COMPARISON BETWEEN COMSTOCK AND

RENISON MINES

September 1999

Prepared by
M.H. Adabi
Carbonate Petrologist and Geochemist

For
Oceania Tasmania PTY LTD
and
Bass Resources NL

AMG REFERENCE POINTS ADDED

496002

Contents

Abstract

The Neoproterozoic dolomite and associated clastic sediments at Renison, in western Tasmania, hosts significant stratabound carbonate replacement and vein styles of tin deposits. Mineralisation resulted from the passage of hydrothermal fluids, sourced from the underlying Devonian Pine Hill Granite, through major faults and fractures, partially to completely replacing three dolomite horizons, and forming a cassiterite-rich pyrrhotite orebody. Mixing of magmatic fluids with meteoric water was possible during the Devonian Tabberabberan Orogeny. The proportion of meteoric water that infiltrated late into the Renison hydrothermal system was potentially as high as 65% by volume.

The sulphide and skarn mineralisation at Comstock mine is hosted in carbonate units of the Neoproterozoic upper Oonah Formation. Mineralisation, similar to that at Renison mine, resulted from the passage of hydrothermal fluids, through major faults and fractures, forming a Zn-Pb-Ag sulphide orebody. It is suggested that the Heemskirk Granite supplied the source of hydrothermal fluids responsible for carbonate replacement sulphide mineralization. The principal structural control in relation to mineralisation is the Balstrup Fault. The $\delta^{34}S$, $\delta^{18}O$ and $\delta^{13}C$ values of carbonates in Comstock mine suggest that a combination of magmatic and meteoric fluids, similar to that at Renison mine, were responsible for mineralisation. The dolomite-meteoric water $\delta^{18}O$ and $\delta^{13}C$ equilibrium fractionation curves for variable $\delta^{13}C$ and uniform $\delta^{18}O$ values of Devonian temperate meteoric water (-9.5‰ SMOW) indicate that Comstock carbonates were in equilibrium with meteoric water having $\delta^{13}C$ values near -10‰ PDB.

On the basis of the stratigraphic, structural and isotopic similarities between Renison and Comstock mines it is suggested that Comstock mine, as with Renison, has excellent potential for mineral exploration.

1- Introduction

This report is a study of Neoproterozoic carbonates of the Renison and the Comstock mine area, Tasmania, Australia, which host significant ore deposits. As these deposits have similar age and are located in similar geologic and geographic settings, this study will help to understand the processes involved in the formation of sulphide mineralisation in these two areas. Thus, this report first deals with the Renison carbonates and then focuses on different aspects of the Comstock carbonates. The primary aim in this report is to compare the geological and geochemical characteristics of the Comstock orebody and Renison mine to show potential mineralisation in Comstock mine.

Renison, the largest primary tin producer in Australia, is situated at Renison Bell on the west coast region of Tasmania (Fig.1). Renison also is the largest stratabound, carbonate replacement tin deposit in western Tasmania. Renison carbonates range mainly from ferroan dolomite to ankerite with minor siderite and calcite. These carbonates occur within the central part of the Dundas Trough. Renison ore is dominated by massive pyrrhotite with minor cassiterite (~1%), which partially to completely replaced three dolomite horizons in the mine sequence.

The Comstock mine, which is located approximately 4 km west of Zeehan, western Tasmania (Fig.1), is a Zn-Pb-Ag skarn deposit. The Comstock mine lies within western part of the Zeehan mineral field which is located between the south-eastern margin of the Heemskirk Granite and the township of Zeehan. Exploration in Zeehan district resulted in the discovery of the large sulphide deposits and hundred thousand tonnes of lead, silver, zinc and tin was mined by several mining companies. The term Comstock orebody used in this report refers to the pyrrhotite+sphalerite+galena+chalcopyrite+pyrite orebody replacing both the late stage skarn and dolomite in the footwall of the Balstrup Fault.

The information contained in this report for Comstock mine was heavily drawn from Taylor (1993) and documents supplied by Oceania (Crossing, 1991, 1992; Knight, 1997).
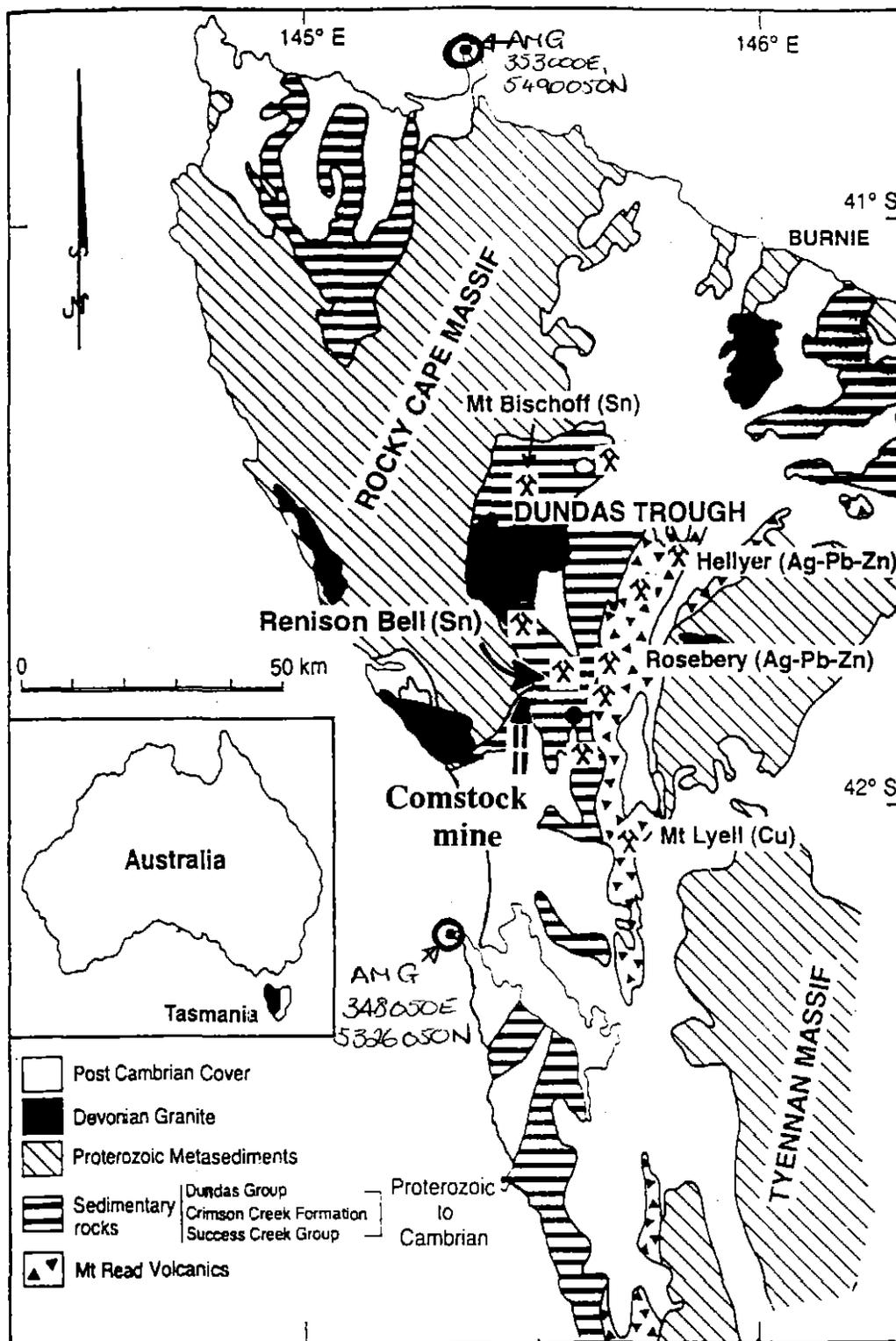
Figure 1. Regional geology of western Tasmania and the location of the Renison and Comstock mines.

AMG REFERENCE POINTS ADDED

2- Regional Geology

Extensive Proterozoic carbonates occur in western Tasmania. These carbonate sequences mainly located within the central part of the Dundas Trough (Cambrian, Crawford and Berry, 1992) consisting of Proterozoic to early Paleozoic rocks (Fig.1).

The oldest sediments in the Dundas Trough are the shallow shelf carbonates and siliciclastics of the Success Creek Group (~1000 m; Brown, 1986) which unconformably overly the upper successions of the Oonah Formation. On the basis of lithological differences, the Oonah Formation has been divided into two distinct successions: the lower Oonah succession (consists of thin bedded micaceous quartzite, siltstone, sandstone and black shale) and the upper Oonah succession (dominated by dolomites, interbedded carbonaceous shale, lava flow and pyroclastic bands; Brown, 1986). The K-Ar dating of detrital muscovite from the Oonah Formation, gives an age of 708 ± 6 Ma (Turner, 1993).

