Title
The geology, geochemistry and structure of the Mount Darwin-South Darwin Peak area, western Tasmania

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The Geology, Geochemistry and Structure of the Mount Darwin - South Darwin Peak Area, Western Tasmania.

by

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A thesis submitted in partial fulfihnent of the requirements for the degree of Bachelor of Science with Honours.

CENTRE FOR ORE DEPOSIT AND EXPLORATION STUDIES

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Abstract

The Cambrian Darwin Granite intrudes calc-alkaline rhyolites of the Central Volcanic Complex on the Darwin Plateau, western Tasmania. Two distinct granite phases are recognised, an equigranular granite and a granodiorite. A biotite grade contact aureole is preserved in the Central Volcanic Complex immediate to the Darwin Granite. Debris flow deposits of volcaniclastic conglomerates and sandstones, and coherent dacite lavas of the Mid - Late Cambrian Tyndall Group unconformably overlie the Darwin Granite and Central Volcanic Complex, and are in turn overlain unconformably by pebble to boulder conglomerates of the siliciclastic Owen Conglomerate.

Stratigraphic and structural evidence recognise three deformation periods within the Mt Darwin - South Darwin Peak area: the Mid - Late Cambrian, Late Cambrian - Early Ordovician, and the Devonian Tabberabberan Orogeny. Mid - Late Cambrian deformation, evidenced by granitic and foliated volcanic clasts in basal Tyndall Group conglomerate, indicates catastrophic uplift and subsequent unroofing of the granite prior to Tyndall Group deposition. This unconformity represents a significant Cambrian hiatus in the southern Mount Read Volcanics. A second unconformity between the Tyndall Group and the Owen Conglomerate marks cessation of Tyndall Group deposition with the onset of deposition of large volumes of siliceous detritus. The two Devonian Tabberabberan-related deformations are characterised by, NW and N-trending dextral strike slip faulting and locally intense N-trending cleavage development. The Devonian structures dominate the region and have obscured the effects of earlier deformations. Devonian metamorphism to greenschist facies, characterised by chlorite-sericite assemblages, occurs throughout the area with intense development in shear zones.

Epigenetic, granite-related, vein and disseminated Cu-Au mineralisation occurs within and adjacent to the Darwin Granite. Sulphur isotope data indicates mixing of Cambrian seawater with magmatic-hydrothermal fluids in a hydrothermal convection cell generated during emplacement of the Darwin Granite. Depletion of Na_20 and CaO along with K_20 and FeO enrichment have occurred during pervasive K-feldspar, sericite and chlorite alteration.

Geochemical analyses of the Central Volcanic Complex and the magnetite series Darwin Granite suggest that these units were emplaced within an extensional basin (back-arc?), at an Andean-type margin. Granitic magma was generated through partial melting of an upper mantle to lower crustal source. REE data suggests that the CVC and Darwin Granite are not co-magmatic, and field relationships preclude a genetic relationship between the Tyndall Group and the Darwin Granite. Elemental discrimination trends illustrates some similarities between the Darwin Granite and the most evolved phases of the Murchison Granite. However, the Darwin Granite displays no Eu anomaly in contrast to the negative Eu anomaly and HREE enrichment in the Murchison Granite, suggesting that the two granite systems are not genetically related.

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Chapter 1.0 INTRODUCTION

The role of Cambrian granites in Tasmania's geological history is not yet fully understood. Questions that remain to be answered include their influence upon mineralisation, geochemical affinity to volcanic units of the Cambrian Mount Read Volcanics, and their tectonic setting upon emplacement. The granites may also be used to test reconstruction hypotheses linking the Dundas Trough in Tasmania with the Bowers Trough of Northern Victoria Land, Antarctica, i.e. Quilty (1985).

1.1 AIMS

The primary aims of this project are to:

1. Detail the petrology and geochemistry of the Darwin Granite, ascertain the affects of alteration upon it and consider the tectonic setting of emplacement.
2. Consider geochemical similarities and/or contrasts between the granite and volcanic units of the Mount Read Volcanics.
3. Compare and contrast the Cambrian Darwin and Murchison Granites of Tasmania and the Northern Victoria Land Granites of Antarctica to test reconstruction hypotheses.
4. Determine the relationship of the Darwin Granite to mineralisation and veining exposed within the study area.

Secondary aspects of the project are to:

1. Produce a detailed geological map at a scale of 1:10 000 of the Mt Darwin-South Darwin Peak region.
2. Determine the local stratigraphy, contact relationships, and structure of the Central Volcanic Complex, Tyndall Group and Owen Conglomerate.

1.2 LOCATION AND ACCESS

The Darwin Plateau (average elevation 700m A.S.L.) is located 32km south of Queenstown, western Tasmania, between Mt Darwin (1033m A.S.L.) and South Darwin Peak (760m A.S.L.) in the West Coast Mountain Range (Fig. 1.1). Access to the area is via the Kelly Basin Road, which heads south from Queenstown and is sealed for the initial 25km. The turnoff to a 4WD access track is located 32km south of Queenstown. Once on the plateau, a large portion of the study area is accessible via a series of bulldozed survey tracks.

