INTRODUCTION

This study of the cassiterite-sulphide deposits is part of a research project on the geology and mineral resources of Western Tasmania that has been supervised by Dr. M. Solomon. The research is partly a continuation and re-examination of an investigation of the Waratah District by the author for an honours B.Sc. in 1963.

The original scope of this thesis involved detailed investigation of the cassiterite-sulphide ore-bodies, particularly at Renison Bell and Mt. Bischoff. Difficulties arose with this programme based essentially on the control of these mines by different companies, that have competing exploration activities. As detailed mapping of the ore bodies and enclosing rocks at Renison Bell and Cleveland was not allowed, the emphasis of the research was centred on Mt. Bischoff, where censorship of information was less severe, and a comparison made with the other deposits, several aspects of which were studied during this investigation. The main result of these restrictions has been a more regional study, with particular emphasis on the granitic rocks spatially associated with the tin deposits.

This thesis contains a brief discussion of the regional geology of the area enclosing the cassiterite-sulphide deposits and associated granitic rocks. This is essential for an understanding of the regional setting of the deposits and for estimation of limiting pressures during mineralization. This discussion is primarily based on a regional map which has been compiled from mapping carried out by the author at intervals between 1962 and 1967, and by various officers of the Geological Survey (Department of Mines, Tasmania) and Rio Tinto Mining Company.
The geological environment of the cassiterite-sulphide deposits is described in detail. The section on Mt. Bischoff is based essentially on work by the author, and the Renison Bell section on investigations by Blissett (1962), Gilfillan (1965), Rubenach (1967), unpublished research by Dr. M. Solomon and Prof. P.A. Hill (Carlton University, Ottawa, Canada) and detailed investigation of some aspects by the author. The section on Cleveland is based on Cox and Glasson (1967) and on regional mapping by the author.

Detailed descriptions of the sulphide ores and host-rock alteration are presented and the geobarometry and geothermometry studied with references to sphalerite and pyrrhotite compositions and fluid inclusion studies in non-sulphide components. Geochemical studies of the ores have been carried out by Mr. G. Loftus-Hills and the author, and the significance of Cd and Mn in sphalerites and Ni, Co and Se in sulphides is briefly discussed. A discussion of zoning at Mt. Bischoff is presented in terms of the mineralogy, alteration, temperature and fugacity of sulphur and oxygen, together with sulphur isotope studies by Drs. T.A. Rafter and M. Solomon.

A geochemical study of the granitic rocks associated with the ore deposits has been carried out and the relationships between spatially separated occurrences is discussed. The distribution of tin in the granitic rocks and its bearing on the tin mineralization is also discussed.

The thesis is presented in two sections: (a) descriptions and interpretations of the investigations described above, and (b) a series of appendices in which details of methods of analysis are given, together
with tables of results. Descriptive work which is not essential to the main theme of the thesis, but on which the interpretation of geochemical work is included in these appendices.

All specimen numbers referred to are those of the Geology Department, University of Tasmania, unless otherwise stated.
LOCALITY MAP - TASMANIA

Figure 1
INTRODUCTION

A brief geological history of the area (Figs. 2, 3, 4) is presented below. Solomon (1965) has presented a more comprehensive geological history of Tasmania, from which this summary is partly compiled.

PROTEROZOIC

The Proterozoic rocks can be subdivided into two main groups, based on their grade of metamorphism. Spry (1962a) considered the metamorphic rocks (schists, quartzites, phyllites and amphibolites) to be older than the relatively unaltered rocks (quartzites, shales and dolomites) and suggested that they were separated by a period of basic igneous activity and regional metamorphism defined as the Frenchman Orogeny.

A belt of metamorphic rocks (Whyte Schist) extends from the Pieman River, along the western flank of the Meredith Granite (Figs. 2, 3) and northwards and westwards into the Savage River area (Urquhart, 1966) where it consists of pelitic and psammitic schist with magnetite-bearing amphibolites. Gee (1967b) suggested that this belt of metamorphic rocks (Arthur Lineament) was not a remnant basement high of older rock (e.g. Spry, 1964) but was probably gradational into the unmetamorphosed Proterozoic rocks. The relationship of the unmetamorphosed Proterozoic rocks to the metamorphosed rocks in Central and SW Tasmania is still uncertain.
Figure 2. Geological sketch map and locality map of Western Tasmania. From Solomon (1965).
The unmetamorphosed rocks of probable Proterozoic age in the Zeehan area (S.W. corner of Fig. 3) have been defined as the Cc'nah Quartzite and Slate by Spry (1958) and have been described by Blissett (1962). Gee (1967b) showed that the major trend of the unmetamorphosed Proterozoic rock units is parallel to the Arthur Lineament, and that the sequences to the east of the lineament are the youngest. Therefore the Oonah Formation is probably at an elevated level in the Proterozoic succession (e.g. Blissett, 1962), and not at the bottom (Spry, 1964).

Similar quartzites and shales to those comprising the Oonah Formation occur at Mt. Bischoff and Renison Bell where they are interbedded with thick dolomites that are host rocks for cassiterite-sulphide mineralization. These sequences have been considered to be the highest stratigraphic levels of the Oonah Formation by Blissett (1962) at Renison Bell and by Groves and Solomon (1964) at Mt. Bischoff. More recently, Solomon (1965) has included these sequences together with the Carbine Group at Dundas and the Smithton and Jane Dolomites in the Success Creek phase. This phase was shown as probably post-Penguin Orogeny and stratigraphically higher than correlates of the Oonah Formation, although Solomon (1965) pointed out that the age was uncertain. At Mt. Bischoff this sequence is probably pre-Penguin Orogeny.

The Rosebery "Series" (Finucane, 1932) or Group (Taylor, 1954) contains at least one unit, the Stitt Quartzite (Campana and King, 1963), that is lithologically similar to the sequences at Renison Bell and Mt. Bischoff. Correlation with these and similar sequences have been made by Blissett (1962), Campana and King (1963) and Solomon (1965).
GEOLOGICAL HISTORY OF WEST TASMANIA

Figure 4
The various features of this sequence have been discussed by Loftus-Hills et al. (1967).

The distribution of the unmetamorphosed Proterozoic successions indicates that during their deposition the metamorphosed Proterozoic rocks formed a geanticline (the Tyennan Geanticline) in the Central Highlands. The surrounding basin formed part of a large miogeosyncline (e.g. Spry, 1962, Solomon 1965). Gee (1967b) suggested that the emergence of the Rocky Cape Geanticline (e.g. Solomon, 1965, p. 467) began immediately prior to Oonah Formation sedimentation and that the major axis of subsidence moved towards the Tyennan Geanticline with accumulation of the Oonah Formation in the new basin. The youngest rocks which include dolomites were probably transgressive over the Tyennan Geanticline to the east. Dolomites (e.g. Smithton Dolomite) accumulated penecontemporaneously in a basin to the west of the emergent Rocky Cape Geanticline and were transgressive over this Geanticline to the west (e.g. Longman and Matthews, 1962; Gee, 1967b). Deposition was terminated by the Penguin Orogeny which caused folding of the sedimentary piles which were transported to the S.E. towards the Tyennan Geanticline (Gee, 1967b). The effect, intensity and exact position of this Orogeny in the area investigated is difficult to determine.

Albite dolerites were intruded into unmetamorphosed Proterozoic rocks at Burnie in the early stages of folding and have been dated as 700 million years (Spry, 1962). Dolerites also occur in unmetamorphosed Proterozoic rocks in the Interview River area (Spry and Ford, 1957; Gee 1967b), and the amphibolites in the Whyte Schist are probably the metamorphic equivalents of these rocks (Gee, 1967b). No dolerites
MAJOR STRUCTURAL ELEMENTS
WEST TASMANIA:
(AFTER SOLOMON, 1965)
Figure 5
occur in the Upper Proterozoic rocks at Mt. Bischoff or Renison Bell although volcanic rocks occur towards the top of the Oonah Formation in the Zeehan District (e.g. Twelvetrees and Ward, 1910; Blissett, 1962), and some fragmental rocks occur towards the top of the sequence at Mt. Bischoff.

CAMBRIAN

The Oonah Formation in the Zeehan-Renison Bell area is overlain, apparently conformably by a maximum of 10,000 feet of unfossiliferous purple and green mudstone, greywacke and slate of the Crimson Creek Formation (Blissett and Gulline, 1961a after Taylor, 1954). This passes upwards into the fossiliferous Dundas Group, which ranges in age from lower Middle Cambrian to Franconian (Banks, 1962a). The Dundas Group consists of alternations of greywacke, siltstone, mudstone and shale with conglomerate and grit and is a maximum of 8900 feet thick (Blissett, 1962, Elliston, 1954). It includes the Huskisson Group of Taylor (1954).

Correlation with these major subdivisions of the Cambrian succession elsewhere in the area is made difficult by the lack of fossil and coherent structural interpretation in critical areas.

The sequence along the Wilson River extends NW for seven miles from the type section of the Crimson Creek Formation and contains the Mt. Lindsay tin deposit. It is lithologically similar to the Crimson Creek Formation and is probably an extension along strike as suggested by Taylor (1954). The sequence extending northwards from the Pieman River just west of Rosebery to the headwaters of the Huskisson River
is probably co-extensive with the mudstone and greywacke sequence of the Coldstream River shown on the Mackintosh 1 inch to 1 mile map sheet (Department of Mines, Tasmania). These sequences are also lithologically similar to the Crimson Creek Formation and are unfossiliferous. Loftus-Hills et al. (1967) recorded possible inter-bedding of sedimentary rocks of this sequence with the Rosebery "Series" near Rosebery. The mudstone and sandstone sequence of the Arthur River (Fig. 3), which contains the Cleveland cassiterite-sulphide deposit, may represent the northern extension of the Crimson Creek Formation. It appears to be structurally equivalent to Crimson Creek Formation correlates south of the Meredith Granite. Sequences of greywacke-conglomerate, greywacke-sandstone and mudstone occur to the east of the predominantly mudstone sequences and possibly overlie them. They exhibit similarities to the Dundas Group but are apparently unfossiliferous.

Spilites and associated pyroclastics are common in Cambrian sequences throughout the area. Numerous spilites occur with Cambrian sedimentary rocks in the Waratah District (e.g. Scott, 195_l. Groves and Solomon, 1964; Solomon, 1964; and Cox and Glasson, 1967). Large areas along the northern end of Bett's Track and the Heazlewood area (Fig. 3) which were considered to be predominantly ultramafic rocks (e.g. Nye, 1923; Reid, 1923) have recently been shown to contain a significant proportion of extrusive rocks including altered porphyritic and spherulitic basalts and agglomerates (Jack and Groves, 1964; Groves, 1965a).
Large ultramafic-mafic igneous complexes occur in the Heazlewood-Bald Hill area north of the Meredith Granite, in the narrow, elongate strip from Colebrook Hill via Rileys Knob to the Harman River south of the Meredith Granite, and at Serpentine Hill near Renison Bell (Fig. 3). These complexes contain layered pyroxenites peridotites and hartzburgites with serpentines, gabbros, norites and dolerites in association with spilites and agglomerates (e.g. Jack and Groves, 1964; Groves 1965a, Rubenach, 1967). Small gabbro and dolerite bodies which are commonly approximately concordant with the regional structure are abundant in the Arthur River sequence (e.g. Groves and Solomon, 1964; Cox and Glasson, 1967). Rubenach (1967) recorded that Dundas Group conglomerates overlying rocks of the Serpentine Hill Complex contain abundant detrital pyroxenes and gabbro pebbles which suggests that the ultramafic and mafic group of this complex crystallized prior to the Middle Cambrian and were exposed to erosion at the beginning of Dundas Group sedimentation. Rubenach (1967) suggested that it was possible that the rocks were extruded on the sea floor, as envisaged by Solomon (1965).