The Success Creek Group is conformably followed by a thick succession of relatively shallow marine carbonates, siliciclastics and volcaniclastics of the Crimson Creek Formation (~5000 m; Brown, 1989). A Neoproterozoic age has been suggested for the both Success Creek Group and Crimson Creek Formation based on radiometric age dating and lithological and chemical correlation with the sequence in the Smithton Basin (Brown, 1986). Carbon isotope chemostratigraphy supports the Neoproterozoic age of about 570-820 Ma for the Crimson Creek Formation and Success Creek Group respectively (Adabi, 1997a). The Crimson Creek Formation is overlain by a flysch-type sequence of siliciclastics called the Dundas Group (~3800 m; Middle to Upper Cambrian, Corbett, 1981; Crawford et al., 1992). Deposition of the Dundas Group sediments, was accompanied by the development of the Mount Read Volcanic Belt, along the eastern margin of the trough (Fig. 1). The Dundas Group is in turn overlain by late Cambrian to early Ordovician Owen Conglomerate. This unit was followed unconformably by early Ordovician Gordon Group and Silurian to early Devonian Eldon Group.

Sedimentation in western Tasmania was interrupted in the Middle Devonian by a period of intense deformation, due to major orogenic episodes correlated with the Tabberabberan Orogeny (Corbett, 1981; Crawford et al., 1992). During the late Devonian to early Carboniferous, widespread granitoid plutons (340 to 375 Ma; Solomon, 1981) were emplaced into the Oonah Formation and Dundas Trough. Mineralisation in parts of western Tasmania are believed to be genetically associated with the emplacement of these granitoids.

3- General Geology

3.1 Renison mine

3.1.1 Stratigraphy

In the Renison mine area, the Success Creek Group, Crimson Creek Formation, Dundas Group, Serpentine Hill Complex are present (Fig.2). The Neoproterozoic Success Creek Group, a 1000$^+$ m thick shallow shelf sequence of siliciclastic facies hosting the No.2 and No.3 dolomites, are host sediments to tin mineralisation. The Crimson Creek Formation, which conformably overlies the Success Creek Group, includes the No.1 dolomite horizon and a thick (~1000 m) sequence of siliciclastic and carbonate rocks (Morrison, 1982). The Renison deposit at the mine area occupies the upper part of the Success Creek Group and the lower part of the Crimson Creek Formation. This portion is called the Mine Sequence by mine geologists (Fig.3).

The Serpentine Hill Ultramafic Complex, which consists of serpentinite, ultramafic rocks and basic volcanics, is located to the east and southeast of the mine area. The Dundas Group outcrops adjacent to the Serpentine Hill Complex. Pre-Devonian rocks in the Renison mine area are intruded by Pine Hill Granite (Fig.3, Kitto, 1994).

3.1.2 Geologic structure

The regional fault structures at Renison are attributed to a tensional regime associated with emplacement of the Devonian Pine Hill Granite (Fig.3, Lea, 1991; Kitto, 1994). Major faults are exclusively normal, with dips generally in the range of 55-80°. The Mine Sequence is disrupted by at least three major groups of mineralised faults known as:

• The Federal-Bassett Fault (FBF) and Blow Fault Complex (BFC)
• The Transverse Faults which are also called the Shear Fault
• A series of north-south striking faults which form minor horst and graben structures

The Federal-Bassett Fault (FBF), which is a major fault in the mine area, has an inferred strike length of several tens of kilometres and dips to the northeast at approximately 70° (Lea, 1991; Kitto, 1994). The FBF project steeply upward into the overlying Success Creek Group and Crimson Creek sediments (Kitto, 1994). The Renison mine area is bounded to the northeast by the Federal-Bassett Fault and to the southwest by Argent Fault. The Argent Fault together with the FBF are the major boundary faults in the Renison mine
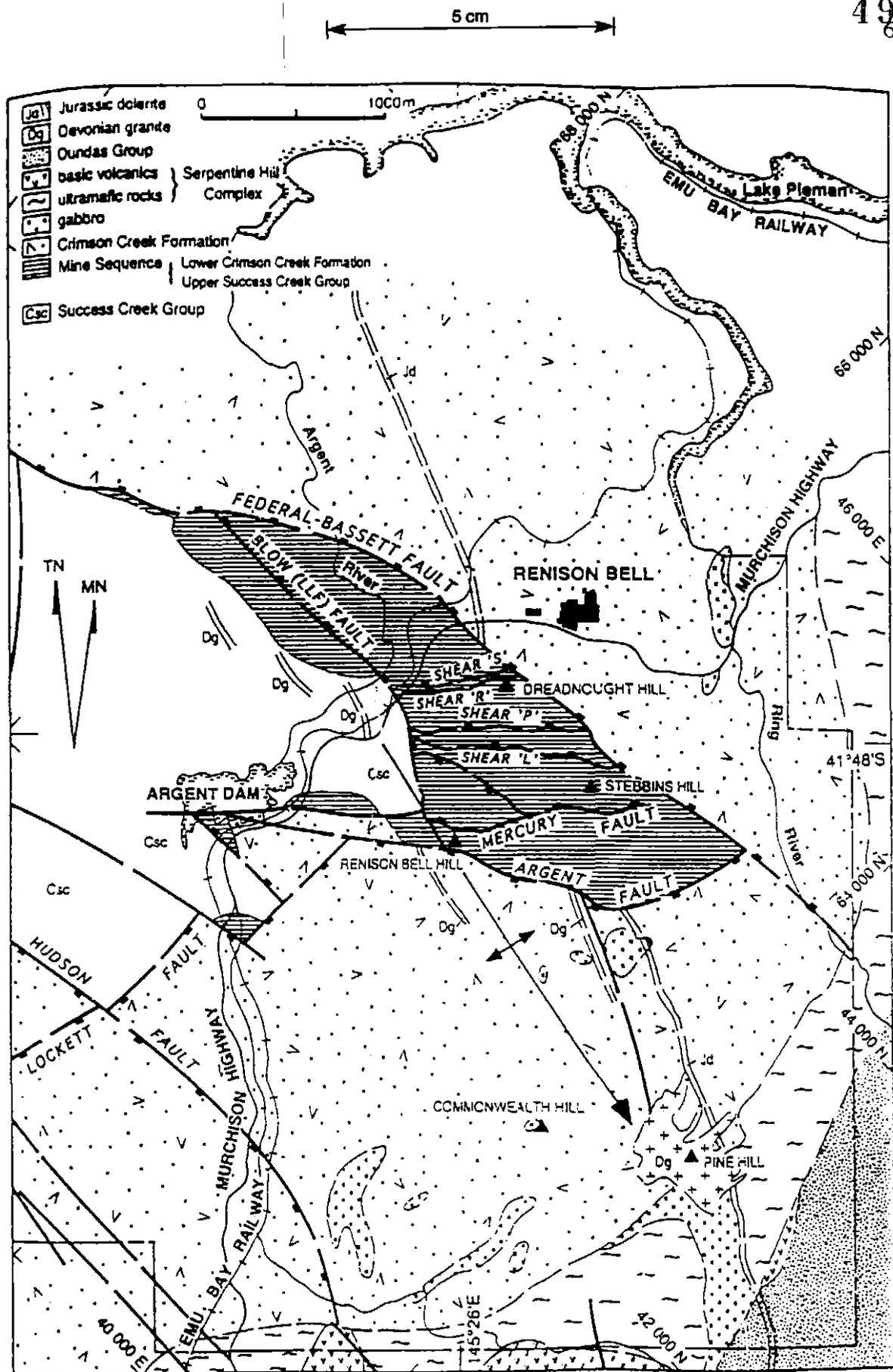
Figure 2. Geological Map of the Renison district (Kitto, 1994).

horst (Fig.3). The Blow Fault Complex (BFC) which is subparallel to the FBF is terminated by the Argent Fault in the south.

The Transverse Faults, or Transverse Shear (Fig.3), are a series of east-west trending faults that interconnect with the FBF and BFC structures. There are also a series of north- south oriented minor faults which developed above the Transverse Faults.