1.3 LOCAL MINING HISTORY

The study area lies within the Jukes-Darwin Mining Field (Fig. 1.2). Over the past century there have been discoveries of minor Cu-Au mineralisation at several localities and several periods of intense exploration activity have occurred. The region was first explored following the discovery of Cu-Au mineralisation at Mt Lyell in 1883 (Hills, 1914). Copper was discovered at Lake Jukes in the Jukes-Darwin field in 1897, and at East Darwin in the following year (Hills, 1914; Reid, 1977). The major mineralisation occurrences in the Mt Darwin-South Darwin Peak region are Prince Darwin, East Darwin and Tasman Darwin (Fig. 1.2; Green *et al.*, 1988). Chalcopyrite has been the principal source of Cu; minor Pb, Ag and Au have also been won from some of the small operations (Hills, 1914). Alluvial gold on the North Darwin Plateau has been worked periodically since its discovery in 1900. However alluvial gold is believed to be related to Permian glacials, and will not be discussed further (Hills, 1914).

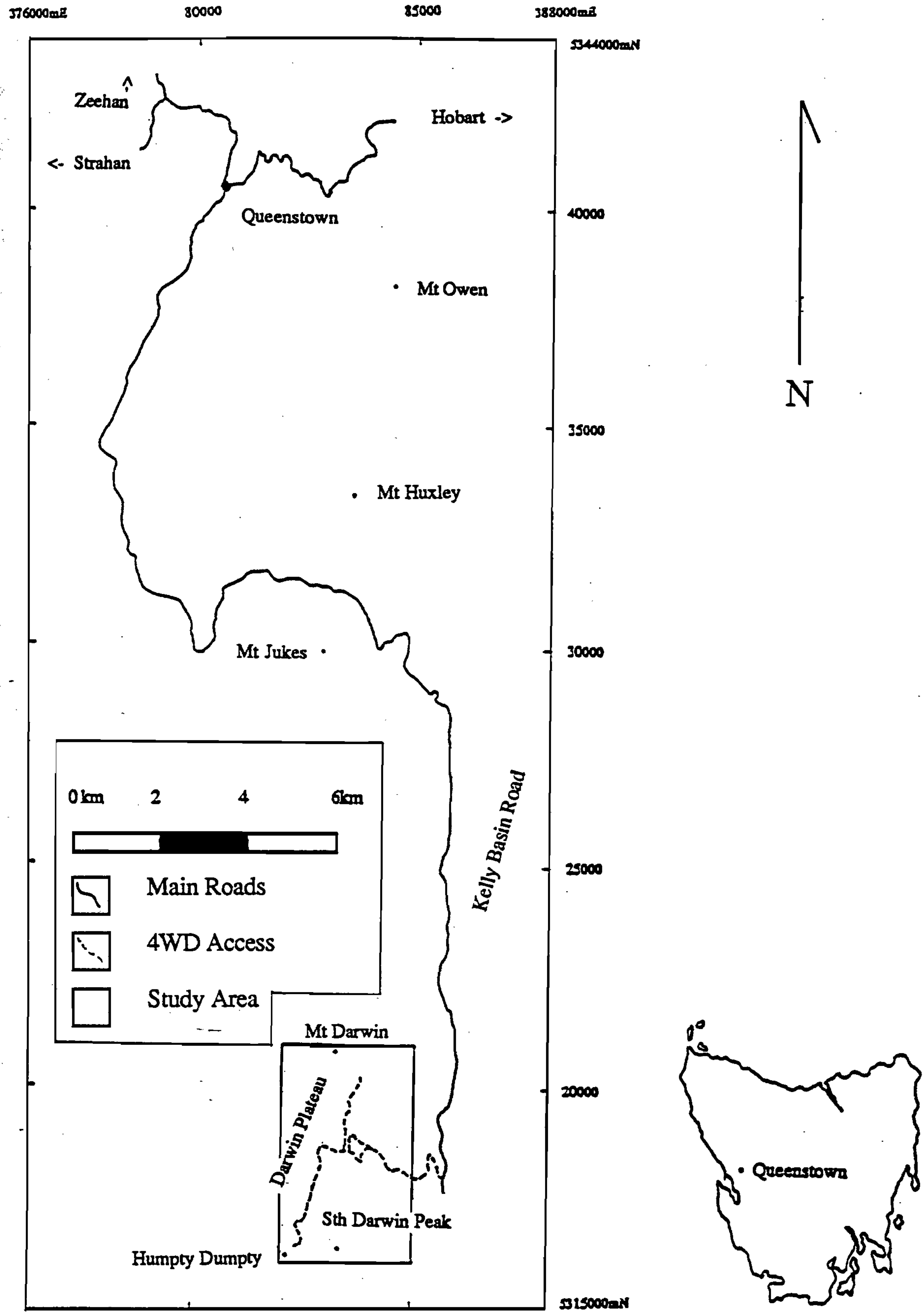
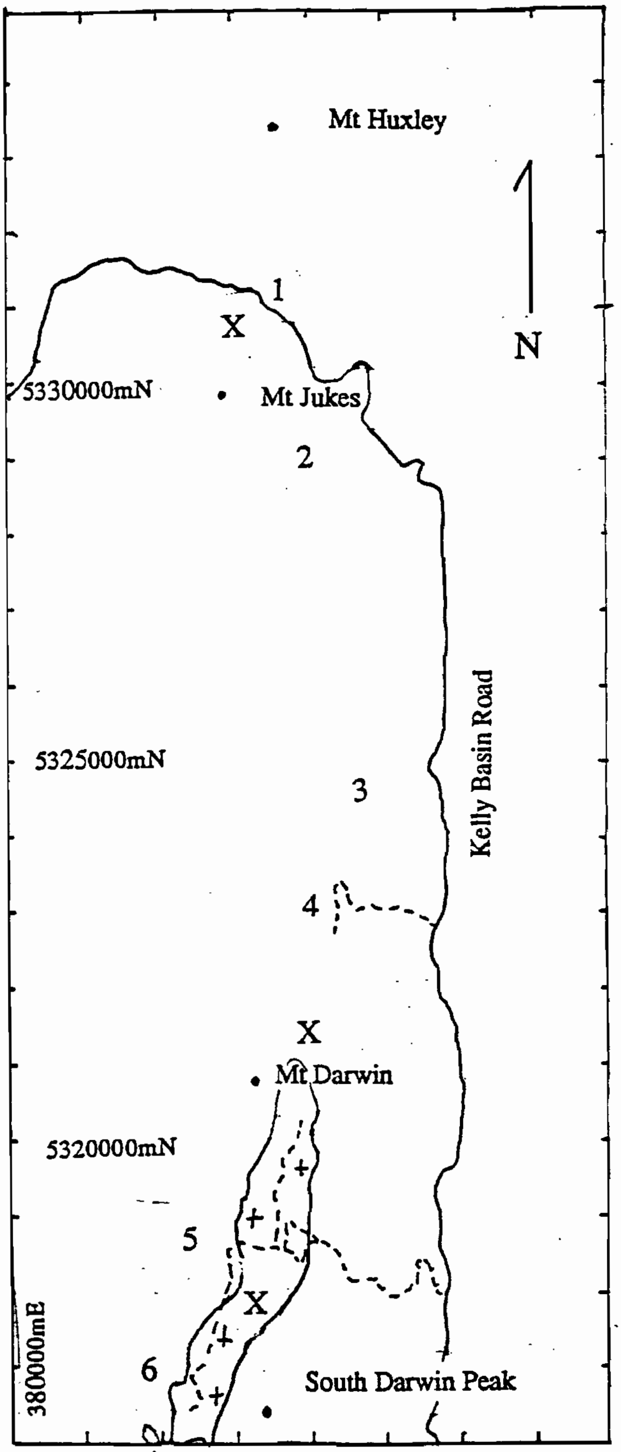