Another important feature of Cambrian igneous activity was the development of a thick volcanic pile, which is now represented by an arcuate zone of acid volcanic rocks known as the Mt. Read Volcanics. These volcanics are intruded by granitic bodies of similar composition (Fig. 2). They have been described in detail by Solomon (1964) and appear to be Cambrian and possibly Upper Proterozoic (Loftus-Hills et al., 1967). The stratiform Pb-Zn - pyrite and disseminated Cu ore bodies at Rosebery-Hercules and Mt. Lyell respectively occur within
this arcuate zone of volcanic rocks and a genetic relationship between ore deposition and vulcanism has been suggested (Campana and King, 1963; Solomon, 1967).

The Cambrian sedimentation included abundant vulcanism and involved a deepening of the sedimentary basin (the Dundas Trough) towards the Tyennan Geanticline and a change to sedimentation typical of eugeosynclinal development (see Solomon, 1965, p. 468), with extrusion of ultramafic and mafic rocks on the sea floor. Solomon (1965) suggested that the development and destruction of local ridges and troughs was a feature of Cambrian development and that this resulted in variable, impersistent accumulation of sediment.

Sedimentation was terminated over most of West Tasmania in the Upper Cambrian by the Jukesian Orogeny which produced folding of the Cambrian and older rocks on trends subparallel to the margin of the Tyennan Geanticline. Solomon (1965) suggested that the major feature was faulting on a similar trend which uplifted the Tyennan and Rocky Cape Geanticlines and produced an intervening basin divided by an axial ridge of Cambrian rocks (the Porphyroid Anticlinorium of Carey, 1953). The Owen Conglomerate was deposited in these basins, with lateral transgression of the younger sandstones and limestones over the initial highland areas.

ORDOVICIAN

The Mt. Zeehan Conglomerate is the oldest formation of the Junee Group exposed in this area and was deposited in the western basin at the same time as filling of the Owen Basin to the east. The
Zeehan Conglomerate correlate is 400 feet thick in the Huskisson River area and consists of rounded pebbles of sandstone and chert up to 2 cm in diameter in a subgreywacke matrix. Its relationship to the Dundas Group is obscure at this locality but Blissett (1962) recorded that they were essentially conformable elsewhere in the Zeehan Quadrangle. The Mt. Zeehan Conglomerate is apparently thinning rapidly to the NE, and is absent north of the Meredith Granite. The Gordon Limestone is also thinning to the north and is absent beneath Silurian sandstones at Heazlewood on the Corinna Road. The limestone is apparently discontinuous around the base of the Eldon Group (Fig. 3). This may be an original depositional or erosional feature, although similar discontinuity of limestone in the Godkin area, north of the Meredith Granite, is probably the result of intersection of minor NW-trending faults with a major NW-trending fault zone. An Ordovician age for this limestone is indicated by the occurrence of Lichenaria ramosa (M. Clarke, pers. comm.)

SILURIAN–DEVONIAN

Minor uplift of the source area at the end of Gordon Limestone sedimentation is suggested by the occurrence of coarse sandstones (Crotty Quartzite) which conformably overlie the Gordon Limestone. The whole Silurian–Devonian sedimentary sequence (the Eldon Group) represents a tectonically quiescent period.
An extensive area between the Wilson and Huskisson Rivers is covered by formations of the Eldon Group, which is a maximum of 6500 feet thick in this area compared with 5800 feet in the Zeehan area (Blissett, 1962). The Eldon Group is incomplete in the Heazlewood-Godkin area, north of the Meredith Granite, where it consists of thickly bedded, white, saccharoidal sandstones lithologically similar to the Crotty Quartzite, interbedded with quartzite, and conglomerate (Groves, 1965). The sandstones unconformably overlie Cambrian igneous rocks to the west and are faulted against similar rocks to the east.

**DEVONIAN**

The Tabberabberan Orogeny followed the close of sedimentation in the Middle Devonian (Banks, 1962b). Undeformed late Middle Devonian cave deposits in deformed Gordon Limestone at Eugena (Banks and Burns in Banks, 1962b, p. 185) indicate an upper limit for the age of the major tectonic phase.

Solomon (1962-1965) suggested that Tabberabberan deformation took place in two stages. The earliest deformation was largely controlled by the Trennan and Rocky Cape Geanticlines and consisted of differential vertical movement which produced long wavelength, arcuate synclinoria and anticlinoria (Fig. 5). The following deformation was not influenced by the orientation of the geanticlines and resulted in structures of smaller wavelength of approximately NW trend. Marked changes of plunge are produced by the resultant interference of these two generations of folds. Large structures of the second generation include the Huskisson and Zeehan Synclines with cores of Eldon Group rocks (see
A pronounced axial surface cleavage is common in most rock types except the most competent Owen Conglomerate and Proterozoic quartzites (Solomon, 1965). In the area investigated, however, cleavage is even rare in the Cambrian mudstone sequences.

Several large granite stocks were intruded in the late Devonian, and were essentially post-folding although they have been faulted in places (e.g. Heemskirk and Pieman Heads). Carey (1953) has suggested that they were intruded along large scale anticlinal structures which were the first phase folds of the Tabberabberan Orogeny.

Deposits of cassiterite and wolframite with minor molybdenite and bismuthinite occur near the granite margins in fissures and stockwork (e.g. Heemskirk). Small lead-zinc deposits at Mt. Stewart (Groves, 1965) are also adjacent to granite intrusions. Pyrrhotite-cassiterite replacements of carbonate rocks occur at Mt. Bischoff and Renison Bell where they are spatially associated with altered granitic rocks and also at Cleveland and Razorback where no granitic rocks were visible in the vicinity. Haloes of lead-zinc mineralization occur around many of these tin deposits, and zoning has been postulated around the Heemskirk Granite (e.g. Twelvetrees and Ward, 1910), and around Mt. Bischoff (e.g. Groves and Solomon, 1964). The position is complicated along the Zeehan - Dundas - Farell line of mineralization where tin mineralization occurs in several areas including Renison Bell, Razorback and Queen Hill. Solomon (1965) suggested that the lead-zinc deposits possibly formed complicated, overlapping haloes around the tin deposits in this area.
POST-LATE DEVONIAN

The post-late Devonian history of the area is represented by periods of igneous activity in the Jurassic and Tertiary and by shallow terrestrial deposition in the Tertiary and Quaternary. Some faulting is considered to have occurred in the Tertiary.

Jurassic dolerite similar to that blanketing much of Central and Eastern Tasmania occurs in the Pieman River some 10 miles west of Renison Bell where it forms a large cone sheet in contact with Oonah Quartzite and Slate (Spry, 1958). Other sill-like bodies occur at Mt. Dundas and Firewood Siding (Blissett, 1962) and north of the Magnet Mine (Reid, 1923) and small dykes of probable Jurassic age occur at Renison Bell and in Yellowband Creek.

Sub-basalt sediments of Tertiary age occur in the Waratah area (Reid, 1923; Groves, 1963) and contain minor accumulations of cassiterite. A maximum thickness of 200 feet is recorded for Tertiary sediments in the Zeehan Quadrangle (Blissett, 1962), and similar sediments have been described from the Meredith Granite area by Jack and Groves (1964). It is probable that Tertiary sedimentation was more widespread particularly in the Meredith Granite area, but that the sediments have been subsequently reworked or removed during the Quaternary. An extensive plateau area south and east of Waratah is covered with basalt which is some 50 to 200 feet thick, the base being at an elevation of 1800 to 2000 feet. Thin dykes of basalt have also been recorded from this area by Groves (1963).
Pleistocene glacial activity was restricted to an area north of Renison Bell where moraine and fluvioglacial deposits occur on both sides of the Pieman River.

Recent deposits of gravel and sand occur in the present streams and along higher alluvial terraces. They consist largely of reworked Tertiary or Pleistocene deposits and contain some cassiterite (e.g. Stanley River, Wombat Flat, Pine Creek), osmiridium (e.g. Wilson River, Loughnan Creek) and monazite (e.g. Yellowband Creek).
Cassiterite-sulphide deposits are at present being mined at Renison Bell and Cleveland and active exploration is currently being undertaken at Mt. Bischoff and Mt. Lindsay (Fig. 3). Deposits at Razorback and Grand Prize in the Dundas district have also been assessed in recent years.

The greatest tin production has come from Mt. Bischoff where the grade averaged 1 per cent tin, and a little over 5,500,000 tons of ore have yielded 54,100 tons of tin metal. Most of this production was between 1875 and 1900. Approximately 3800 tons of tin metal were produced at Renison Bell between 1890 and 1965, when the ore reserves were estimated at 6,000,000 tons averaging 0.85 per cent tin. Less than 280 tons of tin metal were produced at Cleveland until 1968 when the ore reserves were estimated at approximately 3,000,000 tons averaging 1.02 per cent tin and 0.43 per cent copper. The production from the Razorback, Grand Prize and Mt. Lindsay mines has been extremely small and accurate estimates of ore reserves are not available.

MT. BISCHOFF TIN MINE

Mt. Bischoff, situated about 1 mile north of Waratah, is a small monadnock rising some 600 feet above an extensive, deeply dissected plateau area which is largely covered by Tertiary gravel and basalt (Fig. 2). The oldest rocks exposed are the quartzite, shale and dolomite sequence of Mt. Bischoff (the Mt. Bischoff sequence) which was originally called the Mt. Bischoff Series by Reid (1923) who considered them to be of Ordovician age. Subsequent authors (Carey,
1953; Knight, 1953; Groves and Solomon, 1964) have suggested they are Upper Proterozoic, although Solomon (1965) suggested that they may be lower Cambrian in part, and may be included within the Success Creek phase. Overlying this sequence are Cambrian sequences of indeterminate thickness, which consist of greywacke, mudstone, shale, chert and spilite. There is at least local unconformity between the Proterozoic and Cambrian sequences at Mt. Bischoff. The structural aspect is dominated by the large east-west trending Bischoff Anticlinorium that generally controls the shape of the Proterozoic inlier. Numerous quartz-porphyry dykes and sills have intruded the hinge zone of this structure.

The succession in the vicinity of Waratah is summarised below:

Quaternary:

River gravel and alluvium.

Tertiary:

Gravel, conglomerate, siltstone, lignite and basalt.

0-200 ft.

Unconformity.

Cambrian:

Waratah River sequence - greywacke and mudstone
and Arthur River sequence - mudstone, greywacke, chert.

<10,000 ft.

Proterozoic:

Mt. Bischoff sequence - quartzite, shale, dolomite.