Numerous researchers believe that at Renison, the fault structures developed due to forceful asymmetrically emplacement of the Upper Devonian Pine Hill Granite beneath the mine area, which is related to the Tabberabberan Orogeny (Holyland, 1987; Lea, 1991). The age of the major longitudinal faulting in the area was considered to be pre-ore and the age of Transverse Faults were regarded as post-ore because they displaced ore bodies (Groves, 1968).
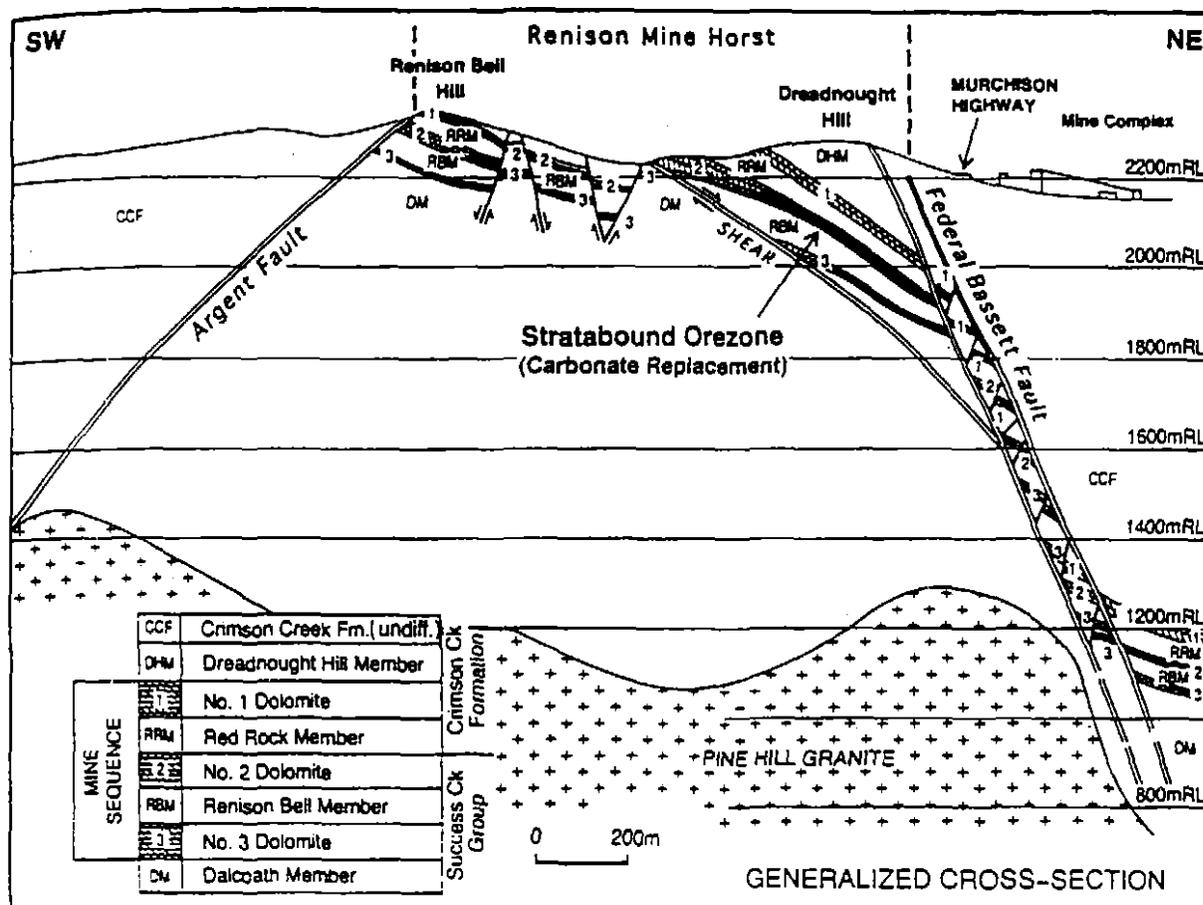

Figure 3. Schematic cross section of the Renison deposit showing the location of the Renison mine horst and the distribution of stratabound carbonate-replacement tin deposits.

3.2 Comstock mine

3.2.1 Stratigraphy

The Comstock massive sulphide orebody is located within a wedge of the upper Oonah Formation. The wedge of upper Oonah Formation is bounded to the north by Crimson Creek Formation and lower Oonah Formation. To the south, the wedge is a fault contact with gabbros of the McIvor Hill Complex. The upper Oonah Formation consists of laminated sandstone, siltstone and shale sequences, as well as dolomite, pillow lavas and pyroclastic units. The upper Oonah Formation situated between the Balstrup and Tenth Legion Faults (Fig.4). The mineralisation in Comstock mine is hosted in dolomitic carbonate units of the upper Oonah Formation. The carbonate units vary in drill core thickness from 50 cm's up to 300m. In the dolomite units, irregular occurrences of magnesite, siderite, ferroan dolomite and strong talcose overprinting was reported (Taylor, 1993). It has been suggested that these features were probably developed during recrystallisation related to the Heemskirk Granite emplacement and/or mineralisation (Crossing, 1992; Taylor, 1993). Deformational events resulted in the disruption and contortion of beds. The occurrence of gypsum in carbonate units may indicate deposition in a shallow water, possibly sabkha-type, environment (Crossing, 1991).
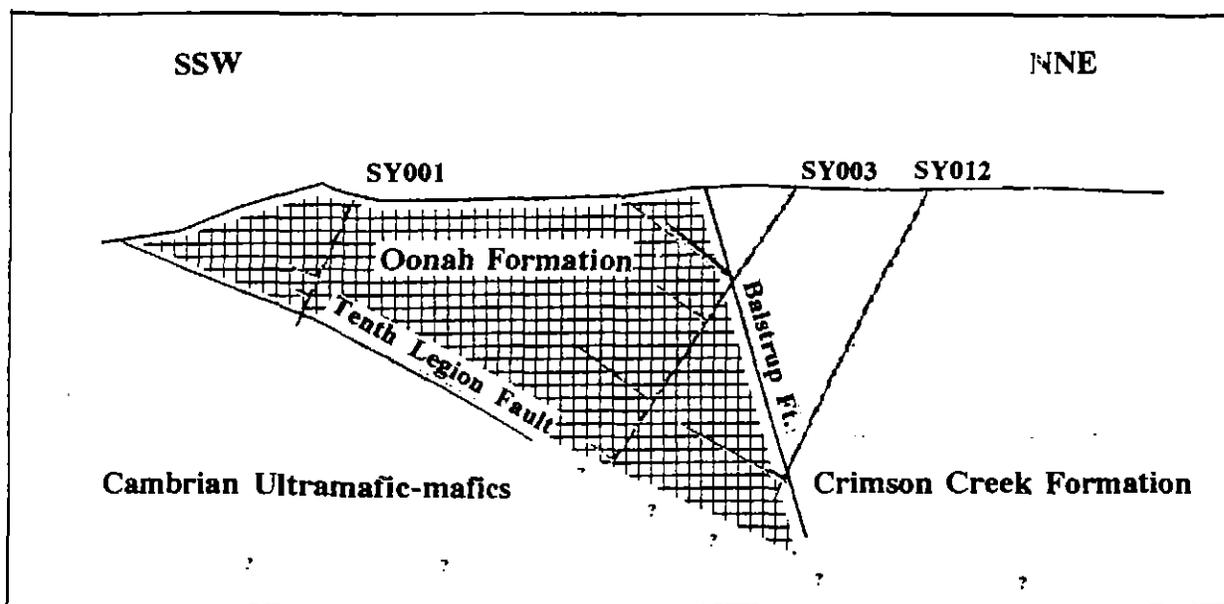

Figure 4. Schematic cross section through SY001 and SY 003 showing stratigraphy and the location of Balstrup and Tenth Legion Faults (modified from Knight, 1997).

The Crimson Creek Formation consists of grey to grey-green and red-brown greywacke and siltstones interbedded with laminated mudstones, and rare carbonate units. The vocaniclastic units are rarely observed in the area (Crossing, 1991). Based on overall sedimentary features, Crimson Creek Formation can be interpreted as a turbidite sequences (Taylor, 1993). A number of small porphyritic mafic dyke are observed in the Crimson Creek Formation in the hangingwall of the Balstrup Fault. In the thin section, the extensive development of chlorite, epidote, sericite, and calcite suggests that pervasive hydrothermal alteration occurred in the Crimson Creek Formation.

3.2.2 Geologic structure

The Comstock prospect is transected by 2 major NW trending faults: namely as the Balstrup Fault and the Tenth Legion Fault (Fig.5). The Tenth Legion Fault is regarded as a major regional low angle Cambrian thrust (personal communication with Dr Clive Burrett) along which sediments of the upper Oonah Formation thrusted over the McIvor Hill Complex, west of the south Comstock mine. The Tenth Legion Fault has a length of a few kilometres and dip to the NE at about 45 degrees in the south Comstock mine area (Crossing, 1991).

The Balstrup Fault is considered as a major feeder fault to mineralisation in Comstock mine area. The average dip of the Balstrup Fault is about 70 degrees NE. West of Comstock mine, the fault merges with the Tenth Legion Fault. The movement on the Balstrup Fault is inferred to be oblique-slip, consisting of sinistral and normal displacement (Crossing, 1991). This fault structure developed due to forceful emplacement of the Upper-Devonian Heemskirk Granite beneath the mine area, which is related to the mid-Devonian Tabberabberan Orogeny.

