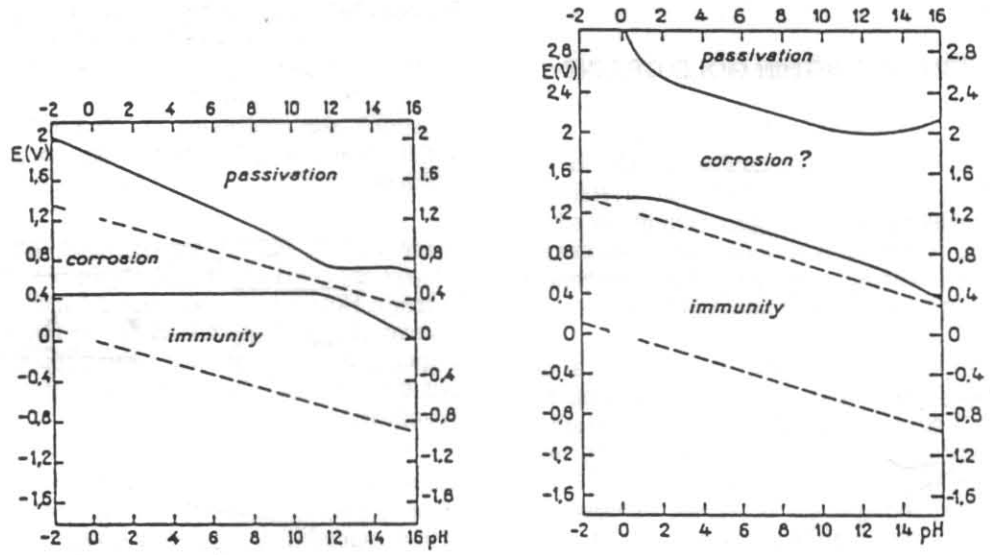


Figure 12

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

5 cm

14/20

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

Figure 13

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

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

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

STABLE ISOTOPE GEOCHEMISTRY

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

SULPHUR ISOTOPES

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

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

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

The results are show in the table below.

SOURCE OF SULPHUR

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

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

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

Figure 14

Pyrite and chalcopyrite sulphur isotope values.

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

OXYGEN ISOTOPES

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

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

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

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

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

Figure 15

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

SOURCE OF THE TRANSPORTING WATERS

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

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

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

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

ARSENOPYRITE GEOTHERMOMETRY

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

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

DISCUSSION

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

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

GOLD TRAP

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

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

16/20

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

Figure 16

Oxygen isotope values for parent waters ($\delta^{18}O_{H2O}$).

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

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

Figure 17

Temperature of formation of the Tasmania Reef.

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

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

HEAT ENGINE

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

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

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

METAL SOURCE

There could be several sources of the gold and silver. In the absence of suitable volcanic rocks or intrusions from which the metals could be leached (the closest outcrop of Mount Read Volcanics is 60 km away), the source is unlikely to be the host sedimentary rocks (minor Cambrian slate, Ordovician conglomerate, sandstone and limestone). A magmatic plume of ore fluids derived from an underlying granitoid magma would provide a feasible source for the metals, particularly if it was associated with the eastern batholith as this body has generated significant gold reef deposits. This granitoid dips steeply to the west, towards the

two goldfields. However Lefroy is 20 km and Beaconsfield is 40 km away from the 4 km gravity-derived contour of granite/crust subsurface (Richardson, 1989), as shown in Figure 18. There is no accurate data relating to the granite subsurface beneath these goldfields.

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

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

SOURCE OF SULPHUR AND OXYGEN

The consistently high $\partial^{18}O_{SiO2}$ value of about + 17.9‰ for the eight quartz samples from the Tasmania Reef correspond, as discussed earlier, with initial mineralising fluids with a $\partial^{18}O_{H2O}$ between + 11.4 and + 15.3‰ at respective temperatures of 370° and 440°C, as indicated by the arsenopyrite thermometry of the waters.