Figure 1.1: Map showing the location of the study area in western Tasmania. Road access can only be gained along the Kelly Basin Road from Queenstown.

1.4 PREVIOUS STUDIES

Previous studies within the Mt Darwin-South Darwin Peak region have documented mining activity in the Jukes-Darwin field (eg. Hills, 1914; Corbett, 1970; Corbett & Cuffley, 1970; Reid, 1977). These studies also provide information on past exploration activity throughout the region, and upon the styles of mineralisation at individual prospects. Lithological descriptions and regional stratigraphic relationships have been provided by White (1975) and Corbett (1976a, 1979, 1992), while Corbett (1976b), Corbett & McNeill (1988) and Corbett *et al.* (1993) represent the most detailed geological mapping immediate to Mt Darwin. White (1975) suggested that the Darwin Granite and Central Volcanic Complex are not co-magmatic, despite their geochemical similarities, while Crawford (1987) has suggested that the Darwin Granite is co-magmatic with volcanic units belonging to the Tyndall Group. Other work that has been carried out on the Darwin Granite includes Bradley (1954), Solomon (1960) and Leaman & Richardson (1989). All those provide summaries of previous research together with a geophysical interpretation of the granite morphology.



Old Mines and Prospects

1 Jukes Proprietary Prospect

2 Lake Jukes

3 Taylours Prospect

4 East Darwin

5 Prince Darwin

6 Tasman Darwin

X Minor Prospects

4km

Figure 1.2: Location of old mines and prospects in the Jukes - Darwin Mining Field, south of Queenstown, in relation to outcrop of the Cambrian Darwin Granite (red). Copper and gold are the metal products which have been mined in the field (after Hills, 1914; Corbett, 1979; Green *et al.*, 1988).