There are also a series of northeast- southwest trending minor faults that interconnect with the Balstrup and Tenth Legion Faults (Fig.5). These northeast- southwest faults cut by a few east-west trending faults which are subparallel to the Balstrup and Tenth Legion Faults (Fig.5). The Balstrup Fault and series of interconnecting faults have a major control on mineralisation in the Comstock mine area.

Crossing (1991) suggested that two sets of folds are present in the Comstock mine area. The early phase of folding corresponds to the mid-Devonian Tabberabberan Orogeny, and the late phase of folding occurred in respose to thrust and wrench movements on the
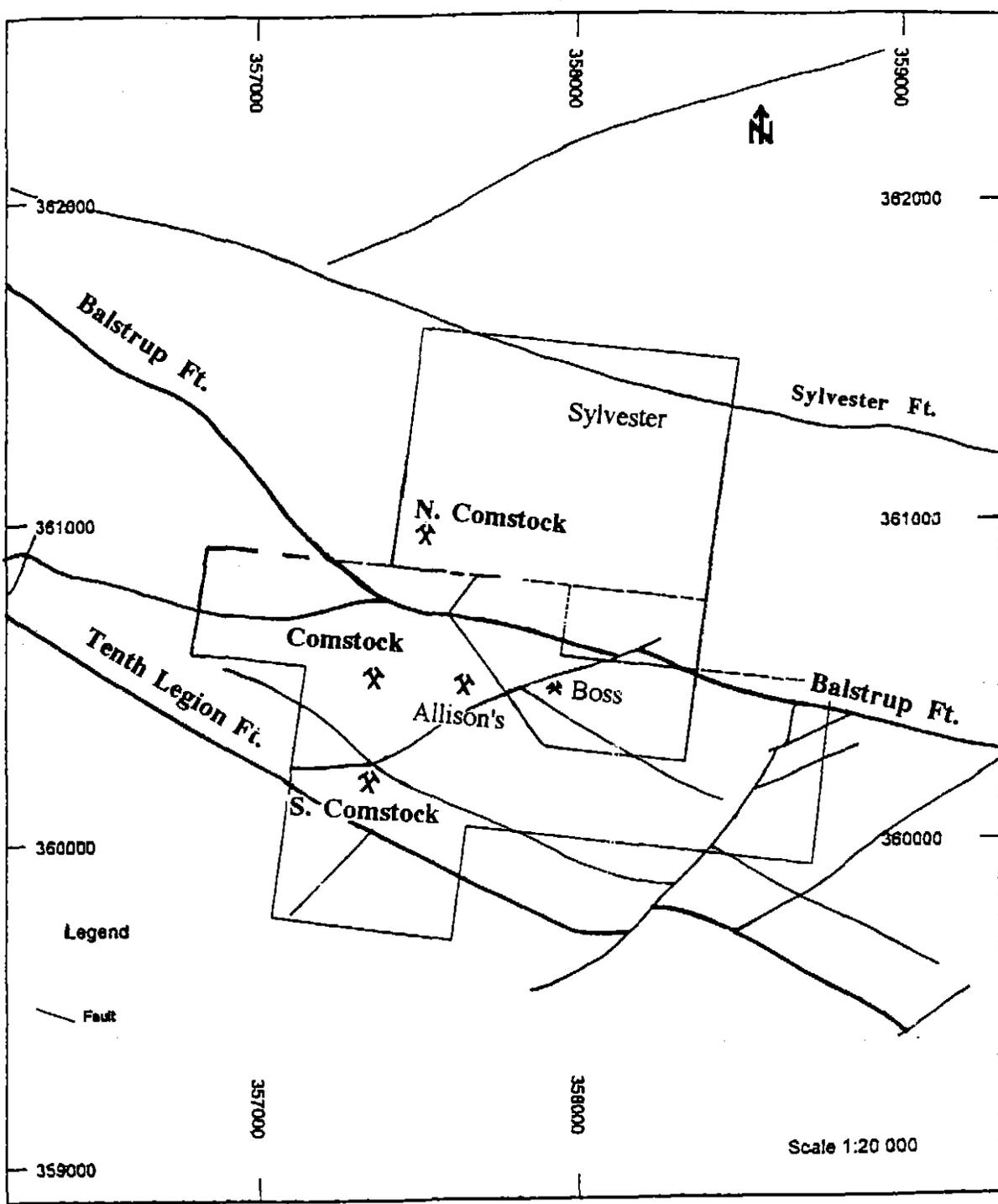
Figure 5. Structural base map with lease boundaries of the Comstock mine (modified from Knight, 1997).

Balstrup and Tenth Legion Faults. The mid-Devonian Tabberabberan Orogeny produced the most significant period of deformation in the area.

The Heemskirk Granite which intruded the Neoprpterozoic Oonah Formation in the late Devonian supplied the source of hydrothermal fluids responsible for carbonate replacement and vein styles of mineralisation. In Comstock mine area, some interconnecting fault structures may developed due to forceful emplacement of the Upper Devonian Heemskirk Granite beneath the mine area (Fig.6), which is related to the Tabberabberan Orogeny. Leaman and Richardson (1989) have shown that the granite surface occurs within two kilometres of the ground surface over a large area of the Zeehan field (Fig.6). East of Zeehan the granite surface occurs in depths of about six to eight kilometres. At these depths, the granite is interpreted to continue regionally towards the Pine Hill Granite (Fig.6, Leaman and Richardson, 1989). The gravity interpretation of the granite form indicates irregularities on the granite surface, which may have controlled on the occurrence of mineralisation in the Zeehan district. These irregularities are seen as cupolas which intrude into the overlying rock, and act as channels for mineralising fluids (Leaman and Richardson, 1989). The Zeehan mineral field have been regarded as a classic example of hydrothermal ore zonation, based primarily on distance from the Heemskirk Granite (Solomon, 1981).
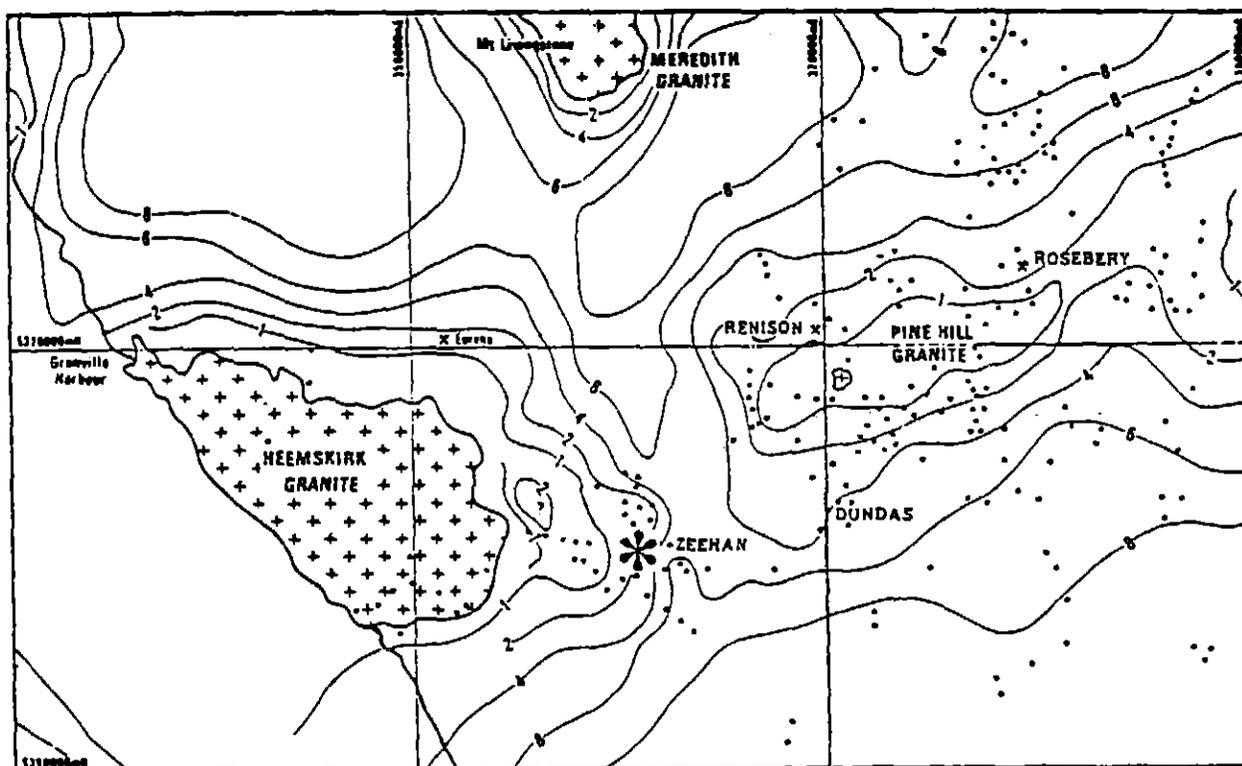

Figure 6. Distribution of Devonian granites in the Zeehan district. Mineralisation sites are indicated by dots. Star indicates location of Comstock mine (modified after Leaman and Richardson, 1989).