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

CONCLUSIONS

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

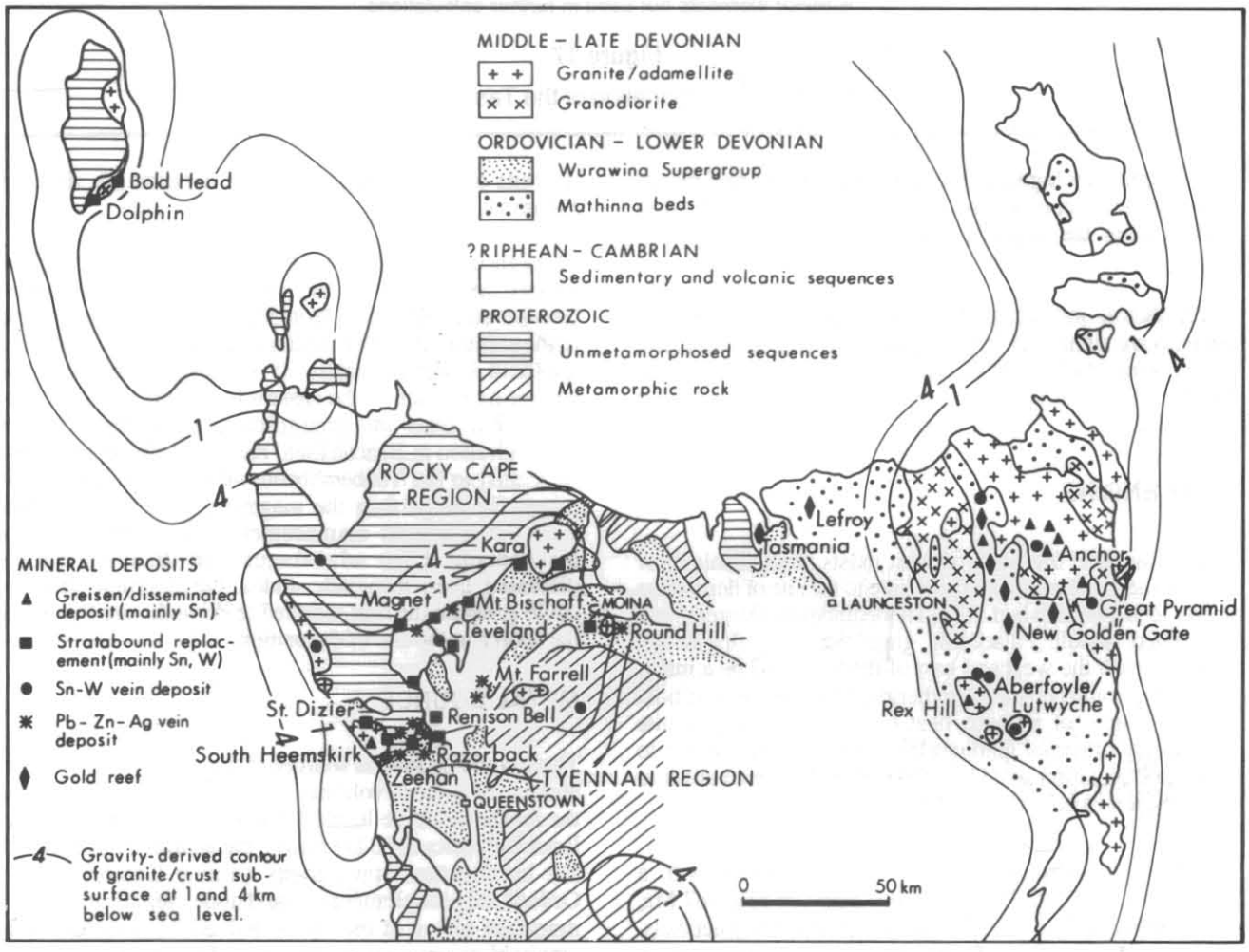


Figure 18

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

5 cm

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

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

ACKNOWLEDGMENTS

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Figure 7

Colour plates of micrographs (in pocket).

1. Sample B4A, 517.6 m (PTS). *Phase 1:* First generation quartz crystals growing out from the vein wall. Void filled with carbonate. Width of field = 2 mm (XPL, TL).

2. Sample B4A, 518.6 m (PTS). *Phase 3:* Small free gold grains (A) in finely crystallised quartz. Width of field = 1 mm (RL).

3. Sample B4A, 513.4 m (PTS). *Phase 4:* Gold in pyrite. The early stages of gold replacing pyrite, forming exsolution(?) structures in pyrite. Width of field = 0.7 (RL).

4. Sample B4A, 513.4 m (PTS). *Phase 4:* Gold fillings in micro-fracture in pyrite caused by recrystallisation. Width of field = 1 mm (RL).

5. Sample B4A, 518.8 m (PTS). *Phase 4:* A thin vein of gold connecting a finely crystalline quartz vein with a euhedral pyrite crystal containing recrystallised gold. Width of field = 2 mm (TL, RL).

6. Sample B4A, 518.8 m (PTS). *Phase 4:* A coarse grain of gold (in quartz) almost completely replacing an euhedral pyrite crystal, the remains of which can be seen in the top right of the gold grain. Note the way in which the gold invades the adjacent quartz. Width of field = 2 mm (TL, RL).

7. Sample B4A, 513.3 m (PTS). *Phase 5:* Arsenopyrite has an acicular and fine needle-like habit and often embedded in ankerite. The large crystals are pyrite from a previous generation, some of which have been partially replaced by arsenopyrite. Width of field = 2 mm (TL, RL).

8. Sample B4, 527.8 m, 527.8 m (PTS). *Phase 6:* Chalcopyrite and pyrite (from a previous phase) in a carbonate which in turn is in a 1–2 cm quartz vein. Width of field = 1.5 mm (RL).

9. Sample B11B, 692 mm (DC). *Phase 7:* A broader scale brecciation shattered adjoining host rock; these fragments were then annealed by fine blueish-white quartz crystals (HS).