Chapter 2.0 REGIONAL GEOLOGY

The Cambrian Mount Read Volcanic belt is part of a much larger tectonic feature recognised in western and northwestern Tasmania, the Dundas Trough (Corbett & Turner, 1989). The Dundas Trough is flanked by the Precambrian Tyennan Region to the east, and Rocky Cape Region to the west (Fig. 2.1; Corbett & Turner, 1989). The term Dundas Group is used to encompass the fossiliferous marine sedimentary sequences which lie to the west of the felsic volcanic dominated Mount Read Volcanic belt (Campana & King, 1963; Corbett, 1992). The earliest deposits within the Dundas Trough are shallow marine carbonate and sedimentary sequences of the Eo-Cambrian Success Creek Group. Deep marine turbidite sequences interbedded with tholeiitic basalt flows of the Crimson Creek Formation overly the Success Creek Group (Brown, 1989). Remnants of allochthonous ultramafic-mafic suites overly the Crimson Creek Formation and are overlain by correlates of the Dundas Group (Corbett & Turner, 1989).

2.1 MOUNT READ VOLCANICS (MRV)

The MRV belt is dominated by felsic to intermediate volcanics of rhyolitic, dacitic and andesitic composition, with subordinate units of basalt (Fig. 2.1; Corbett & Solomon, 1989). Volcaniclastic and sedimentary units are also an important component of the belt (Corbett & Solomon, 1989). Cambrian granites are exposed at several localities, including the Darwin Plateau, Mt Murchison and Elliott Bay (Fig. 2.2; Leaman & Richardson, 1989).

The MRV can be divided into four stratigraphic units: the Central Volcanic Complex, Eastern Quartz-Phyric Sequence, Western Volcano-Sedimentary Sequences and the Tyndall Group (Fig. 2.1; Corbett, 1992). To the east the MRV unconformably overlie Precambrian rocks of the Tyennan Region (Corbett & Turner, 1989). The MRV interfinger with Cambrian sedimentary sequences of the Dundas Group to the west and are unconformably overlain by the Cambro-Ordovician Owen Conglomerate (Corbett & Solomon, 1989). Geochemically, the volcanics of the MRV have been separated into five igneous suites: suites I-III with calc-alkaline to shoshonitic magmatic affinities, and suites IV and V with tholeiitic magma affinities (Crawford *et al.*, 1992). Age relationships for units within and overlying the MRV are tabulated in Table 2.1.