>2,000 ft.
Mt. Bischoff Sequence

The Mt. Bischoff sequence crops out in a narrow, east-west trending inlier that extends from the head of Deep Creek to the Magnet Mine (Figs. 6 and 8). It consists of alternating quartzite, sandstone, siltstone and shale with a thick bed of dolomite and associated dolomitic shale, as follows:

- **Hangingwall shales and quartzites**: +1000 ft.
- **Dolomite, including dolomitic shale**: 0-200 ft.
- **Footwall shales**: 0-30 ft.
- **Footwall quartzites, shales and siltstone**: +1000 ft.

The Hangingwall shales and quartzites are similar to the Footwall quartzites, shales and siltstones but in general contain a higher proportion of shales. The sequences are dominantly thinly bedded although massive units of quartzites up to 15 feet thick have been observed. Sedimentary structures in the coarser grained members are common in places, with deformed flow casts, ripple marks and small-scale current bedding. Grading has not been observed. Pre-consolidation brecciation is a common feature of the rocks, particularly those immediately above the dolomite horizon and may be confined to a layer a few inches thick between undisturbed sediments or may involve several feet of sediments. Commonly the sand-grade material has liquefied and has incorporated fragments of adjacent mud layers, which retain a shearing strength during deformation, although in places discontinuous sand layers occur in shale matrix.
LOCALITY MAP
MT. BISCHOFF.

FEET
0  200  400  600  800  1000

METERS
0  100  200  300

Figure 7
Figure 8. Geological map of Mt. Bischoff area.
After Groves and Solomon (1964).
Figure 8
Figure 9. Cross sections through Bischoff Anticlinorium in the Waratah District.

A. Cross section through Mt. Bischoff.

B. Generalized cross section through Waratah District.

C. Cross section through Magnet Mine.
The coarse silt to fine sand grade sedimentary rocks are well sorted with a continuous framework and consist of up to 70 per cent clastic quartz grains with minor muscovite, grains of siltstone and chert, and accessory rutile, zircon and tourmaline. The matrix, constituting 10 to 15% of the rocks, is composed predominantly of quartz, sericite and minor chlorite. Hypogene pyrite is commonly present. The average grain size of the rocks varies from 0.05 mm. to 0.2 mm. The rocks (Pettijohn, 1957, p. 291) are lithic sandstones (subgreywackes and protoquartzites). Although the quartz grains show undulose extinction in part, they exhibit a dimensional orientation subparallel with clastic muscovites which are aligned parallel to bedding, suggesting that the orientation is a depositional feature.

The fine-silt grade horizons consist of fine clastic quartz and chert grains with a high proportion of clastic muscovite in a finer matrix of quartz and sericite. The grainsize of the rocks is generally 0.015 mm and grains of this diameter comprise approximately 10 per cent of the clay-grade rocks. Lamination appears due to variations in the proportions of clastic muscovite. The extremely siliceous nature of the rocks and their high $K_2O/Na_2O$ ratios are shown by analyses of both quartzite and shale (Table 1).
<table>
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<tr>
<th></th>
<th>l *(shale)</th>
<th>30641 (quartzite)</th>
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<tbody>
<tr>
<td>SiO₂</td>
<td>77.18</td>
<td>83.6</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.59</td>
<td>0.62</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>11.96</td>
<td>8.0</td>
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<tr>
<td>Fe₂O₃</td>
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</tr>
<tr>
<td>FeO</td>
<td>0.38</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>1.30</td>
</tr>
<tr>
<td>MnO</td>
<td>tr.</td>
<td>0.06</td>
</tr>
<tr>
<td>MgO</td>
<td>0.99</td>
<td>1.25</td>
</tr>
<tr>
<td>CaO</td>
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</tr>
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<td>Na₂O</td>
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</tr>
<tr>
<td>K₂O</td>
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<td>2.6</td>
</tr>
<tr>
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</tr>
<tr>
<td>H₂O +</td>
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<td>1.63</td>
</tr>
<tr>
<td>H₂O -</td>
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<td>0.80</td>
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<tr>
<td>CO₂</td>
<td>0.63</td>
<td>N.D.</td>
</tr>
</tbody>
</table>

99.56  100.03

Table 1. Analyses of sedimentary rocks of the Mt. Bischoff sequence.

1* from Table 1, Groves and Solomon (1964) Analyst:
Department of Mines Assay Laboratories, Tasmania.

Plate 1 - Flexural fold in quartzite and shale, Mt. Bischoff sequence, Mt. Bischoff.

Plate 2 - Agglomerate, Bett's Track 3 miles south of Corinna Road.
The dolomite shows a local transition to dolomitic shales. It is a cream to pale grey, fine grained rock consisting almost exclusively of crystalline dolomite with minor interstitial quartz grains. Irregular patches of coarsely crystalline carbonate were developed during recrystallization related to porphyry intrusion and/or mineralization. The dolomite also exhibits a fine macroscopic banding which almost certainly is bedding lamination. Analyses of the dolomite (Appendix D3, Table 47) indicate that it is almost pure dolomite mineral, with only minor SiO₂, FeCO₃ and MnCO₃.

The thin banding (bedding?) and fine grained texture of the dolomite and its regional concordant relations to contiguous rocks, indicate a sedimentary origin (e.g. Knight, 1953; Groves and Solomon, 1964). There is considerable doubt that dolomites may form by direct precipitation (e.g. Degens and Epstein, 1964), although it is evident that dolomites may form early in diagenesis by replacement of calcite adjacent to the surface of deposition, and that they are presently forming in this way in shallow water environments (e.g. Wells, 1962; Alderman and Von der Borsch, 1963; Curtis et al, 1963; Von der Borsch et al. 1964).
Figure 10
MT. BISCHOFF
CROSS SECTION F.

SECTION COMPILED FROM DRILLING
BY MINES EXPLORATION PTY. LTD.
AND SURFACE MAPPING BY D. L. GROVES
Waratah and Arthur River Sequences and Associated Igneous Rocks.

Detailed descriptions of the Cambrian sequences, particularly the volcanic activity associated with sedimentation, are given by Groves (1963), Groves and Solomon (1964) and Groves (1965a).

Unfossiliferous sedimentary rocks of probable Cambrian age occupy the major portion of the Waratah area (Figs. 3 and 6). They can be subdivided into the greywacke-sandstone and mudstone sequence of the Waratah River (Waratah River sequence) and the mudstone and sandstone sequence of the Arthur River (Arthur River sequence). The sand-grade rocks of both sequences are usually greywacke (Pettijohn, 1957, p. 291) in contrast to the lithic sandstones of the Mt. Bischoff sequence.

The Waratah River sequence, which is restricted to an area near Waratah (Fig. 6) consists of greywacke-sandstones and siltstones with grey to yellow-brown laminated mudstones and rare cherts and breccias. Lavas are generally absent. The Arthur River sequence consists of interbedded red-brown mudstones, greywackes, massive chert-breccias and abundant volcanic rocks. It contains numerous, generally concordant bodies of dolerite and gabbro (Figs. 3, 6). Limestone occurs in this sequence in the Arthur River to the north of Waratah. It is dark grey in colour, fine grained and contains small bands of coarsely crystalline calcite.

The sand-grade rocks of both sequences are similar and are both compositionally and texturally immature. They are greywackes, show varying degrees of grading, are poorly sorted with a disrupted framework, and consist of large, subangular to sub-rounded clastic grains
in a finer grained matrix that forms up to 50 per cent of the rock. The clastic grains are largely quartz with albite, muscovite, hornblende, augite, chlorite, magnetite and rare rock fragments including altered lava, siltstone, mudstone and quartzite. Some microcline is also present (e.g. 30659), the grains showing a fine, spindle-like normal albite twinning and some pericline cross-twinning; they are optically negative and 2V measurements range from 79° to 87°.

The clay-grade rocks are extremely fine-grained and the composition cannot be determined microscopically although some small, angular fragments of quartz, plagioclase and chlorite are recognizable. Small carbonate veinlets are commonly present. The red colouration of mudstones in the Arthur River sequence is due to limonite and possibly haematite.

Individual lava flows occur within the Arthur River sequence and are largely spilitic (e.g. 636, 642, 30658a, 30662a and 3565, 3569 of the Mines Department, Tasmania). They are described by Groves (1963) and Groves and Solomon (1964). Many are porphyritic with phenocrysts of albite, augite and chlorite in a felted groundmass of albite, chlorite, calcite, epidote, magnetite and ilmenite. Some have intersertal texture and consist of interlocking aggregates of albite, augite and chlorite with interstitial chlorite, calcite etc. The albite, as in the Cambrian spilites elsewhere in Tasmania, is partially altered to sericite, displays low temperature optics and varies in composition from Ab_{90-10} to Ab_{95}An_{5}. Augite occurs rarely and is largely altered to chlorite or fine dusty aggregates of chlorite and sericite. Chlorite - quartz spherulite rocks and amygdaloidal
rocks with vesicles filled with chlorite and quartz spherulites are common in places (Plates 5, 6). Pillow-structure occurs in spilites on the Corinna Road some eight miles from Waratah and confirms the submarine nature of the volcanic rocks.

Keratophyric lavas occur rarely. The quartz phenocrysts in these lavas are rounded, euhedral or shard-like in form, and are commonly embayed in identical fashion to crystals in the keratophyres of the Mt. Read Volcanics (e.g. Solomon, 1964). Volcanic rocks with fragmental texture are not common. An interesting example (646) contains a pale reddish-brown isotropic mineral that is probably hydrogrossular, similar to that described by Scott (1951) in spilites from King Island.

The occurrence of microcline in the greywackes, which are largely locally derived, is unusual in that K-feldspar is absent in the spilites and keratophyres. Groves and Solomon (1964) suggested that it is possibly derived from potassic rhyolite or quartz keratophyre flows and necks that have been largely disintegrated by explosive activity during eruption.

Massive sequences of Cambrian ultramafic and mafic rocks associated generally with spilites and agglomerates and in places with syenitic and granophyric rocks occur to the west and south of Waratah. They have been described by Nye (1923), Scott (1954), Groves (1963), Groves and Solomon (1964), Jack and Groves (1964), Solomon (1964), and Groves (1965a). The sequences are very similar to those of submarine ophiolites.
An important sequence of these rocks in the Waratah area is the "Magnet Dyke" which has localised ore deposition at Magnet, Fawkners Tunnel and Persic (Figs. 6 and 9C). It is an elongate strip of igneous rocks which occurs along the northern contact of the Mt. Bischoff sequence and the Arthur River sequence and is roughly concordant with both sequences (Fig. 9C). It reaches a maximum thickness of 1000 feet at the Magnet Mine. It consists predominantly of porphyritic to amygdaloidal spilites or albite dolerites which have been deuterically altered locally to spherulitic quartz-chlorite rocks. Marginal lenses of ultramafic rocks (websterites and orbicular websterites, which have been locally serpentinized) appear concordant with the probable extrusive rocks, but contains blocks of both Proterozoic and Cambrian sedimentary rocks. The "Dyke" has been described in detail by several authors (e.g. Scott, 1954; Groves, 1963; Groves and Solomon, 1964; Solomon, 1964) and it is generally considered that it represents a sequence of extrusive or shallowly intrusive rocks.