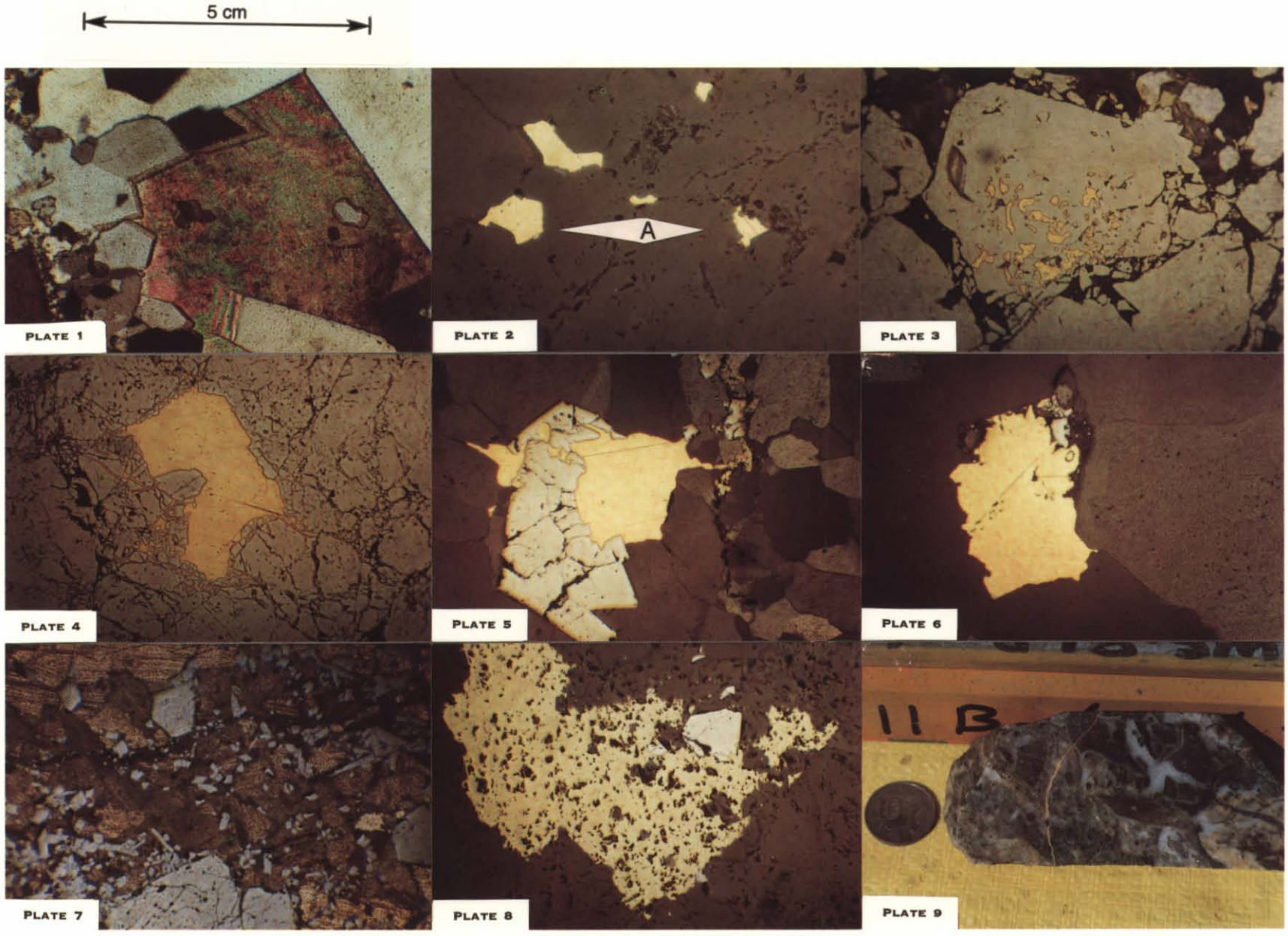


Figure 7 (Plates 1 to 9)
(Russell and Van Moort)

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1/7

Geology and prospectivity of the Arthur Mobile Belt

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INTRODUCTION

The Proterozoic rocks of northwest Tasmania are transected by a tectonic feature known as the Arthur Lineament which contains an assemblage of metasedimentary rocks and amphibolite called the Arthur Metamorphic Complex. The Arthur Mobile Belt encompasses the Arthur Lineament and the relatively unmetamorphosed rocks on either side. Rather than being strictly defined, the name of Arthur Mobile Belt is simply a term of convenience.

This paper briefly describes the setting of the Arthur Mobile Belt and outlines the styles of mineralisation which occur in it. More detailed discussion of these matters and a fuller citation of published work are given by Turner (1990). Work in preparation has been drawn on in compiling this paper. The work includes mapping and related studies by Turner, mineral determinations by Bottrill, rock chemistry by Crawford and Ar-Ar geochronology by Villa.

STRATIGRAPHY AND DEPOSITIONAL SETTING

Successions comprising formations characterised by shallow-water quartz arenite, by siltstone or, subordinately, by dolomite underlie much of the Tyennan region (fig. 1), the Jubilee region and the region west of the Arthur Lineament which includes the Rocky Cape Group. These similar successions are the basement rocks in their respective regions and are probably of broadly similar age, perhaps in the vicinity of the c.1100 Ma depositional/provenance age determined for metapelite in the Tyennan region (Råheim and Compston, 1977).

Extending eastwards from inside the Arthur Lineament (fig. 1–3) is a sandy turbidite facies which includes the Burnie Formation and the correlated Oonah Formation, also the Badger Head Group. An approximate depositional age of c.725 Ma for the turbidite facies is provided by dolerite which was intruded whilst the sediments were still wet (Crook, 1979).

Successions of siliceous clastics, dolomite then basaltic volcanics at Smithton, Corinna and middle Pieman River (fig. 2–3) are thought to belong to the same tectonic episode (fig. 4) as the sandy turbidite facies. Shallow-water clastics resting on basement at Smithton appear to be equivalent to proximal turbidite fan deposits resting on basement at Corinna which, in turn, are regarded as lithological correlates of the sandy turbidite facies east of the Arthur Lineament where the basement is not exposed. This apparent transition from Smithton eastwards is interpreted as a passage from shelf to continental margin or basinal conditions (see also Gee, 1967). Subsequent structural disruption of the original transition has been considerable, particularly along zones such as the Arthur Lineament.

The basal beds at Smithton and Corinna pass conformably upwards into shallow-water dolomite, whilst at middle Pieman River (Brown, 1989) there are shallow-water clastics and stromatolitic dolomite in the succession overlying the sandy turbidite facies. In the latter locality the stratigraphic relationships are obscured by variations in the character of both early Palaeozoic and Devonian deformation and by the presence of disrupted, predominantly mudstone intervals which may represent large, low-angle faults (Findlay and Brown, 1992) and possibly, early decollement structures. The palinspastic reconstruction in Figure 4 assumes the presence of the latter and thus, that the shallow-water units at middle Pieman River are olistoliths. Alternatively, they may mark the emergence of the area occupied by the turbidite fan.