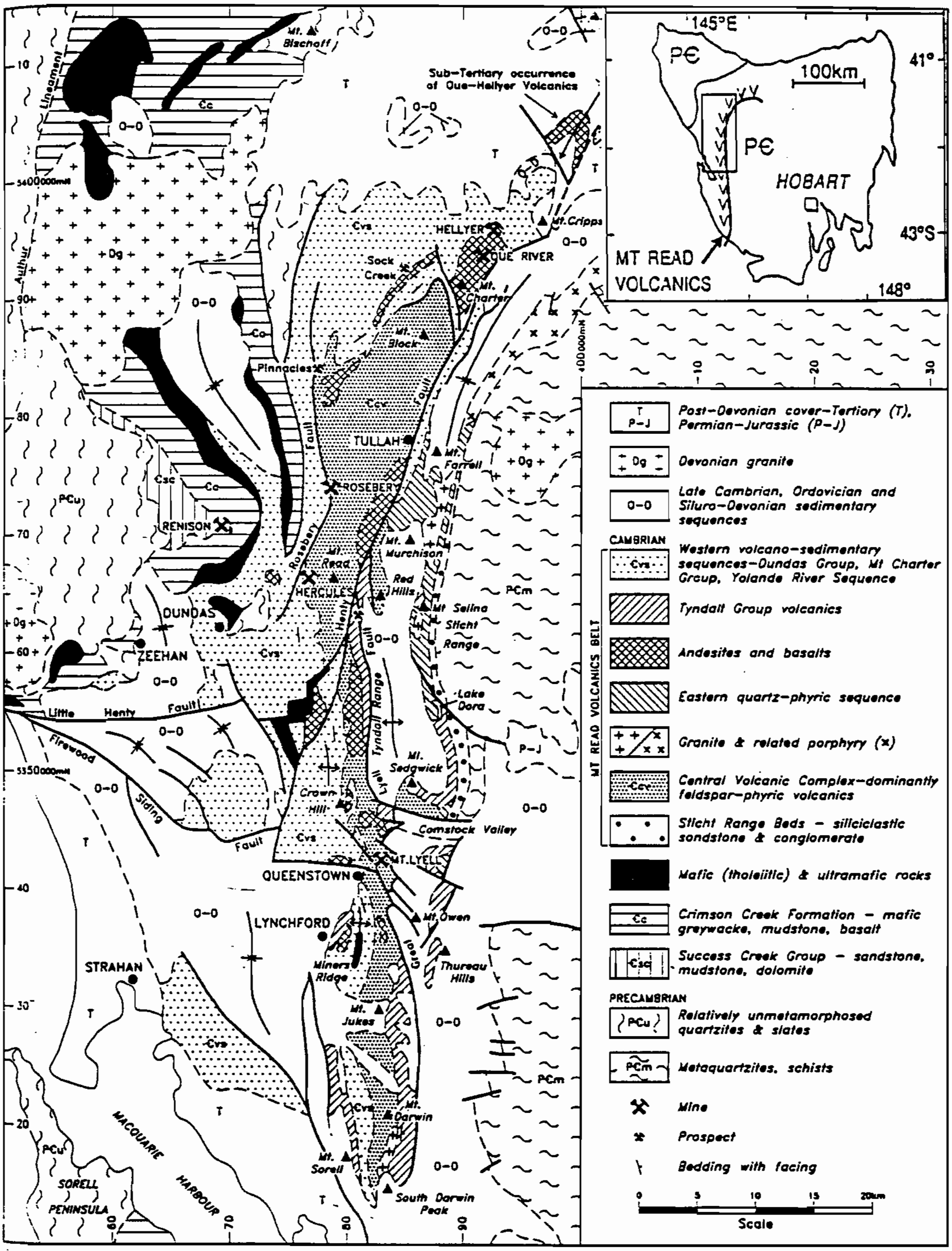


Figure 2.1: Major geological subdivisions across western Tasmania (modified after Corbett, 1992).

Table 2.1: Accepted ages for certain geological formations in the MRV and overlying sequences (after Jago *et al.*, 1972; Adams *et al.*, 1985).

Formation	Dating Method	Absolute Age (Ma)
Murchison Granite	U-Pb	498
Murchison Granite	K-Ar	524 ±15
Darwin Granite	U-Pb	510
Tyndall Group	Biostratigraphic Evidence	505 - 530
Owen Conglomerate	Biostratigraphic Evidence	480 - 510

2.1.1 *Central Volcanic Complex (CVC)*

The CVC is dominated by feldspar(±quartz)-phyric volcanics of rhyolitic, dacitic and andesitic composition, minor volcaniclastic and sedimentary units (Corbett & Solomon, 1989; Corbett *et al.*, 1993). Volcanics of the CVC are generally a distinctive pink-orange colour due to pervasive K-feldspar-chlorite-hematite-magnetite alteration (Pemberton & Corbett, 1992). Units of the CVC interdigitate to the west with the Western Volcano-Sedimentary Sequences, and to the east with the Eastern Quartz-Phyric Sequence (White, 1975; Corbett, 1992; Crawford *et al.*, 1992).

2.1.2 *Western Volcano-Sedimentary Sequences*

Due to major fault disruptions and difficulties with regional correlations, the Western Volcano-Sedimentary Sequences have been subdivided into the Dundas Group to the north of the Henty Fault, Yolande River Sequence to the south of the Henty Fault and the Mount Charter Group in the Hellyer area (Corbett, 1992). These sequences run along the western edge of the MRV belt and are dominated by sedimentary units containing Middle to Late Cambrian fossils and abundant volcanic detritus, volcaniclastic mass-flow deposits, quartz-phyric lavas and intrusive porphyries, with minor andesitic and basaltic lavas (Corbett & Solomon, 1989; Corbett, 1992).

2.1.3 *Eastern Quartz-Phyric Sequence*

Rock units of the Eastern Quartz-Phyric Sequence are composed of quartz-feldspar-phyric volcanics, volcaniclastics and porphyritic intrusives, along with mudstones and siltstones (Crawford *et al.*, 1992; Corbett *et al.*, 1993). The Murchison Granite intrudes the sequence at Mt Murchison (Crawford *et al.*, 1992). Regionally the sequence is recognised as overlying the Sticht Range Beds to the east and north of Mt Murchison, and has an interfingering to erosional relationship with the CVC (Corbett, 1992; Corbett *et al.*, 1993). The Eastern Quartz-Phyric Sequence is believed to be older than the Tyndall Group, although contact relationships are not consistent between localities (Corbett, 1992).

2.1.4 *Cambrian Granites of Tasmania*

Granitic rocks of Cambrian age crop out intermittently along the length of the MRV belt in western and northwestern Tasmania, with at least five separate bodies recognised: the Darwin Granite, Murchison Granite, Elliott Bay Granite, Dove Granite and Timbertops Granite (Fig. 2.2; Leaman & Richardson, 1989). Although the amount of Cambrian granite exposed in Tasmania is minor compared with the Devonian granites, they were nevertheless important, having possibly driven convection cells for some of the Cambrian VHMS deposits (Polya *et al.*, 1986; Large, 1989, 1992).

2.1.5 *Tyndall Group*

The Tyndall Group comprises a stratigraphically diverse range of dominantly quartz-phyric to quartz-feldspar-phyric clast-rich to clast-poor volcaniclastic units with minor volcanics, ignimbrite and mudstones (Pemberton & Corbett, 1992). This unit represents the final phase of volcanism in the Mount Read Volcanics (McPhie & Gemmell, 1992; Pemberton & Corbett, 1992). Trilobite fossils within a basal limestone unit at Comstock are indicative of a Middle-Late Cambrian age of deposition (Jago *et al.*, 1972). Units from the Eastern Quartz-Phyric Sequence are similar to those of the Tyndall Group, and volcaniclastic conglomerates within the two groups are indistinguishable (Pemberton & Corbett, 1992). The Tyndall Group unconformably overlies the CVC (White, 1975; Corbett, 1976, 1992).