4- Mineralisation

4.1 Renison mine

Tin deposition at Renison Bell was associated with stratabound carbonate-replacement mineralisation and vein deposits resulting from the passage of hydrothermal fluids through major fault structures (Fig.3, Patterson et al., 1981; Kitto, 1994, Adabi, 1997 a, b). The regional fault structures at Renison are attributed to a tensional regime associated with emplacement of the Devonian Pine Hill Granite. Renison ore is dominated by massive pyrrhotite with minor cassiterite (~1%), which partially replaced three dolomite horizons in the mine sequence. The No. 2 and No. 3 dolomite horizons were heavily mineralised, particularly at the intersections of major fault structures in close proximity to hydrothermal feeders (Patterson, et al., 1981; Holyland, 1987; Kitto, 1994).

The Federal-Bassett Fault (FBF) was the primary structural control on distribution of ascending magmatic hydrothermal fluids at Renison. Other significant fault structures which controlled the distribution of fluid were the Blow Fault Complex (BFC), subparallel to the Federal-Bassett Fault, and a series of east-west transverse faults that interconnect the Federal-Bassett Fault and Blow Fault Complex (Kitto, 1994, Fig.3).

More recently, detailed fluid inclusion studies have shown that the homogenisation temperatures for the earliest oxide-silicate stage of mineralisation ranged from $>400^{\circ}$C at the base of the Federal-Bassett Fault (3000 m beneath the Devonian paleo-surface) to nearly 300° C at the top of the mine workings. $\delta^{18}O_{fluid}$ values of 9‰ SMOW were determined from quartz associated with this stage of mineralisation.

$\delta^{18}O$ values in sedimentary and hydrothermal dolomites are thought to correspond to decreasing temperatures from above 350° C at feeder faults to less than 150° C at a distance of 200 -1000 m from these regions (Holyland, 1987).

4.2 Comstock mine

Mineralisation in the Comstock prospect consists of Zn-Pb-Ag sulphide mineralisation hosted in dolomitic carbonate units of the Neoproterozoic upper Oonah Formation and late stage skarn mineralisation. Three stages of skarn formation has been recorded: 1- contact metamorphic stage; 2- early metasomatic; and 3- late (hydrous) metasomatic stage (Taylor, 1993). Contact metamorphism of the upper Oonah Formation carbonate, and siltstone and sandstone lithology resulted in widespread recrystallisation, and

formation of massive biotite hornfels respectively. The occurrence of biotite hornfels has been related to the outer margin of the contact metamorphic aureole of the Heemskirk Granite. The temperature between 400 to 500°C was estimated for biotite hornfels facies (Turner, 1981). The early metasomatic stage skarn, occurring in a unit of upper Oonah Formation carbonate, has been divided into three distinct skarn, namely as: garnet-clinopyroxene skarn, clinopyroxene skarn and tremolite-talc-calcite skarn. The formation of garnet and clinopyroxene in carbonate of the upper Oonah Formation is indicative of carbonate alteration through the reaction of metasomatic fluids, heated by and at least partly derived from the Heemskirk Granite. The late metasomatic stage is the largest extent of skarn within the Comstock area. The late metasomatic stage, which is most evident in the dolomitic rocks, has been divided into: 1- massive serpentine-magnetite skarn and 2- carbonate-serpentine-magnetite ± brucite skarn. The occurrence of brucite suggests that temperatures during the late metasomatic stage skarn formation were relatively high (at 2kb, brucite is stable between 400 to 650°C (Einaudi et al., 1981). The formation of brucite at higher temperatures than other mineral such as serpentinite and carbonate may suggest mineralogical zonation, where the higher temperature mineralisation precipitates first closest to the fluid source, while the lower temperature phases form later further from the source. In this case, the Balstrup Fault was the most probable fluid channel way.

Mineralisation in the Comstock mine is composed primarily of five sulphides; pyrrhotite, sphalerite, galena, chalcopyrite and pyrite. The Comstock massive sulphide body occurs in the immediate footwall of Balstrup Fault. The Comstock massive sulphide body consists of two distinct styles of mineralisation: 1- massive pyrrhotite replacing the late stage magnetite-serpentine skarn close to footwall of the Balstrup Fault, and 2- massive pyrite replacing dolomitic carbonates at the margins of the sulphide body. Pyrrhotite is the dominant sulphide mineral in the Comstock massive sulphide body. Massive pyrrhotite is the earliest stage of mineralisation which formed relatively soon after the development of the late stage serpentine-magnetite skarn. Massive pyrrhotite proximal to the Balstrup Fault containing patches of sphalerite and galena. In massive pyrite mineralisation, sphalerite and galena occur as patches and disseminations, and account for 10% of total sulphides. Massive pyrite mineralisation is concurrent with the deposition of massive pyrrhotite replacing skarn in the footwall of the Balstrup Fault (Taylor, 1993).

Stockwork vein mineralisation occurs predominantly in zones of fractures and minor faults, mainly associated with the Balstrup Fault. Disseminated sphalerite, galena (~5%) and

pyrite with minor carbonate occur in the zones of stockwork mineralisation. Many pyritic veins occurring between the Balstrup and Tenth Legion Faults.

4.2.1 Metal distribution and association

Metal distribution shows that Cu, Pb, Zn, Ag predominantly occur in the intersections of massive sulphide mineralisation close to the Balstrup Fault. The highest concentration of copper correspond to both massive pyrrhotite and massive pyrite mineralisation, while the highest lead (average ~3%) and zinc (average ~5%) grade correspond to the massive pyrite mineralisation (Taylor, 1993). The average concentration of lead and zinc in the massive pyrrhotite mineralisation ranging from 0.6% to 2% and 1.2% to 3% respectively. Silver grades are highest in the massive pyrite mineralisation where average values are around 40 ppm. Silver abundance in the massive pyrrhotite mineralisation is around 15 to 20 ppm. The distribution of silver follows closely that of lead (Taylor, 1993).

4.2.2 Controls on mineralisation

Since most of the skarn and massive sulphide mineralisation occurred within carbonate beds of the upper Oonah Formation, this restriction may indicate the importance of stratigraphic controls on mineralisation. The presence of patches of sulphide mineralisation within the carbonate units in the Comstock mine area may indicate that mineralisation occurred in selective portions of the carbonate units. This selectivity can be a function of permeability and/or the composition of carbonate unit. These two controlling factors have the effect of forcing fluids to migrate along bedding planes as a permeability barriers (Taylor, 1993).

The occurrence of sulphide and skarn mineralisation in Comstock prospect are also attributed to major faults and fractures. The principal structural control in relation to mineralisation is the Balstrup Fault. Since the entire Comstock sulphide body is located within ~15m of the footwall of the Balstrup Fault, this strongly suggests that the Balstup Fault acted as the main conduit for mineralising hydrothermal fluids.

5- Isotope Studies in Renison and Comstock Mines

$\delta^{18}O$ and $\delta^{13}C$ values of carbonates can provide useful criteria to determine the source (s) of hydrothermal fluids responsible for carbonate alteration, the temperature range for carbonate replacement mineralisation, and isotopic compositions of infiltrating fluids. Thus, in this report , $\delta^{18}O$ and $\delta^{13}C$ values of carbonates in Renison and Comstock mines are compared to understand the processes involved in the formation of sulphide mineralisation in these areas.

5.1 Renison mine

Carbon and oxygen isotope values for both less recrystallised and strongly recrystallised Renison dolomites show a positive correlation. $\delta^{18}O$ values in carbonates from strongly recrystallised sections (-2.5 to -21‰ PDB) are lighter on average than less recrystallised carbonates (-2.7 to -15‰ PDB, Fig.7). The lightest $\delta^{18}O$ and $\delta^{13}C$ in the Renison dolomites correspond to the maximum extent of alteration in the original dolomites and provide support for the potential composition of the infiltrating fluid(s).