Basaltic volcanics with associated volcaniclastics and other, fine grained, sedimentary rocks occur above the dolomitic rocks in all three areas. The major, trace and REE chemistry of these basalts and of amphibolites in the Arthur Metamorphic Complex leave little doubt that they are rift tholeiites belonging to a period of stretching and rifting of the NW Tasmanian crust. Dolerite dykes which intrude the basement display, at least in part, similar chemistry to the tholeiites and are apparently a feature of the same extensional episode. Two dykes have been dated at about 600 Ma (Adams *et al.*, 1985). Thus, the Late Proterozoic shelf and margin phase in NW Tasmania appears to have had a duration of some 125 my from c.725 Ma to c.600 Ma.

METAMORPHISM AND DEFORMATION

High pressure, prograde metamorphic assemblages are locally preserved in the Arthur Lineament and in the higher grade parts of the Tyennan region. In the Arthur Lineament glaucophane/crossite in blueschist facies metabasite has compositional parameters that are consistent with crystallisation at about 700 MPa. The compositional parameters of the glaucophane/crossite closely match those of blue amphiboles in the Japanese Sambagawa metamorphic belt. On the basis of comparison with the Sambagawa Belt (Banno, 1986), hornblende-bearing metabasite assemblages in the Arthur Lineament are of rather higher grade than the blueschist assemblages. In the Tyennan region the highest grade rocks include eclogite which crystallised at 1520±105 MPa and 698±28°C (Goscombe, 1990, after Kamperman, 1984). Garnet amphibolite which is closely associated with the eclogite may reflect retrogression at high P_{H_2O} (Råheim, 1976).

Prograde assemblages in the Arthur Lineament are strongly retrogressed to actinolitic assemblages which are syntectonic

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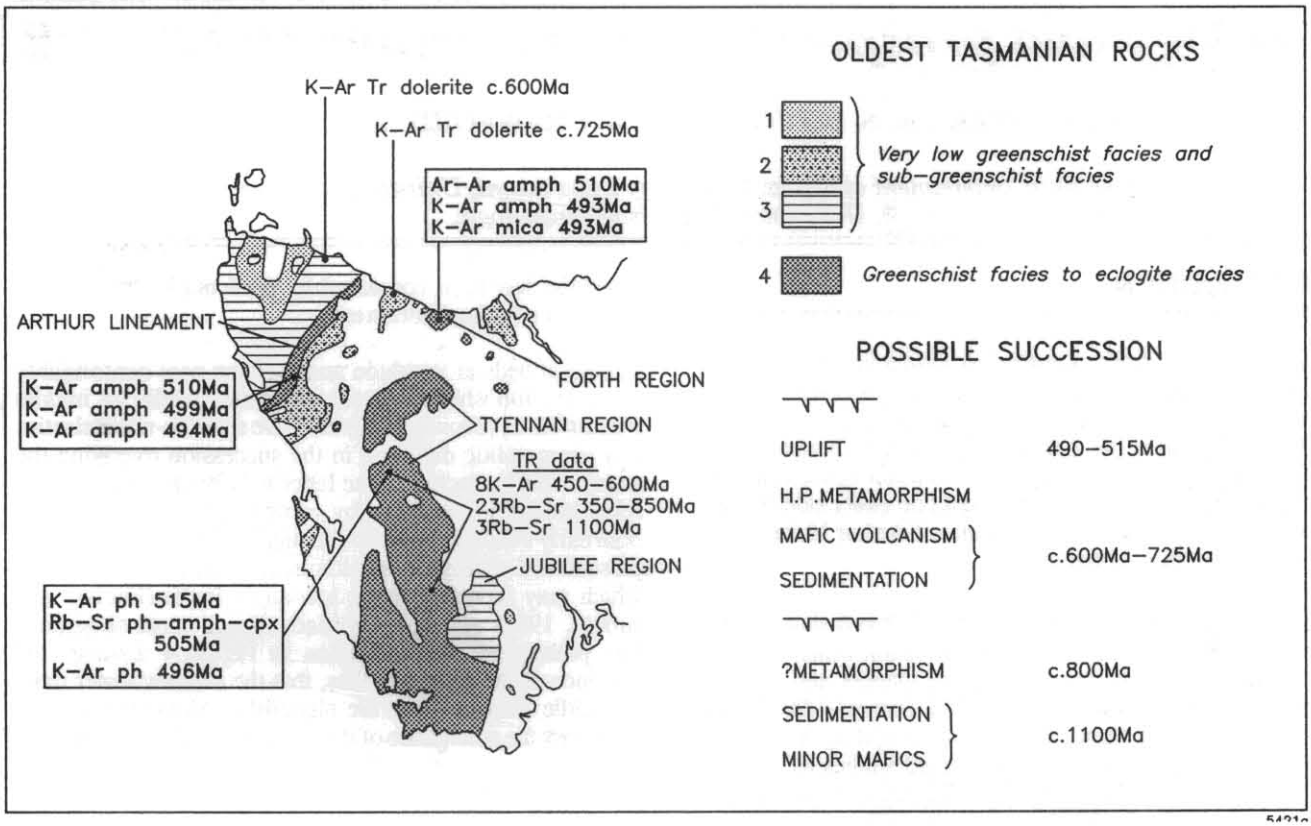


Figure 1

Distribution of Tasmania's oldest rocks. 1. Continental shelf and margin deposits with rift tholeiites near top – not all occurrences shown; 2. sandy turbidite facies; 3. quartzarenite, siltstone, minor dolomite; 4. Largely similar to 3 though protolith in high grade zones obscured.