**Proterozoic - Cambrian Contact**

Reid (1923) considered that the contact was a fault, but Groves and Solomon (1964) showed that the boundary was regionally conformable. Recent sluicing at Don Hill has revealed the contact over a strike length of several hundred feet (Fig. 12). It is a few centimetres wide, is locally subparallel to the strike of both sequences (i.e. NNE to NE) and dips at a variable high angle to the SW. The contact zone contains numerous slickensides. Small fractures subparallel to the contact
Figure 12. Detailed geological plan of sluiced area, Don Hill, Mt. Bischoff showing contact between Upper Proterozoic – Lower Cambrian sequences.
Figure 12 - Geological Sketch Map Waratah District (after Gomes & Boulanger, 1983).
intersect both sequences imparting a shredded appearance, particularly in the greywacke-sandstone of the Waratah River sequence. It is evident that the contact has been a surface of movement. The exact relationship of the bedding in both sequences to the orientation of the contact zone is difficult to determine. In general, the siltstone and shale layers of the Mt. Bischoff sequence dip steeply away from the contact while the greywacke-sandstone beds dip towards the contact at variable angles.

The greywacke-sandstone of the Waratah River sequence locally encloses large blocks of laminated mudstone, which are irregular in detail but show an overall subparallelism to bedding. These blocks are apparently confined to within 300 feet of the contact. In general it is impossible to determine whether these blocks consist of mudstones of the Mt. Bischoff sequence. At least one large block, approximately 40 feet in length, in the NE corner of the mapped area is of grey shale identical to those of the Mt. Bischoff sequence. These blocks indicate extensive slumping penecontemporaneous with deposition of the Waratah River sequence. The irregular to wispy contacts of some blocks suggest that they were partly unconsolidated at the time of slumping; these blocks possibly represent penecontemporaneously deposited mudstones that have been transported from another part of the depositional basin. It is probable that the surface of deposition was a zone of movement represented by the present contact zone, movement on this zone possibly occurring at several times.
Knight (1953) believed the Mt. Bischoff sequence to be folded into a large recumbent syncline. However, Groves (1963) and Groves and Solomon (1964), using the dolomite as a marker horizon, considered that the Mt. Bischoff sequence formed the core of an east-trending, east- and west-plunging anticlinorium with an approximate wavelength and amplitude of five and two miles respectively, flanked by the younger Cambrian rocks. The anticlinal structure is well demonstrated by the poles to bedding in the Mt. Bischoff sequence (Fig. 14C). The crestal area is not represented due to poor exposure and abundance of porphyry intrusions in this area. Superimposed on this structure are smaller, subparallel, shallowly to steeply plunging, flexural folds with wavelengths of 100 to 1000 feet which are typically associated with sub-longitudinal faults that obliterate limbs of the folds (Figs. 8 and 9). Smaller flexural folds, with a predominant ENE - NE and subordinate NNW - NW trend of axes, are superimposed on the longer wavelength folds and are so strongly developed in places that the east-trending folds are obscured. This is particularly evident when the axial surfaces of folds in the Mt. Bischoff sequence are plotted stereographically (Fig. 14A), and the interference is clearly shown by the spread of axes of folds (Fig. 14B). In general the axial surfaces of the ENE - trending folds dip steeply towards the SSE on the southern limb of the anticlinorium and steeply towards the NNW on the northern limb.
Figure 13. Diagrammatic representation of folding, Don Hill, Mt. Bischoff.

A. Diagrammatic representation of deformation of layer north of fault zone on SE slope of Mt. Bischoff. Early folds (f1) disturbed by later folds (f2) of box type resulting from stress field indicated.

B. Field sketches of outcrops with hammer included for scale. Broken lines indicate traces of axial surfaces of early (f1) and later folds (f2) in Mt. Bischoff sequence.
   a. All general fold trends present. Note fold "hooks" characteristic of superimposed folds.
   b. NNE trending late folds (f2) superimposed on early (f1) fold.
   c. WNW trending late folds (f2) superimposed on early (f1) fold.
   d. Contemporaneity of WNW and NNE trending axial surfaces of late box folds (f2)

C. Bedding layers from conjugate folds in rocks south of fault zone. Contortions of bedding surfaces indicate stress pattern shown; Note F median in bedding surfaces.
FOLDING
DON HILL—MT. BISCHOFF
Structural Elements - Mt. Bischoff

Equal Angle - Lower Hemisphere

Figure 14
A regional comparison of fold geometry in the Mt. Bischoff sequence and Cambrian sequences is virtually impossible due to the lack of suitable folds for measurement in the Cambrian sequences. A comparison of bedding orientation (Figs. 14c and D) indicates a similar spread of poles to bedding, the almost exclusive southerly dip in the Cambrian sequence being due to selective measurement on the southern limb of the anticlinorium. Structures which appear to be exclusive to the Mt. Bischoff sequence are discussed by Groves (1963) and Groves and Solomon (1964) and include isoclinal, chevron and recumbent folds and small monoclinal "warps". These are not diagnostic of an earlier phase of deformation associated with a major orogeny as it is difficult to be certain of distinguishing between pre- and post-consolidation structures, particularly in these rocks which lack cleavage.

A comparison of structural elements across the contact on Don Hill is however possible. The deformation of the Mt. Bischoff sequence is depicted in Figure 12 and may be analysed in the critical exposures sketched in Figure 13. A predominant NNE and NE trend is evident, this being subparallel to the dominant trend of the smaller wavelength folds. Three main trends of folding are demonstrated in Figure 13, early (f1) folds being refolded by later (f2) folds which trend obliquely in two directions. Figures 13B and C demonstrate the superimposition of (f2) folds (with axial surfaces trending NNE-NE and WNW-NW) on early (f1) folds. The contemporaneity of the NE and NW trending axial surfaces of the late box-type folds (f2) is demonstrated in Figure 13B. "Hook" structures characteristic of
superimposed folds are present in places due to interference of f1 and f2 folds (e.g. Fig. 13B, A). Other features of the deformation include the occurrence of detached blocks of coarse siltstone or fine siltstone which form distinct trains, subparallel to bedding in the shale horizons, with elongation of the blocks parallel to the bedding direction. In places these boudins appear to have formed by rotation of joint blocks, probably during folding.

The beds of the Waratah River sequence also exhibit a predominant NE trend (Fig. 12). In this sequence box-type folds or conjugate folds are common. A typical fold is reproduced in Figure 13C and the local stress field is indicated. It is noteworthy that the direction of maximum stress for the production of box-type folds in the Mt. Bischoff and Waratah River sequences are at right angles. There is no evidence of f1 folds, ubiquitous in the Mt. Bischoff sequence, and refolded axial surfaces and "hook" structures are absent.

It is evident that there is a marked structural hiatus between the two sequences and that the Mt. Bischoff sequence with the more complicated fold development is the older, as predicted from regional mapping. It is also significant that this early east-trending structure is a discordant trend in the regional framework of this section of Tasmania where the majority of Tabberabberan structures trend NW or NNE (Carey, 1953; Solomon, 1962). Groves and Solomon (1964) concluded that the east-trend may reflect an earlier deformation which has locally affected the dominant trends associated with the Tabberabberan Orogeny. The early (f1) folds may represent deformation during the Penguin Orogeny while the later (f2) folds almost certainly represent
Tabberabberan deformation (see Fig. 4). If the Mt. Bischoff sequence is in fact pre-Penguin Orogeny and hence in an equivalent position to the Oonah Formation it does not occupy the position of the Success Creek phase as envisaged by Solomon (1965).

The faulting and jointing has been particularly important in localizing ore deposition. Stereographic plots of joints in Proterozoic and Cambrian rocks together with the porphyry dykes (Fig. 15) show common maxima which indicate a strong post-folding and intrusion joint set which trends approximately NNW and dips steeply to the WSW. A stereographic plot of tension fractures and lodes (Fig. 15A) indicates a similar orientation, which is almost normal to the axis of the anticlinorium. The post-intrusion age of the fractures is demonstrated by displacement of porphyry dykes, the fractures being filled with quartz and cassiterite and forming small lodes. The displacements (e.g. Western Dyke: Fig. 10) can all be explained in terms of normal movement on these faults.

Devonian Igneous Rocks

Anastomosing quartz-porphyry dykes and sills intrude the Mt. Bischoff sequence near the crest of the anticlinorium. They have been dated at $349 \pm 4$ million years, a similar age to porphyritic adammellites of the Meredith Granite ($353 \pm 7$ m.y.) which crop out some four miles SW of Waratah (Brooks, 1966).

The unaltered porphyry comprises quartz and orthoclase phenocrysts in a quartzo-feldspathic groundmass (see Appendix A1). Throughout the mine area the porphyry has been extensively replaced by topaz, tourmaline, quartz, carbonate, fluorite and sulphides. This alteration
JOINTS AND LODES
WARATAH AREA
EQUAL ANGLE -
LOWER HEMISPHERE

A. TENSION FRACTURES
AND LODES, MT. BISCHOFF
30°N; 2-4-6-8-12-16%

B. JOINTS - WESTERN DYKE
MT. BISCHOFF
250°; 2-3-4-5-6%

C. JOINTS - WHITE FACE DYKE
MT. BISCHOFF
250°; 2-3-4-5-6%

D. JOINTS - CAMBRIAN ROCKS
WARATAH - MAGNET
200°; 2-3-4-5-6%

E. JOINTS - MT. BISCHOFF
SEQUENCE, WARATAH
200°; 2-3-4-5%

Figure 15
is described in detail in a later section.

The majority of the intrusions are dyke-like bodies, from 15 to 700 feet in width, which form a general radial pattern with dominant orientations east-west and north-south and steep dips to the north and west respectively. Large, flat-lying sills occur in places (e.g. summit of Mt. Bischoff) and large irregular masses occur to the NE of Mt. Bischoff and at Don Hill, the former being the merging point of several extensive dykes. Numerous small discordant bodies occur throughout the area, the majority being irregular offshoots from the main dyke system. Relatively thin sills of porphyry are common particularly at the junction of dolomite and Footwall shales (e.g. Brown and Slaughteryard Faces).

At the surface, probable fault breccias consisting of fragments of the country rocks occur along the margins of the dykes and up to 20 feet from the dyke walls. The contact between porphyry and breccia is irregular with small lenticular tongues of porphyry extending into the breccia for several feet from the contact. The breccias are composed essentially of angular to subangular fragments of quartzite and siltstone up to 10 cm. in diameter with a matrix of crushed sedimentary rock and fine grained porphyry. Xenoliths of recrystallized country rock are also commonly enclosed within the porphyry bodies close to their margins. Displacement along the lines of intrusion is small and may be due to dilation by the intrusions rather than pre-intrusion movement. The geometry of dyke distribution is suggestive of a radial fault pattern similar to that over diapiric
structures (e.g. Hawkins Oilfield in De Sitter, 1956, p. 261). The fractures may be a combination of radial near-vertical tension fissures and normal cross fractures, that formed with an approximately north-south trend (e.g. De Sitter, 1956, p. 206-208).