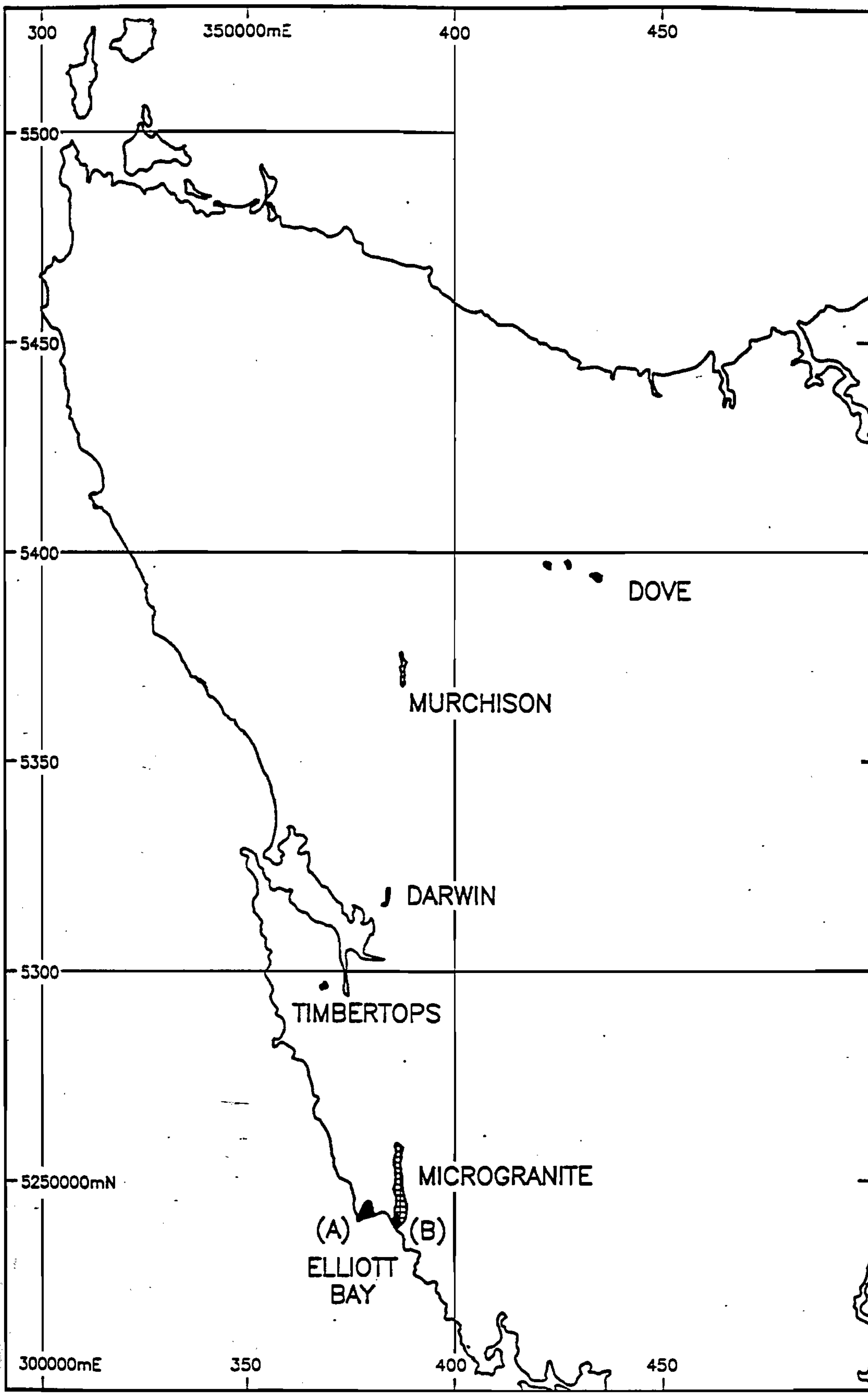


Figure 2.2: Outcrops of Cambrian granite across western and northwestern Tasmania (modified after Leaman & Richardson, 1989).

2.2 OWEN CONGLOMERATE (DENISON GROUP)

The Owen Conglomerate consists of resistant siliceous conglomerate, sandstone and siltstone units that display a distinctive purple hematitic colouring (Corbett & Turner, 1989). Detritus that formed the Owen Conglomerate was eroded following regional uplift associated with the Jukesian Orogeny, from the Precambrian Tyennan Region (Corbett & Solomon, 1989). Biostratigraphic evidence within units of the Owen Conglomerate (eg. presence of trilobites, gastropods, brachiopods, cystoids and merostome trails) are suggestive of a depositional age around the Late Cambrian-Early Ordovician in a marine environment (Banks & Baillie, 1989). The Owen Conglomerate unconformably overlies Cambrian and older rocks across much of western Tasmania, and caps many mountains in the region (Corbett & Turner, 1989).