Mineral ages from Turner and Crawford (in prep); McDougall and Leggo (1965); I. Villa – unpublished Ar-Ar; ph-amph-cpx age derived from 71–352 of Råheim and Compston (1977) and is approximate. Total rock data from Adams *et al.* (1985); Crook (1979); Råheim and Compston (1977).

with respect to the main deformation (D_2). In the Tyennan region the peak assemblages crystallised early in the main deformation phase (D_2) and display variable retrogression which may have occurred late in D_2, during D_3 and subsequently. In both the Arthur Lineament and the Tyennan region the climax of deformation was accompanied by mylonitisation. Also in both regions, and elsewhere in the Tasmanian Proterozoic, the regional transport direction associated with the main deformation was west over east.

The metamorphic and deformational similarities displayed by rocks in the Arthur Lineament and the Tyennan region are complemented by similar mineral ages (fig. 1) derived from hornblende amphibolite in the Arthur Lineament, garnet/hornblende amphibolite in the Forth region and eclogite in the Tyennan region. However, the relationship between these cooling or 'uplift' ages and the age of prograde metamorphism is a matter of some conjecture.

From the stratigraphic record it is clear that strong uplift and erosion of the Tyennan metamorphics occurred from the Middle Cambrian through to the earliest Ordovician (Corbett, 1990). This time range is generally consistent with the uplift indicated by the metamorphic mineral ages though the relationship between the fossil and radiometric time scales for the Cambrian is not particularly well established. The strong uplift of the Tyennan region probably reflects isostatic adjustment that would have quickly followed the deep burial that apparently generated the peak metamorphic assemblages. Thus, it seems likely that peak metamorphism occurred around the beginning of the Middle Cambrian or a little earlier.

There is some difficulty in reconciling the reconstruction of events based on the relatively precise dataset provided by the combined K-Ar, Ar-Ar and Rb-Sr mineral ages with total rock Rb-Sr data (Råheim and Compston, 1977) and total rock K-Ar data (Adams *et al.*, 1985) derived from the Tyennan region (fig. 1). The Rb-Sr data set comprises isochrons defined either by total rock and mineral (mainly phengite) pairs or total rocks and the resultant ages scatter very imprecisely from 350 to 1100 Ma. Interpretation of pre-520 Ma metamorphic events in this long time range was based on a preconception of what should be expected from the dataset and on an assumption that there was complete resetting of the total rock system by the inferred events at the localities sampled. It seems equally plausible to interpret the pre-520 Ma ages as representing partial resetting of the 1100 Ma depositional/provenance age thus reconciling the total rock Rb-Sr data with the mineral ages. Similarly, the K-Ar total rock data are imprecise and do not appear to mark complete resetting either.

In conclusion, it appears that in the Early–Middle Cambrian Tasmania was part of a collision zone in which very deep burial metamorphism was experienced by continental and

epicontinental rocks which now form part of the Tyennan and Forth regions and the Arthur Lineament. At about this time an assemblage of rocks with 'oceanic' affinities made an appearance in the Tasmanian geological record (fig. 2). This assemblage which includes boninites, low titanium tholeiites and related ultramafics (Brown, 1989) may have been emplaced as a west-travelling allochthon (Berry and Crawford, 1988), or as part of an allochthon, fairly early in the orogenic episode. Subsequently the sense of structural transport (at ? deeper crustal levels) was west over east.

MINERALISATION

Just as the Mount Read Volcanics and their associated polymetallic deposits compare with the setting and style of the Japanese Kuroko deposits, so too are there similarities between setting and mineralisation in the older Arthur Lineament and the Japanese Sambagawa Metamorphic Belt.

- Both the Arthur Lineament and the Sambagawa Belt are narrow, linear belts containing high pressure metamorphic assemblages.
- Compositional parameters of blue amphiboles from each terrain are remarkably similar.
- In each terrain the protolith succession comprises thick continentally derived, clastic sediments with rift-related basaltic volcanics.
- Mineralisation at the Alpine locality (fig. 2–3) in the Bowry Formation of the Arthur Lineament comprises pyrite-chalcopyrite with minor sphalerite, magnetite and hematite. Thus, this mineralisation is similar in composition as well as setting to the Besshi style deposits (Fox, 1984) of the Sambagawa Belt.

The Bowry Formation also contains:

- pyrite-magnetite lenses which include the ore bodies at the Savage River iron ore mine (Weatherstone, 1989).
- magnesite lenses (fig. 2–3) at Main Creek (Frost, 1982), Savage River mine (Frost and Matzat, 1984) and Arthur River-Lyons River (Dickson, 1990).
- gold in veins.

Gold also occurs in veins just east of the Bowry Formation and primary gold has been identified in residual soils overlying the Ahrberg Group (fig. 3; Khin Zaw *et al.*, this volume and poster).

Very pure, flour-like silica forms residual deposits over silicified dolomite in the Ahrberg Group near Corinna (fig. 2–3; Khin Zaw *et al.*, this volume and poster). Deposits of similar style are known within the Arthur Lineament where there are also residual deposits of ochre/umber at Main Creek (fig. 2).

Granite-related, vein and carbonate replacement deposits of tin and base metals (Collins and Williams, 1986) occur in rocks on either side of the Arthur Lineament whilst hard rock osmium-iridium-ruthenium alloys and gold (Brown, this volume) occur in ultramafic rocks to the east.

A small number of diamonds have been identified in placer deposits near Corinna.