The elemental and isotopic composition of the Renison carbonates suggest that a combination of magmatic and meteoric fluids were responsible for mineralisation in Renison (Adabi, et al., 1996; Adabi, 1997b). The lighter $\delta^{18}O$ and $\delta^{13}C$ values observed in the Renison carbonates may be due to magmatic fluids. Granite derived magmatic fluids may have distinct $\delta^{13}C$ values (-5 ± 2‰; Ohmoto and Rye, 1979; Golding and Wilson, 1983). The $\delta^{13}C$ values for hydrothermal fluids responsible for alteration of the Renison dolomite must have an isotopic value between the unaltered Renison dolomite value of ~4‰ PDB and lightest siderite value of -7.9‰ (Fig.7).

The $\delta^{13}C$ values decrease with increasingly lighter $\delta^{18}O$ values. This can be due to meteoric fluids. Diagenetic trends based on $\delta^{13}C$ and $\delta^{18}O$ values in different environmental setting are shown in Fig.7. Note meteoric trend passing through Renison dolomite isotopic field. The dolomite-meteoric water $\delta^{18}O$ and $\delta^{13}C$ equilibrium fractionation curves (Rye and Williams, 1981) for variable $\delta^{13}C$ and uniform $\delta^{18}O$ values of Devonian temperate meteoric water (-9.5‰ SMOW) indicate that Renison dolomites were in equilibrium with meteoric water having $\delta^{13}C$ values near -10‰ PDB (Adabi, 1997b, Fig.8). During the Lower Devonian, Tasmania was thought to be at latitude 40° S (Lee, 1993), in a temperate region with temperatures <20° C.
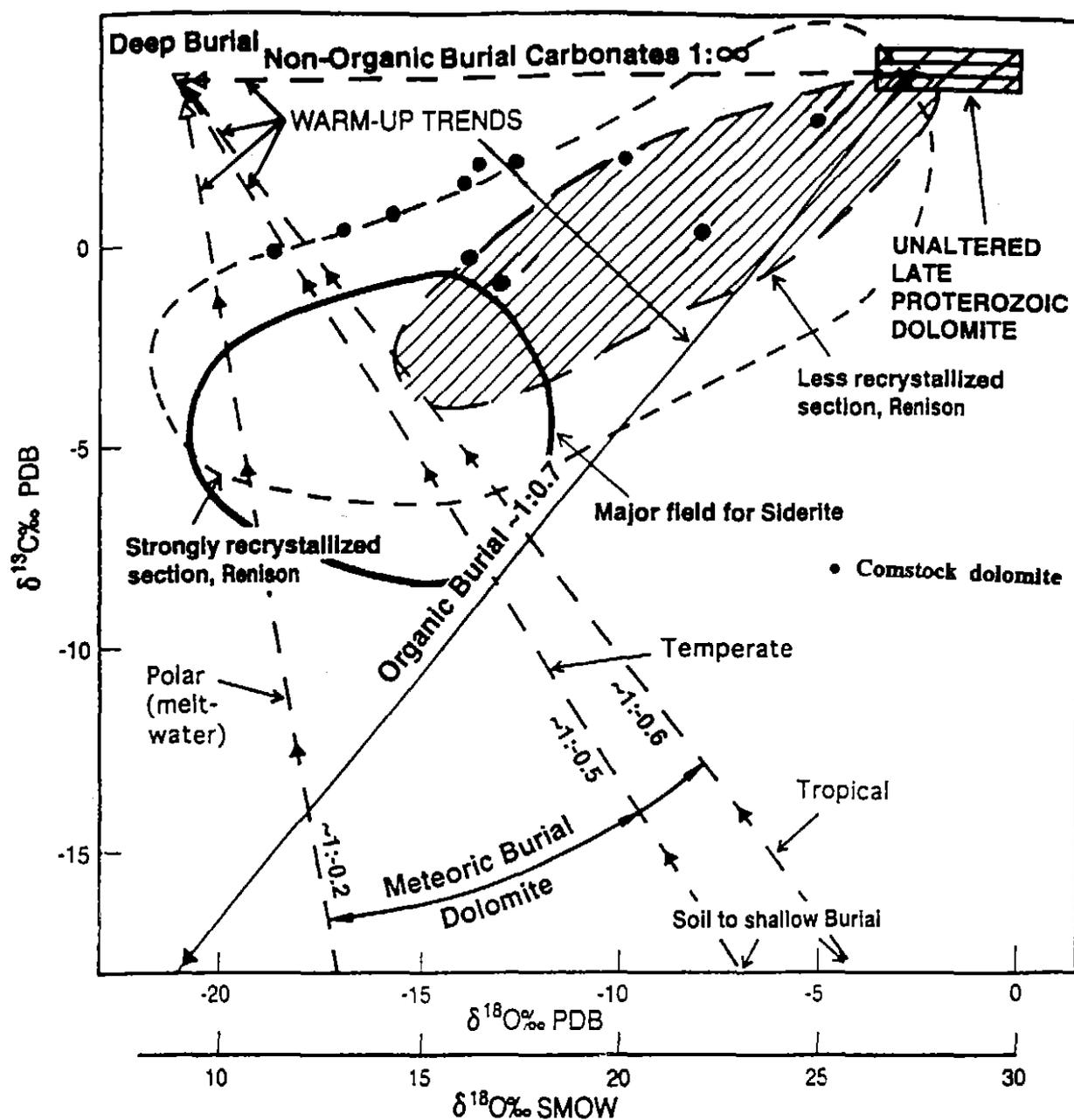
Figure 7. Carbon isotope versus oxygen isotope covariance diagram for the Renison and Comstock carbonates together with isotope models for non-organic, organic and meteoric burial trends. $\delta^{18}O$ values for carbonates from tropical (-4‰ PDB, 26‰ SMOW), temperate (-7‰ PDB, 23‰ SMOW) and polar (-17‰ PDB, 13‰ SMOW) regions are from Adabi (1997). Warm-up trends refer to temperature increases during burial. Note meteoric burial trends pass through Renison and Comstock isotopic fields.

Figure 8. Carbon isotope versus oxygen isotope covariance diagram for Renison and Comstock carbonates with dolomite-water $\delta^{18}O$ (SMOW) and $\delta^{13}C$ (PDB) fractionation curves (after Rye and Williams, 1981) corresponding to temperate Devonian meteoric water ($\delta^{18}O$ = -9.5‰) with variable $\delta^{13}C$ values ($\delta^{13}C$ =0‰; -3‰; -11‰) and a mixed fluid ($\delta^{18}O$ = -3‰; $\delta^{13}C$ = -5.5‰). Note temperate Devonian meteoric water ($\delta^{18}O$ = -9.5‰; $\delta^{13}C$= -11‰ PDB) bisects the isotope field of Renison carbonates and Comstock dolomite and skarn calcite data. This indicates that Renison and Comstock carbonates were in equilibrium with meteoric water having $\delta^{18}O$ = -9.5‰ and $\delta^{13}C$= -11‰ PDB.

It has been calculated that late stage carbonate alteration in Renison may have resulted from the mixing of 65% non-magmatic fluid with 35% magmatic fluid (Fig. 9, Adabi et al., 1996, Adabi, 1997b).

Alteration equilibrium temperatures

$\delta^{18}O$ and $\delta^{13}C$ values of carbonates can be used to determine the equilibrium temperatures responsible for carbonate alteration.

Calculation of $\delta^{18}O$ temperatures for hydrothermal solutions, using $\delta^{18}O_{fluid}$ (magmatic) values of 9‰ SMOW (Kitto, 1994), indicate a range of temperatures up to 350° C. Based on homogenisation temperatures from fluid inclusions, a temperatures between 150-200°C correspond to mixed magmatic and meteoric water for late stage mineralisation.
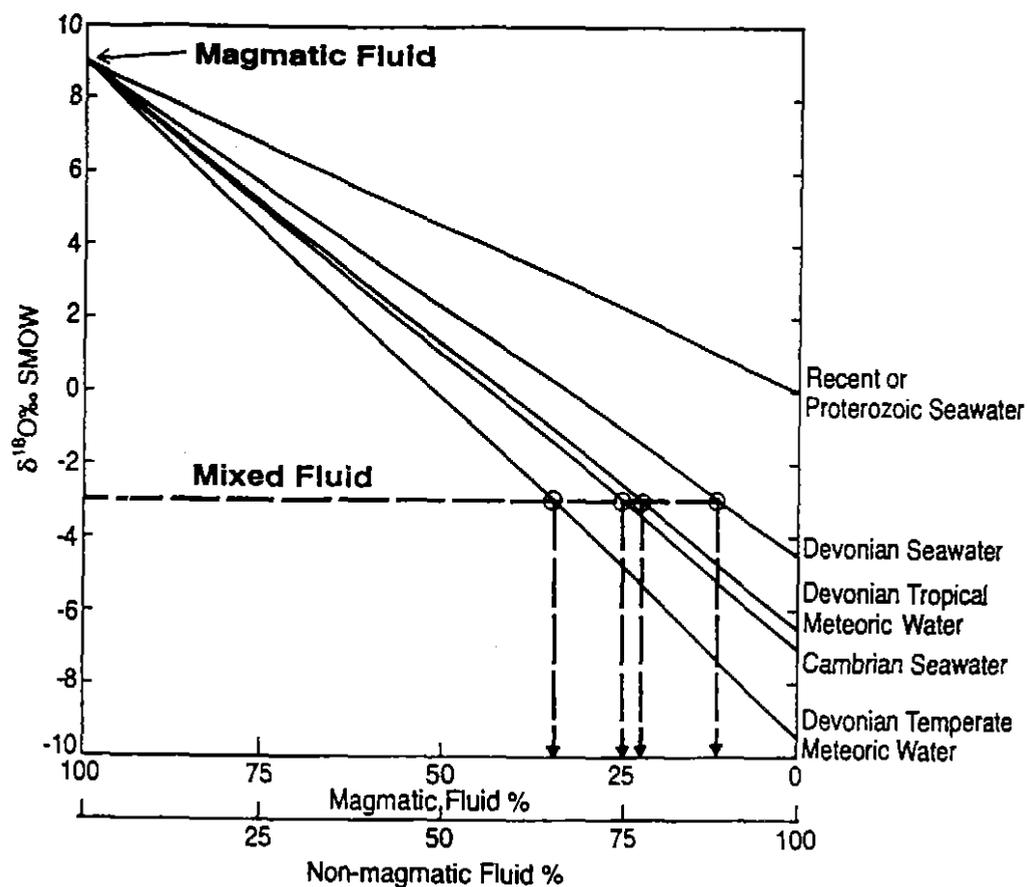