2.3 REGIONAL STRUCTURE

Deformation throughout the Mid Cambrian-Early Ordovician resulted in the development of a Mid Cambrian unconformity, separating early MRV products from the Tyndall Group, and the Jukesian Unconformity, separating Cambrian MRV units from the overlying Owen Conglomerate (Banks & Baillie, 1989; Corbett & Solomon, 1989; Corbett & Turner, 1989). These unconformities are the result of major tectonic activity which also produced folding in N-S trending depositional features throughout the Dundas Trough (eg. the West Coast Range) along with significant faulting (Williams, 1979, 1989; Reid & Meares, 1981; Banks & Baillie, 1989).

Several major faults transect the MRV; the major structure is the NNE-SSW trending Henty Fault (Corbett, 1992). The Henty Fault is intersected by the N-S trending Great Lyell Fault to the north of Queenstown (Bottrill *et al.*, 1992). These faults are recognised as Cambrian structures which have been reactivated by later deformation events, such as the Tabberabberan Orogeny (Berry, 1989). Fault activity has included over 1km of reverse movement along the Great Lyell Fault through the earliest Ordovician, with faulting continuing during deposition of the Owen Conglomerate (Arnold & Fitzgerald, 1986; Berry, 1989).

While the Cambrian-Ordovician period was tectonically active, the major deformation event within the MRV is attributed to the Tabberabberan Orogeny, which overprinted or enhanced features of earlier deformation (Corbett & Brown, 1976; Williams, 1979). Seymour (1980) defined four separate Tabberabberan-related deformation events within northwestern Tasmania that produced regional scale folds along a E-W trend (D1), NE-SW trend (D2), N-S trend (D3) and a NW-SE trend (D4). Other workers (eg. Corbett & Brown, 1976; Williams, 1979) have separated features of the Tabberabberan Orogeny into two distinct deformation phases. The initial phase of Tabberabberan deformation, driven by NE-SW compression, developed NW-SE to WNW-ESE trending asymmetrical to symmetrical folds, faults and axial cleavage (Corbett & Brown, 1976; Williams, 1979). The final phase of Tabberabberan deformation, induced by E-W shortening, lead to Devonian granitoid intrusions and developed NW-SE trending folds and N-S to NW-SE dominated faulting (Williams, 1979; Corbett & Lees, 1987; Corbett & McNeill, 1988; Berry, 1989). Following the Tabberabberan Orogeny, the resultant major fault and thrust trend across the region is NW-SE (Berry & Keele, 1992).

Chapter 3.0 LOCAL GEOLOGY

3.1 INTRODUCTION

Units from four separate geological formations, the CVC, Darwin Granite, Tyndall Group and Owen Conglomerate, crop out in the Mt Darwin-South Darwin Peak region. This chapter deals specifically with the CVC, Tyndall Group and Owen Conglomerate; the Darwin Granite is dealt with separately in Chapter 4.0. A stratigraphic column incorporating all of the lithological subdivisions encountered in the study region is represented in Table 3.1, while Figure 3.1 shows the distribution of lithologies across the study region. Figure 3.3 is a depiction of the interpreted relationships which exist between the four formations in the region. A discussion of the characteristics of contact metamorphism within the CVC, and regional metamorphism across the study area is presented in section 3.5.

Table 3.1: Stratigraphic column listing the lithologies encountered across the Mount Darwin - South Darwin Peak area. The column lists lithologies from youngest to oldest except for in the CVC where age relationships are unclear.

FORMATION	LITHOLOGICAL SUBDIVISIONS
Owen Conglomerate	Conglomerates, quartz sandstones, siltstones
Tyndall Group	Feldspar-quartz-phyric dacite
	Volcaniclastic sandstone
	Polymictic lithic volcaniclastic sandstone
	Volcaniclastic lithic conglomerate
	Basal conglomerate
Darwin Granite	Granodiorite
	Equigranular granite
Central Volcanic Complex (CVC)	Volcaniclastic sandstone
	Quartz-feldspar-phyric rhyolite
	Feldspar-quartz-phyric rhyolite