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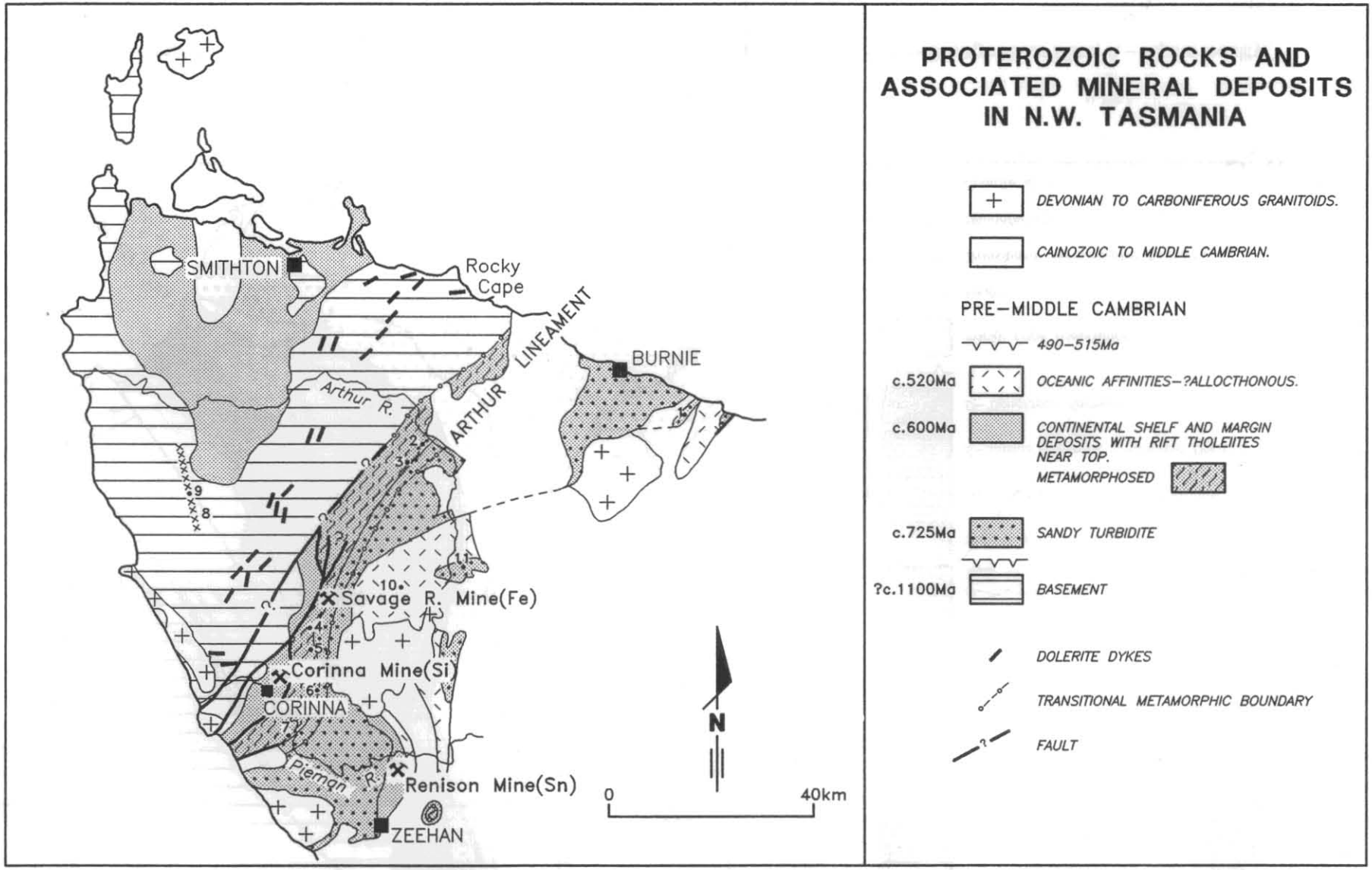


Figure 2. Proterozoic rocks and associated mineral deposits in N. W. Tasmania. Working mines are shown by mine symbols. Other deposits include mt-py-Cu at Keith River-Arthur River (3 to 2) and Alpine (7); mt-py at Long Plains South (5) and Rocky River (6); magnesite at Keith River-Arthur River, Lyons R (3), Savage River mine and Main Creek (4). Cp lodes occur in a quartz vein system (8) and tin occurs in veins at Balfour (9). Hm occurs at 1. Carbonate-replacement tin deposits occur at Cleveland (10) and Mt Bischoff (11). Silver-lead and zinc at Magnet between 10 and 11. Osmiridium in ultramafics in the ?allochthonous unit.