Figure 9. Potential hydrothermal fluids for mineralisation were mixed magmatic fluid with up to 65% Devonian temperate meteoric water.

5.2 Comstock mine

5.2.1 Oxygen and carbon isotopes

The $\delta^{18}O$ and $\delta^{13}C$ analysis of dolomite samples from contact metamorphosed Oonah Formation and calcite from late stage massive serpentine-magnetite skarn indicate two different fields (Taylor, 1993). The $\delta^{18}O$ (ranging from +11.2 to + 24.6‰) and $\delta^{13}C$ (ranging from -0.8 to + 3.5‰) values of dolomite shows some degree of overlap with typical $\delta^{18}O$ and $\delta^{13}C$ values of the Neoproterozoic dolomites (Figs. 7,8; Adabi, 1997b). The overall isotopic composition of dolomite show slight depletions in $\delta^{18}O$ and particularly $\delta^{13}C$ values. The $\delta^{18}O$ (ranging from +3.8 to + 8.2‰) and $\delta^{13}C$ (ranging from -2.6 to -4.6‰) values of calcite from within metasomatic skarn (skarn calcite) are considerably lighter compared to those of dolomitic samples (Figs. 7,8). The very depleted values of skarn calcite can be due to the infiltration of $\delta^{18}O$ and $\delta^{13}C$ depleted fluids (Ohmoto, 1986).

Brown et al (1985) suggested a magmatic source for skarn calcite $\delta^{18}O$ and $\delta^{13}C$ values. The $\delta^{18}O$ and $\delta^{13}C$ values of magmatic fluid are assumed to be +5 to -10‰ and -5±2.5‰ respectively (Shimazaki et al, 1986). The $\delta^{18}O$ and $\delta^{13}C$ values of skarn calcite in this study show only slight overlap with the range of $\delta^{18}O$ and $\delta^{13}C$ values expected for magmatic fluids at the temperatures that correspond to late stage skarn formation (assuming a temperature for late stage skarn formation of 400 to 200°C). The very depleted $\delta^{18}O$ in calcite skarn could be due to the involvement of meteoric water. Shimazaki et al (1986) and Layne et al (1991) have suggested that the depletion of $\delta^{18}O$ values in calcite skarn is due to the mixing of meteoric water with magmatic fluids at higher temperature. The $\delta^{18}O$ and $\delta^{13}C$ values of the Comstock dolomite and calcite samples fall within the mixed magmatic and meteoric fluids (Fig. 8). The $\delta^{18}O$ and $\delta^{13}C$ values of the Comstock dolomites also fall within the less recrystallised and strongly recrystallised dolomite fields of Renison. Dolomite-fluid $\delta^{18}O$ and $\delta^{13}C$ fractionation curves suggest that mineralisation in Renison and Comstock mines resulted from mixing of Devonian magmatic and temperate meteoric fluids.

The $\delta^{18}O$ and $\delta^{13}C$ values of skarn calcite in Comstock mine fall within the Pb-Zn zone of major skarn classes (Taylor, 1993).

5.2.2 Sulphur isotope

The sulphur isotopic analysis of pyrrhotite and pyrite samples from massive sulphide body have an average value of +6 to +7‰ (Taylor, 1993). These values are more positive than for a typical range of $\delta^{34}S$ values encountered in magmatic fluids generated in S-type granites: the typical range being 0±5‰ (Ohmoto, 1986). This implies that the sulphur in the fluids responsible for mineralisation originated from mixing of $\delta^{34}S$ enriched sedimentary sulphur, being leached from the sedimentary rocks, with $\delta^{34}S$ depleted magmatic sulphur, derived from the underlying Heemskirk Granite, resulting an intermediate $\delta^{34}S$ values of +6 to +7‰. This conclusion agrees favaroubly with the $\delta^{18}O$ and $\delta^{13}C$ results.

6- Conclusions

6.1 Renison mine

Renison carbonates have been altered mainly by hydrothermal alteration. The variations in the intensity of the alteration is mainly dependent on proximity to fractures, faults or mineralisation. Magmatic and later meteoric fluids were responsible for alterations. These conclusions are based on the following evidence:

• Variation in carbonate $\delta^{13}C_{PDB}$ values from -5.1 to 4.1‰ and the linear trend between $\delta^{18}O$ and $\delta^{13}C$ values are due to alteration by magmatically derived hydrothermal fluids and later mixed magmatic-meteoric fluids. Overlapping $\delta^{18}O$ and $\delta^{13}C$ fields for Renison carbonates with the Devonian magmatic dolomite field support a magmatic source for the hydrothermal fluids.

• The $\delta^{18}O$ and $\delta^{13}C$ values of the most altered Renison carbonates indicate that they were magmatically derived Devonian hydrothermal fluids of approximately 350°C. These temperatures are similar to those obtained from fluid inclusion studies and from calculations based on $\delta^{18}O$ variations in vein quartz.

• Dolomite-fluid $\delta^{18}O$ and $\delta^{13}C$ fractionation curves that best fit the Renison $\delta^{18}O$ and $\delta^{13}C$ carbonate data are for an early stage Devonian magmatic fluid ($\delta^{18}O_{SMOW}$ = +9‰, $\delta^{13}C_{PD}$ = -5‰), followed by late-stage mixtures of temperate Devonian meteoric water and magmatic fluids.

• Carbonate replacement mineralisation at Renison resulted from magmatic hydrothermal fluids derived from the underlying Devonian Pine Hill Granite. Mixing of magmatic fluids with meteoric water was possible during the Devonian Tabberabberan Orogeny. The proportion of meteoric water that infiltrated late into the Renison hydrothermal system may have been 65% of the fluid.

6.2 Comstock mine

The skarn and sulphide mineralisation in the Comstock prospect is interpreted as metasomatic replacements of dolomite units of the Neoproterozoic Upper Oonah Formation by hydrothermal fluids, heated and sourced (in part) by the late Devonian Heemskirk Granite. Later mixing of magmatic fluids with meteoric fluids resulted in sulphide and late stage skarn mineralisation in the carbonate units in the footwall of the Balstrup Fault. The $\delta^{34}S$ and $\delta^{18}O$ and $\delta^{13}C$ values of calcite formed in the late metasomatic stage support mixing of magmatic and meteoric fluids.

During early stage of skarn formation, temperature of metasomatic fluid exsolved from the granite was high (400-500°C). These fluids migrated into the Oonah Formation along fractures and lithological boundaries, produced isolated patches of diopside, tremolite, talc and calcite skarn in carbonate units. During late stage skarn formation, due to cooling of the granite, the temperature of metasomatic fluids was lower (~200-500°C), resulting in the development of extensive massive serpentine-magnetite± brucite skarn, which replaces a dolomitic units in the footwall of the Balstrup feeder fault.

Sulphide mineralisation in Comstock Mine is closely associated with the late stage skarn formation. Sulphide mineralisation is characterised by massive pyrrhotite+ spalerite+ galena+ chalcopyrite, replacing the late stage skarn, whereas massive pyrite+ sphalerite+ galena+ chalcopyrite+ quartz replaces dolomite units close to footwall of the Balstrup Fault.
The Balstrup Fault which is a major feeder fault structure in the area, formed during Middle Devonian deformation (Tabberraberan Orogeny). However, some interconnecting faults are attributed to a tensional regime associated with emplacement of the later Devonian Heeemskirk Granite.