In drill sections another zone and another type of brecciation is apparent. The limits of this brecciation parallel the margins of the White Face Dyke and extend up to 75 feet from the dyke (Fig. 11). The breccias contain fragments which are generally subangular with shredded margins and are usually rocks of a uniform grain size in a matrix of a significantly different grain size. They exhibit superficial similarities to the pre-consolidation breccias that are common in the country rocks. They may have resulted from further brecciation of pre-existing, pre-consolidation breccias adjacent to tensional fractures but are more likely to have formed by similar mechanisms to those operative during pre-consolidation brecciation. The latter mechanism would indicate brecciation associated with high water or steam pressures related to porphyry intrusion causing partial disaggregation of the host rocks.

Macroscopic features of the dykes include strongly developed subparallel banding which is prominent in weathered exposures but does not appear to be related to any mineral orientation or concentration. Other features are cross bedding structures (Plate 3) and small swirls (Plate 4) which probably reflect flow movements in the partly crystalline porphyries during intrusion. Irregular fracturing or sheeting, which is subparallel to the dyke walls, occurs on the dyke margins and produces a series of crusts of porphyry containing strong linear grooves in subparallel sets.
Plate 3  -  Flow banding in quartz-feldspar porphyry, White Face Dyke, Mt. Bischoff.

Plate 4  -  Small swirl in altered quartz-feldspar porphyry, White Face Dyke, Mt. Bischoff.
Plate 5 - Amygdale containing quartz spherulites in Cambrian spilite, Arthur River. Specimen No. 30662(b) x 86.

Plate 6 - Identical field of view, crossed nicols.
Mineralization

(a) Tin Mineralization

At Mt. Bischoff the tin mineralization is mainly restricted to an approximately circular area of 3000 feet radius from Mt. Bischoff peak.

The main ore bodies have resulted from replacement of the dolomite horizon of the Mt. Bischoff sequence by pyrrhotite with associated cassiterite, pyrite, arsenopyrite, chalcopyrite, sphalerite and stannite accompanying talc, phlogopite, quartz, fluorite and Fe-Mn-Mg carbonates. Pyrite, sphalerite, galena and jamesonite increase, and pyrrhotite decreases, towards the southern margin of the mine area. The mineragraphy and alteration are described in detail in a later section. Folding, faulting and erosion has resulted in a series of spatially separated ore bodies which are, from north to south, Brown Face, Slaughteryard Face, Greisen Face, Pig Flat and Happy Valley Face (Figs. 7, 8). Sulphide mineralization is irregular although it is generally more intensive towards the base of the dolomite, particularly in the southern part of the mine (Figs. 10, 11). Cassiterite is microscopically associated with non-sulphides and zones of tin concentration are commonly slightly oblique to massive sulphide zones.

Replacement of the dolomite becomes sporadic towards the south of the open cut and unmineralized dolomite is common in the Happy Valley Face and in drilling intersections south of Pig Flat (Fig. 11).
The dolomite horizon is presumed to be above the present surface to the north of Mt. Bischoff peak (Fig. 9A) but at its re-appearance north of the Waratah River (Figs. 6, 8) it is unaltered and unmineralized. The replacement of the dolomite horizon is apparently limited to the area of most intense development and alteration of prophyry dykes in the hinge zone of the anticlinorium. Numerous small veins of sulphides occur below the replacement deposit in this area.

Fissure vein deposits carrying cassiterite occur throughout the area within a 3000 feet radius of Mt. Bischoff peak. The lodes occupy late fractures which displace porphyry dykes and cut the replacement ore body. They have strike and dip lengths up to 2500 feet and 1000 feet respectively and pinch and swell along both dip and strike. The lodes commonly branch and converge forming a complex system of subsidiary ore bodies. They consist essentially of quartz and/or carbonate with fluorite and tourmaline carrying cassiterite, wolframite, pyrite, pyrrhotite, arsenopyrite, sphalerite, chalcopyrite, galena, jamesonite, bismuthinite and stannite. The relative proportions of these constituents vary considerably from one vein to another (e.g. Stillwell, 1943).

The major deposits include the North Valley Lode, Giblin Lode and Thompson's Lode (Fig. 7). The North Valley lode consists essentially of quartz and pyrite carrying cassiterite in association with carbonate, muscovite, fluorite, sphalerite, chalcopyrite, galena etc. (Stillwell, 1934). The Giblin Lode also has a predominantly quartz gangue with pyrite, arsenopyrite, sphalerite and cassiterite. Zoning has been recorded from this lode (Weston-Dunn, 1922), cassiterite and
wolframite being abundant and galena rare near Mt. Bischoff peak while sphalerite, galena and jamesonite are predominant and cassiterite and wolframite are rare towards its south-west extremity. Thompson's Lode is unusual in that the gangue consists largely of fluorite and Fe-rich carbonates with only minor quartz and contains abundant cassiterite with rare sulphides (sphalerite and pyrite). Fooks Lode (Fig. 8) occurs outside the general area of tin mineralization but contains cassiterite in association with abundant fluorite, sphalerite and pyrite, and is somewhat similar in mineralogy to Thompson's Lode. Apart from these major veins, which generally have an average width of 2 feet, there are subparallel sets of minor veins, some 1 to 2 inches in width and a few feet long, which commonly consist solely of quartz and cassiterite. Both major and minor veins generally trend from NW to NNW and dip steeply west (Fig. 15A).

The quartz porphyry intrusives have been extensively mineralized by topaz, tourmaline, fluorite, Fe-sulphides and cassiterite. These minerals generally form pseudomorphs after K-feldspar. In places the proportion of disseminated cassiterite was high enough for the porphyry to constitute an orebody. In addition cassiterite occurs with quartz and tourmaline on joint faces intersecting the porphyry intrusives. Where the joint frequency is high, the porphyries have been mined by quarrying.

(b) Lead-zinc-silver Mineralization.
Isolated, small Pb-Zn-Ag veins occur throughout the Waratah district (Fig. 6), and very small occurrences are relatively abundant around the area of tin mineralization at Mt. Bischoff. They generally occur within the Mt. Bischoff sequence or associated with Cambrian volcanic rocks (Fig. 6).

Several veins occur close to the margin of the Magnet Dyke. The largest deposit occurs at the Magnet Mine where a vein some 10 to 15 feet wide occurs on the contact of spilite (and dolerite) and websterite (Fig. 9C). The lode is composed essentially of carbonates with bunches and veinlets of galena and sphalerite with minor arsenopyrite, pyrite, boulangerite, pyrargyrite, tetrahedrite and chalcopyrite (Edwards, 1960). Crustification and cockade textures are abundant in the ore and there is strong evidence of post-ore deformation. The ore body has been described by Nye (1923), Cottle (1953) and Groves (1965b). A small Pb deposit occurs in a similar structural position at the Persic Section (Fig. 6) where irregular uneconomic splashes of galena and carbonate are present (Nye, 1923). Small veins of quartz and carbonate carrying galena and chalcopyrite occur in a similar structural position at Fawkner's Show (Fig. 6).

Small, uneconomic Pb-Zn-Ag veins occur within the Mt. Bischoff sequence around Mt. Bischoff, the largest being at the Silver Cliffs Mine where a well banded lode consists of galena, jamesonite, sphalerite, pyrite and minor boulangerite in a gangue of carbonates and quartz. A similar lode occurs north of the Waratah River (Fig. 8) and is subparallel to the North Valley Lode.
jamesonite, stibnite, galena and boulangerite occur in Tinstone Creek (Fig. 8) and appear to be related to the Pb-Zn-Ag deposits which commonly contain abundant jamesonite.

(c) Oxidation of the orebodies.

Gossans probably developed in the Tertiary over several outcropping sulphide orebodies. The gossan over the Pb-Zn-Ag orebodies (e.g. Magnet) are largely indigenous and consist essentially of limonite with bands of secondary minerals such as cerussite, anglesite, pyromorphite and crocoite. Gossans derived from the pyrrhotite-rich ores at Mt. Bischoff formed extensively and were apparently mixtures of indigenous and exotic types. Pyrrhotite is very unstable in temperate conditions and breakdown resulted either in development of friable limonitic crust with cassiterite concentrated at the base or in complete removal of Fe and S, leaving cassiterite-quartz sand on the surface. Where the orebodies cropped out on hillsides the cassiterite-quartz sand travelled down slope to form extensive eluvial and alluvial deposits, which are still being worked at present.

Post-mineralization activity

Dolerites of Jurassic age intrude rocks of the Arthur River sequence in the Magnet area (see Groves and Solomon, 1964).

Irregularly distributed deposits of Tertiary sediments (probably lacustrine), which include conglomerate, gravel, sand and lignite occur up to a maximum thickness of 100 feet in the Waratah area (Groves and Solomon, 1964). At Don Hill, Tertiary sands have been
Plate 7 - Steeply dipping Tertiary gravels, sands and silts, Don Hill, Mt. Bischoff.

Plate 8 - Tourmaline nodules in gabbro, Pine Hill.
deposited against low bedrock cliffs, and slumping and differential compaction has produced folds and steep dips near these cliffs (Plate 7). Some of the basal conglomerates contain small quantities of cassiterite and gold. A basalt sheet consisting of vesicular olivine-basalt occurs extensively over the Waratah area to a maximum thickness of 200 feet. Recent drilling by the Department of Mines near Fook's Lode has shown that there are at least two flows of basalt separated by terrestrial gravels.

Recent gravels occur in the present streams and in places contain considerable cassiterite.

CLEVELAND TIN MINE

The Cleveland Tin Mine, which is situated approximately 10 miles WSW of Mt. Bischoff, occurs in a belt of predominantly Pb-Zn-Ag mineralization that extends along the northern flank of the Meredith Granite (Fig. 3). Detailed mapping of the mine area could not be carried out by the author because of lack of co-operation by Cleveland Tin N.L., the company exploiting the deposits. The brief summary of the mine geology is taken from Cox and Glasson (1967) and the regional geology is based on mapping by the author between 1962 and 1968.

The ore bodies occur in rocks of the Arthur River sequence which has been briefly discussed in the previous section.

Cambrljan Stratigraphy and Igneous Rocks

Locally the rocks of the Arthur River sequence are predominantly greywacke-sandstones, shales, cherts, spilites and pyroclastic rocks. The total thickness of the section is unknown.
The lowest beds consist essentially of massive greywacke-sandstones with thinly interbedded grey shales and laminated grey chert. The sand-grade rocks are poorly sorted with a disrupted framework and consist of subrounded to subangular, clastic quartz with minor muscovite, albite, K-feldspar and rock fragments in a fine matrix of quartz and sericite. They are texturally and compositionally immature and are similar to sand-grade rocks from this sequence in the Waratah area.

These rocks are overlain by shales, cherts and minor greywacke-sandstones which collectively are typically lenticular and attain a thickness of 100 feet in the mine area. This sequence contains the host rocks for mineralization. The cherts are fine grained, well laminated rocks which contain minor amounts of sulphides near the ore body, and are overlain by shales and cherts which are strongly mineralized.

The overlying rocks are largely spilites and interbedded pyroclastic rocks with minor cherts and shales. The spilites are similar to those in the Waratah area and there is some evidence of pillow formation. The pyroclastic rocks which are confined to the immediate vicinity of the mine, range from coarse breccias and agglomerates to fine grained tuffs.