5 cm

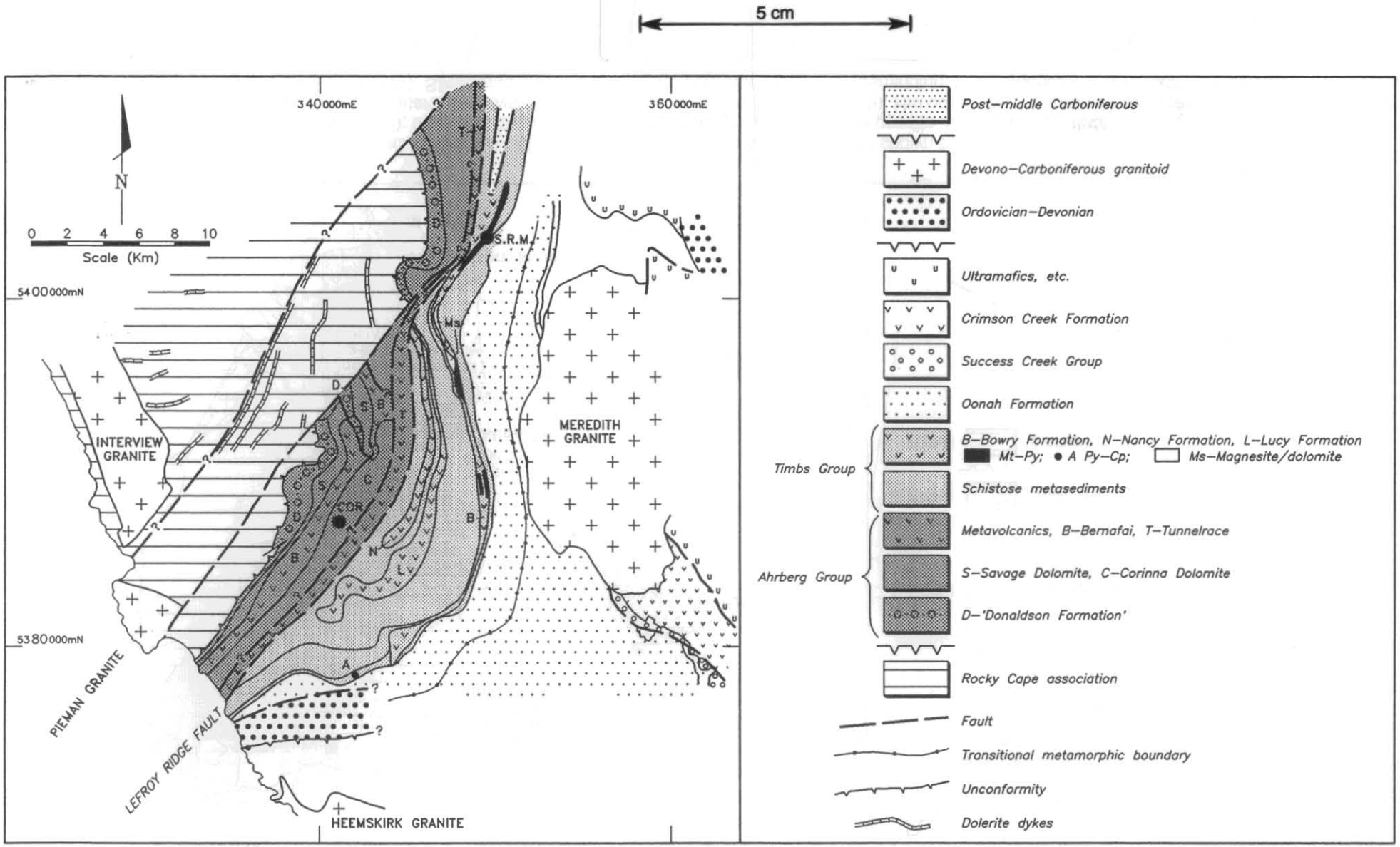


Figure 3.

Geology of the Corinna district after Turner *et al.*, 1991. COR – Corinna township; S.R.M. – Savage River Mine; A – Alpine locality.