On the basis of the stratigraphic, structural and isotopic similarities between Renison and Comstock mines it is concluded that Comstock mine, as with Renison, has excellent potential for mineral exploration. This conclusion is based on:

1- Mineralisation in both Comstock and Renison mines are believed to be genetically associated with the emplacement of Devonian granites.

2- Mineralisation in Comstock and Renison mines resulted from the passage of hydrothermal fluids, sourced from the underlying Devonian granites, through major faults and fractures, partially to completely replacing Neoproterozoic dolomite units.

3- The principal structural controls in relation to mineralisation are the Balstrup Fault (in Comstock) and the Federal-Bassett Fault (in Renison) which are both major feeder faults. The Federal-Bassett Fault and the Balstrup Fault have dips to the northeast at approximately $70°$. The Federal-Bassett Fault and Balstrup Fault project steeply upward into the overlying Neoproterozoic siliciclastic and carbonate sediments. The Renison and the Comstock areas are bounded to the north by the Federal-Bassett Fault and Balstrup Fault and to the south by the less steep, westerly dipping Argent Fault and Tenth Legion Fault respectively.

4- Numerous researchers believe that at Comstock and Renison mines, the major feeder fault structures developed due to forceful emplacement of the late Devonian granites beneath the mine area, which is related to the Tabberabberan Orogeny.

5- $\delta^{18}O$ and $\delta^{13}C$ values of carbonates in Renison and Comstock mines suggest that a combination of magmatic and meteoric fluids were responsible for mineralisation in both Comstock and Renison mines The dolomite-meteoric water $\delta^{18}O$ and $\delta^{13}C$ equilibrium fractionation curves for variable $\delta^{13}C$ and uniform $\delta^{18}O$ values of Devonian temperate meteoric water (-9.5‰ SMOW) indicate that Renison and Comstock carbonates were in equilibrium with meteoric water having $\delta^{13}C$ values near -10‰ PDB. The $\delta^{34}S$ results in Comstock prospect also support mixing of magmatic and meteoric fluids during mineralisation.

REFERENCES

ADABI, M.H., 1997a. Application of carbon isotope chemostratigraphy to the Renison
dolomites (Tasmania, Australia): a Neoproterozoic age: Australian. Jour. Earth Sci.,
v. 44/3, p. 767-775.

ADABI, M.H., 1997b. Sedimentology and geochemistry of the Upper Jurassic (Iran) and
Precambrian (Tasmania) carbonates. Unpub. Ph.D. thesis, Univ. Tasmania, 470
p.

ADABI, M.H., RAO, C.P., and KITTO, P.A., 1996. The source of hydrothermal fluids
responsible for carbonate alteration, Renison, Tasmania, Australia: 13th Geol.
Conv. Australia, (abst), p. 7.

BROWN, A.V., 1986. Geology of the Dundas-Mt Lindsay-Mt Ramsay area: Tasmania
Geol. Survey Bull., v. 62, 221 p.

BROWN, A.V., 1989. Eo-Cambrian-Cambrian: in Burrett, C.F., and Martin, E.L., (eds.),
Geology and mineral resources of Tasmania: Geol. Soc. Aust. Spec. Pub., No.
15, p. 47-83.

BROWN, P.E., BOWMAN, J.R., and KELLY, W.C., 1985. Perologic and stable
constraints on the source and evolution of skarn-forming fluids at Pine Creek,
California: Econ. Geology, v. 80, p. 72-95.

CORBETT, K.D., 1981. Stratigraphy and mineralisation in the Mt. Read Volcanics,
Western Tasmania: Econ. Geology, v. 76, p. 209-230.

CRAWFORD, A.J., and BERRY, R.F., 1992. Tectonic implications of Late Proterozoic-
Early Palaeozoic igneous rock associations in western Tasmania: Tectonophysics,
v. 214, p. 37-56.

CRAWFORD, A.J., CORBETT, K.D., and EVERARD, J.L., 1992. Geochemistry of the
Cambrian volcanic-hosted massive sulfide-rich Mount Read Volcanics, Tasmania,
and some tectonic implications: Econ. Geology, v. 87, p. 597-619.

CROSSING, D.J.F., 1991. E.L. 42/87/ Incorporation M.L.'s 43M/85 and 123M/47,
Zeehan area, Annual Report for the period Oct. 1990 to Sept. 1991. Unpub. RGC
Rpt T/91/23.

CROSSING, D.J.F., 1992. E.L. 42/87/ Incorporation M.L.'s 43M/85 and 123M/47,
Zeehan area, Annual Report for the period Oct.1991 to Sept. 1992. Unpub. RGC
Rpt T/92/33.

EINAUDI, M.T., MEINERT, L.D., and NEWBERRY, R.J., 1981. Skarn deposits: Econ. Geology, 75th Anniversary Volume, p. 317-391.

GOLDING, S.D., and WILSON, A.F., 1983. Geochemical and stable isotope studies of the No. 4 Lode, Kalgoorlie, Western Australia: Econ. Geology, v. 78, p. 438 450.

GROVES, D.I., 1968. The cassiterite-sulphide deposits of western Tasmania: Unpub. Ph.D. thesis, Univ. Tasmania, 294 p.

HOLYLAND, P., 1987. Structure and hydrodynamics of the Renison Tin Mine: Unpub. Ph.D. thesis, Univ. Queensland, 258 p.

KITTO, P.A., 1994. Structural and geochemical controls on mineralization at Renison, Tasmania: Unpub. Ph.D. thesis, Univ. Tasmania, 484 p.

KNIGHT, J.M., 1997. Comstock silver, lead, zinc prospect. Information Memorandum Report. 18p.

LAYNE, G.D., LONGSTAFF, F.J., and SPOONER, E.T.C., 1991. The J.C. Tin skarn deposit, southern Yukon Territory: a carbon, oxygen, hydrogen and sulphur stable isotope study: Econ. Geology, v. 86, p. 48-65.

LEA, J.R., 1991. Renison mine lease exploration: Models, concept, interpretation and future directions: Unpub. Rept. Renison Ltd., 60 p.

LEAMAN, D.E., and RICHARDSON, R.G., 1989. The granites of west and north-west of Tasmania-a geophysical interpretation. Geol. Surv. Bull. No. 66.

LEE, T.F., 1993. The determination of the positions of the Gondwana continents back to the Ordovician using a method of plate path plotting: Gondwana Eight, p. 523-529.

MORRISON, G.W., 1982. Stratigraphy and sedimentology of the Renison mine sequence: Unpub. Rept. Renison Ltd, 102p.

OHMOTO, H., 1986. Stable Isotope Geochemistry of Ore Deposits: in Valley, J.W., Taylor, H.P., and O'Neil, J. R., (eds.), Stable Isotopes in High Temperature Geological Processes: Min. Soc. Am., v. 16, p. 491-560.

OHMOTO, H., and RYE, R.O., 1979. Isotopes of sulfur and carbon: in Barnes, H.L., (ed.), Geochemistry of hydrothermal ore deposits: New York, John Wiley and Sons, p. 509-567.

PATTERSON, D.J., OHMOTO, H.H., and SOLOMON, M., 1981. Geologic setting and genesis of cassiterite-sulfide mineralisation at Renison Bell, western Tasmania: Econ. Geology, v. 76, p. 393-438.

RYE, D.M., and WILLIAMS, N., 1981. Studies of the base metal sulfide deposits at Mc Arthur River, Northern Territory, Australia: III the stable isotope geochemistry of the H.Y.C., Ridge, and Cooley Deposits: Econ. Geology, v. 76, p. 1-26.

SHIMAZAKI, H., SHIMIZU, M., and NAKANO, T., 1986. Carbon and oxygen isotopes of calcites from Japanese skarn deposits. Geochem. Jour. v. 20, p. 297-310.

SOLOMON, M., 1981. An introduction to the geology and metallic ore deposits of Tasmania: Econ. Geology, v. 76, p. 194-208.

YAYLOR, M.I., 1993. Skarn and sulphide mineralisation of the Sylvester Prospect, Zeehan, Western Tasmania: Unpub. B.Sc. thesis, CODES, Geology Department, Univ. Tasmania, 121 p.

TURNER, F.J., 1981. Metamorphic Petrology, Mineralogical and Field Aspects. McGraw Hill, N.Y.

TURNER, N.J., 1993. K-Ar geochronology in the Arthur Metamorphic Complex, Ahrberg Group and Oonah Formation, Corinna district: Mineral Resources Tasmania Rept., No. 27.