Sill-like sheets of albite dolerite and gabbro and serpentinite occur within the Arthur River sequence (Fig. 3). They are regionally concordant although locally discordant with the enclosing sedimentary rocks. Cox and Glasson (1967) recorded dolerites containing olivine,
clinopyroxene and albite in a fine groundmass of chlorite, sericite (?) and quartz with assessor mammite. The dolerites and gabbros examined by Groves and Solomon (1964) are more altered and contain essentially albite or albite-oligoclase with fibrous to ragged hornblende [\(\alpha=1.643, \gamma=1.660, 2V=71^\circ (+ve)\)] and yellowish chlorite. It is evident that the alteration is irregular and patchy (i.e. similar to the Magnet Dyke). The serpentinates are altered peridotites consisting of relic, subhedral to euhedral grains of olivine and interstitial clinopyroxene which have been altered to serpentine and chlorite.

The Cambrian sedimentary sequence (the Arthur River sequence) has been correlated with the Dundas Group by most authors (e.g. Nye, 1923; Mason, 1965; Cox and Glasson, 1967). However no fossils have been found, and the rocks are lithologically more like the Crimson Creek Formation, than the Dundas Group. The occurrence of abundant dolerite and gabbro bodies may be significant. These bodies occur almost exclusively in rocks of the Crimson Creek Formation in the Renison Bell area, and the overlying Dundas Group rocks contain abundant detrital pyroxene and gabbro pebbles derived from the mafic and ultramafic rocks (Rubenach, 1967). On this evidence, the Arthur River sequence is tentatively correlated with the Crimson Creek Formation.

Structure

The Cleveland Mine is situated on the overturned SE limb of a SW-plunging anticline; dips within this limb vary considerably from NW (overturned) to SE. Locally, axial plane cleavage is developed and strikes NE and dips 75° NW. Major thrust faulting parallels the
Figure 15A. A typical cross section through the Cleveland Mine, from Cox (1968). The Arthur River sequence locally has been divided into three formations which are shown; viz.- Deep Creek Basic Volcanics Formation, Halls Formation, and Crescent Spur Mica Sandstone Formation.
CLEVELAND MINE, CROSS-SECTION "Qa"
LOOKING NORTH-EAST

Figure 15A
axial plane orientation with the NW wall downthrown to the SE.

Cox and Glasson (1967) recorded that Hopwood (private Aberfoyle report, 1962) had distinguished two phases of deformation. The earlier phase (f1) is a regional folding about near horizontal SW-trending axes while the second phase (f2) is a complex phase producing folds of variable orientation on the earlier (f1) folds. The first phase (f1) resulted in the major anticlinal structure while the second phase (f2) produced generally smaller, superimposed folds with a preferential shallow plunge to the SW. This sequence of folding is similar to that in the Mt. Bischoff sequence at Waratah.

The major effect of folding and associated axial plane thrust faulting has been to divide the sequence into a number of lenses which are arranged en echelon and become deeper towards to the SE. This general pattern is complicated by movements on smaller faults and by the second phase (f2) folding.

Devonian Igneous Rocks

The northern margin of the Meredith Granite occurs only 2½ miles to the south of the Cleveland Mine (Fig. 3). Reid (1923) recorded several small protrusions of quartz porphyry which had been severely altered in the vicinity of the mine, but these have not been found during subsequent investigations (e.g. Hughes, 1954; Mason, 1965), and it is probable that the rocks were misidentified (P.B. Nye, pers. comm.) Cox and Glasson (1967) recorded a thin quartz porphyry dyke, up to 9 inches wide, which strikes 105°M and dips steeply north and intersects the basal greywacke-sandstones within 600 feet of the tin mineralization.
Mineralization

(a) Tin Mineralization

The ore bodies at Cleveland, which are mineralogically similar to the replacement ore bodies at Mt. Bischoff, are generally stratiform. The horizon controlling mineralization is considered by Cox and Glasson (1967) to represent an extremely finely bedded calcareous shale. It is now almost completely replaced by quartz, carbonate, sulphides (pyrrhotite, pyrite, chalcopyrite, marcasite, arsenopyrite, sphalerite, stannite and tetrahedrite), chlorite, sericite, tourmaline, fluorite, cassiterite and wolframite. The sulphides occur as fine disseminations and irregular massive aggregates whose distribution is controlled by compositional layering of the host rocks, and also as vein-like masses which are oblique to bedding lamination. Small chert beds are common in the ore horizon and Ferrand (1963) suggested that there was little doubt that they are sedimentary beds and not products of the mineralization. The sulphides and cassiterite show a marked concentration in some laminae particularly the quartz and carbonate-rich bands but are rare in the chlorite-rich, tourmaline-rich and chert bands.

(b) Lead-Zinc-Silver Mineralization

As at Mt. Bischoff, the tin ore bodies at Cleveland occur in an area of Pb-Zn-Ag mineralization. The mineralization is confined to relatively thin quartz-carbonate veins, the majority of which are structurally controlled by geologic contacts within the area (Groves, 1965a). The Magnet lode, described previously, is one such deposit that is approximately equi-distant from Cleveland and Mr. Bischoff. The Godkin
lodes (Godkin, Discoverer and Bell's Reward) occur along a faulted contact between Ordovician limestone and Silurian sandstone and Cambrian intermediate and mafic igneous rocks (Fig. 3). The Heazlewood and Boxing Day lodes occur along the faulted contact of serpentinite and spilite and the Mt. Wright lode is subparallel to this contact. The Washington, Washington Hay and Confidence lodes all occur adjacent to small mafic igneous bodies within the Cambrian sedimentary rocks. The Mt. Stewart lode is controlled by the strong schistosity of the enclosing pyroxenite. The lodes have a simple and consistent mineralogy throughout the area. They are generally irregularly banded with argentiferous galena, sphalerite and minor pyrite and chalcopyrite in a quartz and carbonate gangue.

(c) Copper Mineralization.

Limited copper mineralization occurs within the mafic and ultramafic rocks in the Heazlewood area. Small lodes occur at the Old and New Jasper mines and consist of splashes of chalcopyrite and bornite with minor pyrite and sphalerite in bands of jasper or entirely within the igneous rocks. Groves (1965a) suggested that the Cu sulphides may have segregated from the mafic and ultramafic rocks and subsequently been remobilised penecontemporaneously with Pb-Zn-Ag mineralization.
RENISON BELL TIN MINE

Renison Bell is situated some 9 miles NE of Zeehan and some 25 miles south of Mt. Bischoff (Fig. 3).

The oldest rocks exposed are the sandstones, quartzites, shales and dolomites of the Dalcoath Quartzite and Renison Bell Shale which have lately been considered to be Upper Proterozoic to Lower Cambrian in age. They are overlain locally by red cherts, sandstones and conglomerates and a bed of dolomite which have been grouped as the "Red Rock" (e.g. Conder, 1918). These rocks are overlain by mudstones and greywackes of the Crimson Creek Formation which is intruded by numerous sub-concordant to dyke-like sheets of mafic igneous rocks (dolerite and gabbros). The Crimson Creek Formation is overlain by conglomerates, mudstones and greywackes of the Dundas Group. The Serpentine Hill Complex, composed of mafic and ultramafic rocks, is interposed between the Crimson Creek Formation and the Dundas Group. These sequences are intruded by greisenized adamellites and porphyries of Devonian age (Brooks, 1966).

The sedimentary succession in the Renison Bell area is summarised as follows (after Blissett, 1962; Hall and Solomon, 1962; Gilfillan, 1965):

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dundas Group</td>
<td></td>
</tr>
<tr>
<td>Brewery Junction Formation</td>
<td>2000 ft.</td>
</tr>
<tr>
<td>Razorback Conglomerate</td>
<td>250-750 ft.</td>
</tr>
<tr>
<td>Hodge Slate</td>
<td>500-600 ft.</td>
</tr>
<tr>
<td>Crimson Creek Formation</td>
<td></td>
</tr>
<tr>
<td>&quot;Argillite&quot;</td>
<td>8000 ft.</td>
</tr>
<tr>
<td>&quot;Red Rock&quot;</td>
<td>50-100 ft.</td>
</tr>
</tbody>
</table>
Oonah Quartzite and Slate Renison Bell 150-200 ft.

Shale

Dalcoath Quartzite. 200+ ft.

Dalcoath Quartzite and Renison Bell Shale

These formations occupy a NW-SE trending, elongate protrusion surrounded by rocks of the Crimson Creek Formation just west of Renison Bell township, and also a wedge-shaped area which is also surrounded by rocks of the Crimson Creek Formation near the Battery Workings (Fig. 16). The Dalcoath Quartzite consists of medium to coarse grained sandstones and saccharoidal quartzites which are overlain by shales, siltstones and fine sandstones of the Renison Bell Shale. The rocks are lithologically similar to those of the Mt. Bischoff sequence at Waratah, the sand-grade rocks being lithic sandstone (sub-greywackes and protocquartzites). Intraformational folding and brecciation is widespread in the shale members of the Renison Bell Shale. A dolomite bed, up to 100 feet thick, occurs at the top of the Renison Bell Shale. The dolomite is a pale grey to cream, fine grained rock (e.g. 1552) consisting almost entirely of granular dolomite with some clastic quartz and rare fibrous chlorite aggregates. Irregular patches of coarsely crystalline carbonate are developed in places. Analyses of the dolomite (Appendix D3, Table 47) indicate that it contains significantly more FeCO$_3$ and slightly more MnCO$_3$ than the dolomite at Mt. Bischoff and has a slightly higher CaCO$_3$ : MgCO$_3$ ratio and a higher Sr content. The high SiO$_2$ content of
specimen 100213 is due to recrystallization of the carbonate with segregation and probable introduction of quartz which has formed large aggregates. In its broad features, however, the dolomite is similar to that at Mt. Bischoff and is considered to have a sedimentary origin.

In recent years this sequence has been considered to be Upper Proterozoic or Lower Cambrian (e.g. Hall and Solomon, 1962) and to represent the upper part of the Onah Quartzite and Slate (Blissett, 1962). Solomon (1965) has included the sequence in the Success Creek phase.

"Red Rock"

The "Red Rock" is considered by Blissett (1962) and Gilfillan (1965) to be the local base of the Crimson Creek Formation, and to conformably overlie the Renison Bell Shale. However, Solomon (1965) has pointed out that the abrupt change in lithology and the presence of thin lenticular conglomerates at its base may indicate at least localized elevation of shore areas at the beginning of "Red Rock" sedimentation.

The "Red Rock" varies in thickness from 80 to 100 feet (Fig. 17). It consists of an unusual assemblage of red cherts, coarse haematitic sandstones, paraconglomerates, conglomerates and breccias, with a dolomite bed at the top of the sequence. The red cherts (e.g. 1545, 1567-68) are fine grained rocks composed essentially of fine quartz and interstitial haematite or limonite. They contain numerous irregular patches and veins of quartz, carbonate and haematite. In specimen 1567, abundant euhedral magnetite crystals, rimmed by carbonates and micas, occur in a chert matrix and numerous patches and
veins of fibrous green chlorite occur in association with coarsely crystalline carbonate and quartz. Septarian nodules up to 15 cm in diameter are common in thick cherts. Coarse sandstones occur which are composed of oolite-like bodies of chert, generally 1 mm. in diameter, in a fine haematitic matrix (e.g. 1547). Breccias are relatively common (e.g. 1546, 1550, 1565) and consist of angular to rounded quartz grains and fragments of quartzite, siltstone, chert and volcanic rocks up to 20 mm. in length in a carbonate-rich matrix. The rock fragments are largely replaced by carbonate and in specimen 1550 shadowy fragments consisting of discrete quartz grains in a carbonate-rich groundmass occur in a matrix of fine carbonate. Other rocks have extremely irregular textures and appear to consist essentially of carbonate and haematite (e.g. 1548). Pebbles of granite have been found in the basal conglomerates (M. Solomon, 1964).