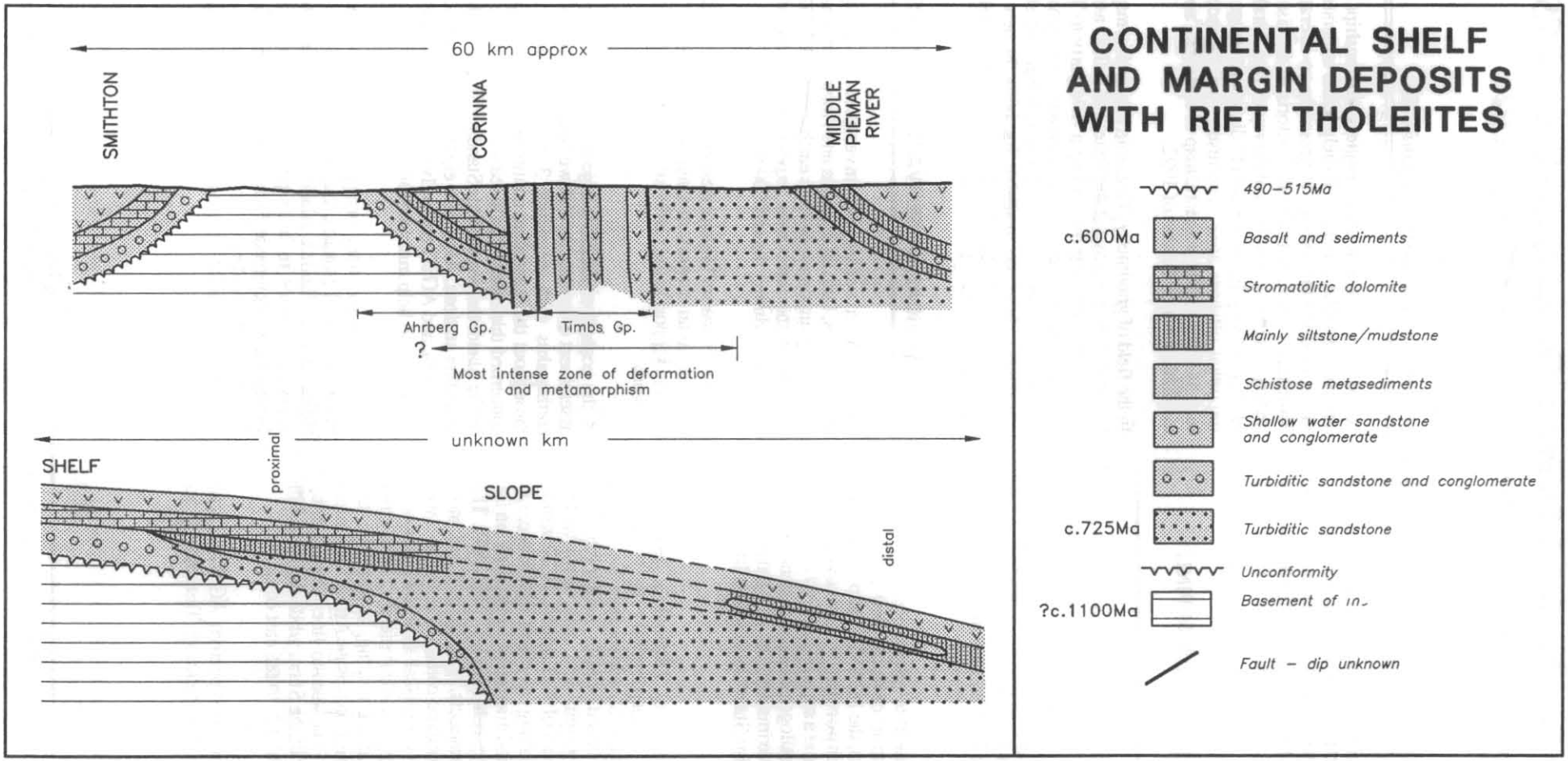


Figure 4

Above — much simplified composite cross section designed to illustrate stratigraphy. It includes the eastern edge of the Smithton synclinorium then is off-set in order to pass through Corinna to Middle Pieman River.

Below — palinspastic reconstruction of the inferred continental shelf and margin – see text for discussion.

5 cm

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Australian Geological Survey Organisation (AGSO): Programs of relevance to Tasmania

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AGSO's programs of relevance to Tasmania include National Geoscience Mapping Accord (NGMA) activities, and geophysical observatory work undertaken to fulfil AGSO's national and international commitments to earthquake seismology and hazard assessment, and geomagnetic field studies.

THE NATIONAL GEOSCIENCE MAPPING ACCORD

Compared to the mainland States and the Northern Territory, Tasmania is geologically well mapped. The Tasmanian Government has consistently supported geological mapping by the Tasmania Department of Mines to the extent that expenditure on mapping in the State is higher than for any other State/Territory on the basis of expenditure per square kilometre.

As a result of this commitment to geoscience, Tasmania is completely mapped at a scale of 1:250 000 to a quality comparable to, or better than, the 1:250 000 map coverage of the mainland. More importantly, however, it is approximately 60% mapped at a scale of 1:50 000 or, in some cases, 1:63 360, and the metallogenically important Mt Read Volcanic belt has been approximately 80% mapped at a scale of 1:25 000 as part of a joint State/Commonwealth funded program.

Because of the present status of Tasmania's geological mapping, AGSO's Tasmanian contribution to the NGMA is different to that for the mainland, where there has been a heavy emphasis on field-based studies underpinned by new-generation airborne geophysical data flown at the NGMA line-spacing standard of 400 metres. In Tasmania AGSO is presently undertaking specialist geochronology studies using the SHRIMP ion microprobe in preparation for a deep seismic profile survey schedule for 1994–1995. The study will involve three transects. The longest and most important lies close to the northern coast of Tasmania. It will cross all major Tasmanian geological structures almost at right angles and should provide a clear picture of the gross structure of northern Tasmania including, in particular, the behaviour at depth of structures such as the Arthur Lineament and the Tamar Lineament. The second line will cross the Dundas Trough in the west of the State, while the third will stretch from the central highlands to the east coast.

From a national geoscience perspective AGSO is also concerned with the special importance of Tasmania as an island State, and with the geological relationships between Tasmania and the mainland. To help refine understanding of these relationships, AGSO is presently co-operating with Tasmania, South Australia and Victoria to digitise an early analogue airborne geophysical survey of Bass Strait and the offshore Otway Basin to provide digital coverage of these important offshore areas. The results will be incorporated into AGSO's digital magnetic map of Australia, and will be available towards the end of 1992.

In the field of gravimetry, Tasmania has made a major effort to improve the coverage of the State, and AGSO assisted the work earlier this year by sending a field party to Tasmania to repair and replace, where necessary, the gravity base stations. There are now 20 well-calibrated gravity stations in Tasmania. These are available for tying in new detailed surveys and also linking the Tasmanian gravity observations to the national and global networks.

GEOPHYSICAL OBSERVATORIES PROGRAM

AGSO has a substantial investment in geophysical observatories, both in Australia and Antarctica. Tasmania is particularly important as far as earthquake risk is concerned, as parts of the State have experienced several damaging earthquakes during the last 100 years.

The then Bureau of Mineral Resources became involved with the Tasmanian network in January 1974, when it agreed to provide support to the University of Tasmania to operate the network.

In the context of AGSO's objective of providing accurate assessment of earthquake risk we need to be able to locate all earthquakes with magnitude 3 or greater that take place throughout the Australian continent. As far as Tasmania is concerned this means that at least three stations are required on the island: the World Wide Standard Station in Hobart and two other stations. At present eight stations are operating in Tasmania, and AGSO currently contributes around $30,000 per annum to help maintain the network.

In the geomagnetism program there is no permanent observatory in Tasmania, but the first-order stations near Hobart and at Flinders Island provide critical information every five years to help put together the Australian Geomagnetic Reference Field. Once again the location of Tasmania provides a unique opportunity for key measurements of the geomagnetic field on this part of the Earth.

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