Solomon (1964) suggested that the haematitic chert sandstones were derived from reworking of chert in shallow water and that the SiO₂ and Fe-oxides forming the cherts may have been derived from volcanic exhalations associated with spilitic volcanic activity which commenced at this level. This would explain the restricted occurrence of these rocks at Renison Bell.

A dolomite bed occurs at the top of the "Red Rock" and is generally some 30 to 60 feet thick. It was examined in drill sections (Fig. 17B) and found to be largely recrystallized with interstitial quartz and muscovite (e.g. 1542, 1544). In specimen 1562 large irregular blocks of fine granular dolomite are separated
by anastomosing masses of coarsely crystalline carbonate. Chemical analyses of the dolomite (Appendix D3, Table 47) indicate a dolomitic composition similar to specimen 100215 from the lower dolomite bed. The SiO₂ content is relatively high.

**Crimson Creek Formation**

The Crimson Creek Formation is apparently about 8000 feet thick in the Renison Bell area. The rocks are predominantly red, purple or green mudstones (argillites) with subordinate siltstones and sandstones. In the vicinity of Pine Hill they have been converted to hornfelses by the acid intrusives which occur at the summit. The presence of calcareous mudstones is suggested by the occurrence of calc-silicate hornfelses near Gormanston Creek (Fig. 16). These hornfelses are described in Appendix A3. The sand-grade rocks are greywackes which are texturally and compositionally immature. In thin section they are poorly sorted rocks with a disrupted framework and consist of sub-rounded to subangular grains of quartz, albite, microcline (some graphic intergrowth with quartz), and spilite fragments, suggesting that the rocks are locally derived. The sequence is lithologically similar to the Arthur River sequence in the Waratah area.

**Dundas Group**

The Dundas Group has been described in detail by Elliston (1954) and Blissett (1962) and has been dated on fossil evidence as Lower or Middle Middle Cambrian to Middle Upper Cambrian. Locally, SE of
Plate 9 - Clastic grains of microcline and quartz in graphic intergrowth in hornfels, Crimson Creek Formation, Pine Hill. Specimen No. 1455, x 86.

Plate 10 - Relic autoclastic texture in clastic grain from hornfels, Crimson Creek Formation, Pine Hill. Specimen No. 1455, x 86.
Pine Hill, the Hodge Slate, Razorback Conglomerate and Brewery Junction Formation overlie gabbros and metadolerites of the Serpentine Hill Complex.

The Dundas Group is locally represented by alternate horizons of mudstones, siltstones, greywackes and acid volcanic rocks and horizons of greywacke - or chert - breccias and conglomerates with minor siltstone beds. The greywacke-sandstones are commonly graded and scouring is common in siltstone beds below coarse greywacke-sandstones. The sand-grade rocks are turbidites. Rubenach (1967) recorded that greywacke-conglomerates immediately overlying the Serpentine Hill Complex in the Ring River contain detrital pyroxenes and pebbles of gabbro and spilite, indicating a pre-Dundas Group age for the cooling of the Complex.

Cambrian Igneous Rocks

Small gabbro and dolerite bodies are common in the Crimson Creek Formation in the Renison Bell area. They are predominantly complex dykes although some are concordant sheets. They are mineralogically similar to the intrusions in the Arthur River sequence of the Waratah area. Solomon (1964) noted that the composition of the gabbros was similar to that of the Cambrian spilites, and it is possible that they were feeders to submarine extrusion during Crimson Creek Formation sedimentation. Rubenach (1967) recorded that they were mineralogically and chemically dissimilar to the rocks forming the Serpentine Hill Complex, with the possible exception of the metadolerites.
Structure

Blissett (1962), Hall and Solomon (1962) and Gilfillan (1965) have shown that the major structure is a NW-trending broad anticline which plunges NW near Renison Bell township, and has a core of Upper Proterozoic rocks (Fig. 16).

The NE limb of this structure is well developed with successively younger rocks occurring to the NE (Fig. 17). A closure of this structure to the SE is suggested by a general swing in strike from NW at Renison Bell to NNE-NE at Pine Hill. This swing in strike is also shown by the minor folds on the NE limb. Folds in the Battery Workings have a general NNE-trend (Fig. 19C) while folds to the north of the workings have a trend ranging from NW to NNE (Fig. 19B). The SW limb of the anticline is poorly defined, largely because of poor exposure. However, it must be considerably shorter than the NE limb as rocks of the Crimson Creek Formation exposed along the Murchison Highway and Emu Bay Railway dip almost exclusively in an easterly direction (Fig. 16).

Solomon (1965) showed the Success Creek phase as probably post-Penguin Orogeny, although he concluded that the age of the phase was uncertain. No conclusive evidence has been presented for a pre-Success Creek phase deformation in this area. The apparent increase in deformation in the Oonah Quartzite and Slate may as well be a function of the controlling thickness of the layers during flexural folding as a function of earlier deformation. A linear relationship between
LEGEND

- MINE RUBBLE IN WORKINGS
- UNDIFFERENTIATED
- SILICEOUS DOLOMITE
- RED CHERT
- RED ROCK
- SANDSTONES
- SHALES, ARAGLITES
- PYRRHOTITE

GEOLOGY—BATTERY WORKINGS, RENISON BELL

Figure 19

A. FAULTS - RENISON BELL

29°

○ FAULT

△ M. MINERALISED FAULT

B. FOLD AXES - RENISON BELL

71°

K. ADJACENT TO FAULT

C. FOLD AXES - BATTERY WORKINGS

42°

STRUCTURAL ELEMENTS - RENISON BELL

EQUAL ANGLE - LOWER HEMISPHERE

fold wavelength and dominant member thickness has been shown by several authors (e.g. Currie et al., 1962). At Renison Bell, there are relatively thick continuous sequences of contrasting competency which may result in less frequent folds with longer wavelengths than those in alternating quartzites and shales of the Oonah Formation in the Zeehan area, although they may involve a similar amount of shortening.

The effect of the Penguin Orogeny in this area is apparently negligible as there is apparent conformity between all the Upper Proterozoic and Cambrian sequences. It is possible that the intensity of the orogenic phase is decreasing southwards from North-West Tasmania where it is a major deformation phase (Gee, 1967a). Relatively mild deformation has occurred at Mt. Bischoff as a probable result of this orogeny. On available evidence therefore the folding at Renison Bell and Zeehan can be attributed to the Tabberabberan Orogeny.

Minor, steeply dipping faults are abundant in the mine area and generally have normal displacements of some 10 to 30 feet (Gilfillan, 1965). The faults have a wide range of orientation (Fig. 19A) but can be resolved into a set which is subparallel to the major fold trend and a set perpendicular to this trend (i.e. NW and NE - trending sets in the mine area). The faults trending NW generally have the largest displacements (up to 100 feet) and both Hall and Solomon (1962) and Gilfillan (1965) recorded that they were largely pre-ore. The NE - trending faults are probably post-ore.

Rubenach (1967) recorded large faults which bounded and offset the margins of the Serpentine Hill Complex. Several of these faults have been the loci for later Pb-Zn mineralization, the most important being Kapi and Melba (Fig. 16).
Devonian Igneous Rocks

A small multiple intrusion, slightly less than $\frac{1}{4}$ mile in diameter, intersects rocks of the Crimson Creek Formation and gabbros of the Serpentin Hill Complex at Pine Hill, approximately 2 miles south of Renison Bell. The intrusion has been described in detail by Ward (1909) and referred to by Blissett (1962), Hall and Solomon (1962), and Rubenach (1967). The complex lies just west of the possible extension of the major anticlinal structure and is surrounded by a series of quartz-porphyry dykes which tend towards a radial orientation with a dominant NW trend. The rocks of the complex have been extensively greisenized and tourmalinized, commonly with complete destruction of original textures. A typical greisen dyke crops out in a small quarry on the Murchison Highway about $\frac{1}{2}$ mile SW of Renison Bell, and has been dated as Upper Devonian ($354 \pm 4$ m.y.) by Brooks (1966).

The unaltered rocks of granitic composition are largely porphyritic and non-porphyritic sodaclose adamellites. They occur predominantly on the western side of the complex, on the northern slopes of the saddle between Commonwealth Hill and Pine Hill (Ward, 1909). The distribution of unaltered adamellites in creeks draining the area indicates that they may also occur in the lower levels of the complex. The intrusion is capped by a mass of tourmalite consisting almost entirely of granular quartz and tourmaline (schorlite) which is intruded in places by partly tourmalinized, greisenized or relatively unaltered quartz-feldspar porphyry dykes. The upper part of the exposed tourmalite is finer grained than the underlying rock.
The contact between the igneous rocks and country rocks is largely obscured by talus.

Ward (1909) considered the complex to be a mass of intersecting dykes but Blissett (1962) suggested that it was a complex sill. A dyke-like or cupola-like body is the most likely structural form for the complex because of:

(a) The lack of similar rocks on adjacent hills,
(b) the high angle between the contact and topographic contours on the western margin,
(c) the occurrence of porphyry dykes apparently continuous with the main mass, topographically lower than the mass itself,
(d) the lack of any known sub-horizontal structure likely to provide a zone of weakness for intrusion of a sill,
(e) the steep dip of all igneous bodies seen in the workings below the talus cover (Ward, 1909), and
(f) the radial extent of contact metamorphism (Fig. 16).

Petrographic descriptions of the igneous rocks and the hornfelses are given in Appendices A1 and A3 respectively.

Mineralization

(a) Tin Mineralization

Minor cassiterite-quartz-tourmaline veins occur in the Pine Hill Complex. They are generally small and irregular although some small ore shoots have been mined in the Penzance workings, where they have preferential NW and NE trends (Ward, 1909).
The major ore deposits at Renison Bell are gently dipping, lenticular pyrrhotite sheets ("sills"). These sheets consist essentially of pyrrhotite with pyrite, arsenopyrite, sphalerite, galena and cassiterite in a gangue of quartz, carbonate and fluorite. There are three sheets which occupy three distinct stratigraphic horizons, the upper two horizons being dolomite beds. As at Mt. Bischoff the distribution of sulphides and cassiterite is irregular, and can be independent. Fisher (1953) considered these sulphide sheets to be dilational but Hall and Solomon (1962) suggested that they were formed by replacement. The replacement origin appears probable because of the stratigraphic control of most of the ore deposits in the most chemically unstable dolomite horizons.

The uppermost ore deposit (No. 1 Horizon) occurs in the dolomite bed at the highest level of the "Red Rock". The horizon is generally poorly mineralized and in places poorly bedded recrystallized dolomite occupies the ore horizon. Gilfillan (1965) recorded that the horizon was a maximum of 50 feet thick. The central horizon (No. 2 Horizon) occurs in the dolomite bed at the top of the Renison Bell Shale, and replacement extends down into the siltstones beneath the dolomite. It is the most extensively mineralized horizon and has been mined over a wide area. The average thickness of the lode is approximately 26 feet with an average grade of 1 per cent tin. The lowest ore horizon (No. 3 Horizon) occurs about 100 feet below the No. 2 Horizon (Fig. 17), and occurs entirely within siltstones and shales. Gilfillan (1965) discussed the difficulty of testing this lode but suggested that it was of similar thickness and grade to the No. 2 Horizon.
Steeply dipping, discordant fissure lodes also occur. The two major lodes, the Federal-Dreadnought Lode and Blow Lode (Fig. 16), are parallel to and probably occupy NW-trending fault zones. They can be traced for over 2000 feet at the surface and have been proven down dip for 800 feet. Hall and Solomon (1962) recorded that they contained more pyrite and quartz and less pyrrhotite than the concordant sheets. The relationship between the discordant and concordant sheets is not clear.

Gilfillan (1965) recorded ubiquitous development of gossan over the fissure lodes and Hall and Solomon (1962) recorded a maximum depth of oxidation of 50 feet.

Small cassiterite deposits occur in the Exe River Tinfield some 2 miles east of Renison Bell on the west side of Colebrook Hill. The main mines are the X Proprietary, Olympic and Fenton (Fig. 3). The cassiterite occurs with quartz, tourmaline, pyrite, arsenopyrite and chalcopyrite in thin, impersistent, generally uneconomic vein deposits intersecting rocks of the Crimson Creek Formation (e.g. Blissett, 1962).

(b) Lead-zinc-silver Mineralization.

As at Mt. Bischoff and Cleveland, the tin mineralization at Renison Bell occurs in a district of predominantly Pb-Zn-Ag mineralization. The Dundas district occurs approximately 6 miles to the south of Renison Bell and contains numerous fissure lodes of argentiferous galena or galena-sphalerite in a siderite gangue. A series of small, structurally controlled, galena-sphalerite-siderite fissure lodes
occur at Melba, Kapi, McKimmie and Lead Blocks within a radius of 2 to 3 miles south and SW of Renison Bell. Two miles NW of Renison Bell there are a series of small fissure lodes including the Success, Owen Meredith, Bon Accord and Success Extended (Fig. 3) which consist of argentiferous galena with minor pyrite, chalcopyrite and sphalerite in a quartz-siderite gangue.

(c) Copper Mineralization.

Massive to banded sulphide deposits occur at Colebrook Hill about 3½ miles east of Renison Bell (Fig. 3). The sulphides occur in metasomatic replacement veins in the Crimson Creek Formation. The veins consist of sulphides, axinite, actinolite, calcite and quartz with minor datolite and danburite (Blissett, 1962) and are mineralogically similar to the veins in calc-silicate hornfelses in the contact aureole of the Pine Hill Complex at Gormanston Creek (Appendix A3). The sulphide bands, which have a maximum thickness of 15 feet, consist essentially of pyrrhotite with pyrite, chalcopyrite, arsenopyrite, galena, sphalerite and tetrahedrite. Blissett (1962) recorded copper values generally less than 3 per cent.

Post-mineralization Igneous Rocks

Thin, dilational mafic dykes, a few feet in width, intrude all sedimentary sequences and the ore horizons in the mine area. They have been regarded as basalts (e.g. Hall and Solomon, 1962). In thin section (1428) the rock consists of a fine intergrowth of augite and labradorite with phenocrysts of augite, partially altered to chlorite, and labradorite. No olivine is present. A chemical analysis
of the rock (Table 2) is very similar to that of an average Jurassic chilled dolerite from Tasmania and is quite dissimilar to the saturated olivine baslats, which are the most common Tertiary extrusive rocks in the area.
Table 2. Chemical analysis of post-mineralization dyke-rock from Renison Bell and comparison with Jurassic chilled dolerite and Tertiary saturated olivine basalt.

<table>
<thead>
<tr>
<th></th>
<th>1428</th>
<th>1*</th>
<th>2*</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>54.9</td>
<td>53.3</td>
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<tr>
<td>TiO₂</td>
<td>0.66</td>
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<td>100.17</td>
</tr>
</tbody>
</table>

1428: - Dyke-rock, Renison Bell. Analyst

1* - Average Jurassic chilled dolerite from Spry (1962b p. 283).

OTHER CASSITERITE - SULPHIDE DEPOSITS

Razorback-Grand Prize

The Razorback and Grand Prize Mines are situated some 5 miles south and 4 miles SSE of Renison Bell respectively. They occur in an area of numerous small Pb-Zn-Ag deposits which have been discussed in the previous section. The tin deposits have been described in detail by Blissett and Gulline (1961b).

At the Razorback Mine schistose serpentinite is faulted against sedimentary rocks of the Dundas Group. Talc and silicified dolomite have formed in the NNW-trending fault zone to a maximum width of 150 feet by hydrothermal alteration of the host rocks. Mineralization has occurred along the fault zone, irregular ore-shoots of sulphides with quartz, carbonates and cassiterite occurring within the contact zone with disseminations and sporadic rich vughs of cassiterite in the talcose serpentinite. The sulphides are predominantly pyrrhotite with pyrite, arsenopyrite, chalcopyrite and small quantities of galena. Oxidation extends to a maximum depth of 120 feet, the sulphides being almost completely oxidised to a yellow-brown limonitic gossan.

At the Grand Prize Mine the orebody occupies a 25 feet wide fault zone which is parallel to the Razorback fault zone but occurs entirely within greywackes, mudstones and breccia-conglomerates of the Dundas Group. The fault is apparently a tear fault with the east block moved south at least 300 feet. The mineralization is similar to that at the Razorback Mine although there has been little replacement of the wall rocks. Oxidation has occurred to a depth of some 200 feet.
Blissett and Gulline (1961b) have pointed out the mineralogical similarity of these lodes with the lodes at Renison Bell.

**Mt. Lindsay**

The Mt. Lindsay workings occur less than ½ mile south of the Meredith Granite, approximately 9 miles NW of Renison Bell and 20 miles SW of Waratah. Recent reports on exploration by the Aberfoyle Tin Development Partnership are not available, and this summary is based on reports by Waterhouse (1914) and Reid (1927).

The host rocks to mineralization are grey, green, chocolate or purple mudstones, greywacke-sandstones, breccias and probable spilitic lavas. Both Waterhouse (1914) and Reid (1927) have included the sequence at Mt. Lindsay in the Dundas Group but it is apparently continuous with the Crimson Creek Formation in the type locality (Fig. 3). Cox and Glasson (1967) suggested that the sequence is similar to that at Cleveland. The sedimentary rocks have locally been converted to hornfelses by the adjacent Meredith Granite, from which several porphyritic adamellite dykes protrude. The mineral assemblages described by Waterhouse (1914) suggest that there is an inner aureole of pyroxene hornfels facies, with local development of sillimanite, with a more extensive zone of hornblende hornfels facies metamorphism, typified by hornblende, diopside, garnet and wollastonite, with some albite-epidote hornfels facies metamorphism which is in part retrograde. The orebody is largely conformable with bedding in the host rocks and there is abundant evidence of replacement. The orebody is a skarn consisting of hornblende, biotite, quartz, garnet, vesuvianite, diopside, epidote, axinite, wollastonite,
scheelite, calcite, fluorite, tourmaline and abundant magnetite. Sulphides and cassiterite are demonstrably later than the magnetite and most silicates. The sulphides consist essentially of pyrrhotite and pyrite with minor chalcopyrite and galena. Small patches of galena-sphalerite occur but no major Pb-Zn-Ag mineralization has been recorded from the area.

The orebodies appear to be localised in skarns produced by metamorphic and metasomatic alteration of calcareous rocks in the sedimentary sequence with subsequent introduction of sulphides and cassiterite.

SUMMARY

The cassiterite-sulphide deposits occur generally as stratiform replacement deposits (Mt. Bischoff, Renison Bell, Cleveland, Mt. Lindsay) or as replacement fissure deposits (Renison Bell, Razorback-Grand Prize). Fissure lodes also occur at Mt. Bischoff. The stratiform replacement deposits are generally replacements of dolomites or calcareous sedimentary rocks and the replacement fissure deposits and fissure lodes occur in fault zones. The sequence of mineralization may be complex with several phases within the main period of mineralization (e.g. Mt. Bischoff). The tin deposits generally occupy isolated, relatively small areas in larger districts of predominantly Pb-Zn-Ag mineralization.

The replacement deposits at Mt. Bischoff and Renison Bell occur in dolomite horizons which occur at a similar stratigraphic level in each area. They occur at the top of an Upper Proterozoic-Lower Cambrian
miogeosynclinal sequence of sandstones, shales and mudstones, in which the sand-grade rocks are subgreywackes and protoquartzites. This sequence is followed by an eugeosynclinal sequence consisting of greywackes, mudstones, cherts, spilitic lavas and mafic intrusives. The intervening sequence of haematitic cherts, sandstones and conglomerates ("Red Rock") is unique to the Renison Bell area. It is significant that the greater proportion of Pb-Zn-Ag mineralization in the Zeehan-Dundas area has occurred at the same stratigraphic level as the tin mineralization at Renison Bell and Mt. Bischoff (e.g. Solomon, 1965; King and Blissett, 1967). Solomon (1965) has grouped the sequences at this level as the Success Creek phase and has suggested that they were probably post-Penguin Orogeny, while the Oonah Quartzite and Slate were pre-Penguin Orogeny. There is no conclusive evidence of a structural break between this "phase" and the Oonah Quartzite and Slate in the Zeehan - Renison Bell area, and available evidence at Mt. Bischoff suggests that the "phase" is locally probably pre-Penguin Orogeny.

The deposits at Mt. Bischoff, Renison Bell and Cleveland occur on the limbs of major anticlinal structures which are complicated by extensive normal faulting and flexural folding. The structure at Mt. Lindsay is not known. A spatial association of tin mineralization with Upper Devonian igneous rocks is shown to varying degrees. It appears possible that the anticlinal structures have localised intrusion.

At Mt. Bischoff, numerous greisenized, topazized and tourmalinized quartz-feldspar porphyry dykes of Upper Devonian age have intruded a faulted anticlinal structure. The tin mineralization is restricted to the area of highest dyke frequency.
A small cupola of tourmalinized adamellite intrudes close to an anticlinal crest at Pine Hill, less than 1 mile from the Battery Workings in the Renison Bell area. Associated with this cupola are numerous greisenized quartzfeldspar porphyry dykes of Upper Devonian age, which are generally restricted to the area of tin mineralization. The Razorback-Grand Prize tin mineralization is within 3 miles of the Pine Hill Complex, although acid dykes have not been recorded from the immediate vicinity.

A close relationship between the Mt. Lindsay deposit and the Meredith Granite of Upper Devonian age is evident, the deposit occurring within the contact metamorphic aureole of the "Granite". The relationship at Cleveland is less obvious, the deposit occurring some 2½ miles from the northern margin of the Meredith Granite. However, Cox and Glasson (1967) have recently discovered a small quartz-porphyry dyke some 600 feet from the replacement deposit.