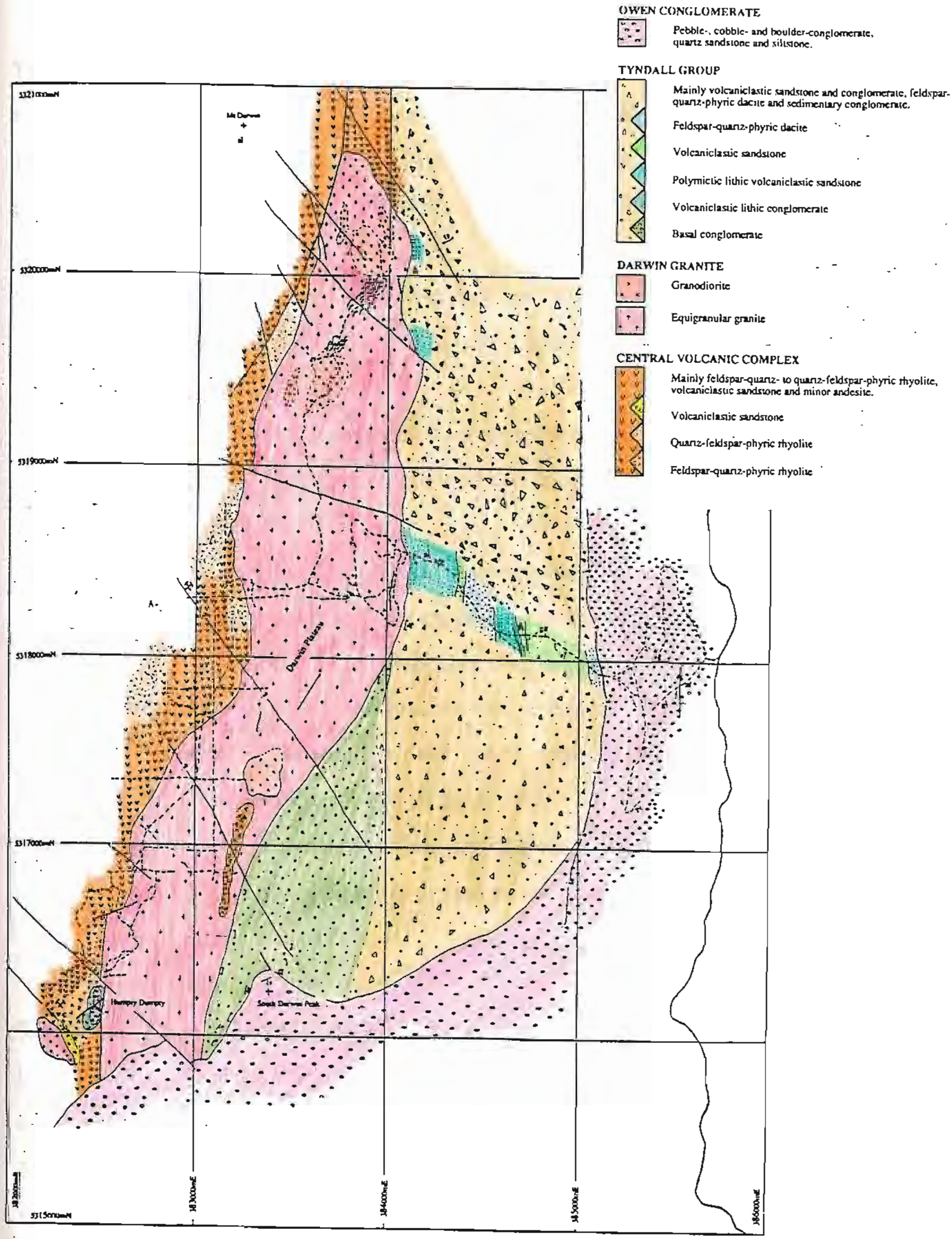


Figure 3.1: Distribution of the CVC, Darwin Granite, Tyndall Group and Owen Conglomerate in the Mount Darwin - South Darwin Peak area.

3.1.1 *Terminology*

Terms used for the classification of volcanic and sedimentary units within this chapter have been drawn from several sources (eg. Blatt *et al.*, 1972; Cas & Wright, 1987; McPhie *et al.*, 1992a,b). Classifications of particle grainsize and roundness follow the method of Pettijohn (1957). Definitions for several of the main terms used throughout this chapter are given below.

<u>Volcaniclastic</u> - a rock or deposit composed predominantly of particles derived from volcanic processes irrespective of origin (Cas & Wright, 1987; McPhie *et al.*, 1992a).

<u>Pyroclastic</u> - a rock or deposit composed predominantly of particles derived from explosive processes at a volcanic vent and deposited in result of these processes (Cas & Wright, 1987).

<u>Debris Flow</u> - poorly sorted matrix- to clast-supported deposits of massive to graded structure deposited via sediment gravity flow processes (McPhie *et al.*, 1992a).

<u>Dacite-Rhyolite</u> - coherent acid volcanic rocks characterised by modal compositions of plagioclase > K-feldspar (dacite) and K-feldspar > plagioclase (rhyolite). Phenocrysts of quartz and feldspar can be present in hand specimens, and flow banded texture is common (Middlemost, 1988).

<u>Conglomerate</u> - coarse grained sedimentary rock composed of dominantly subangular-rounded fragments set in a finer grained matrix. Clast size can vary from granule to boulder (Blatt *et al.*, 1972).

3.2 CENTRAL VOLCANIC COMPLEX (CVC)

Units of the CVC dominate the topography within the study area, forming the exposed ridge of the West Coast Range from Mt Darwin along the western edge of the Darwin Plateau (Fig. 3.1). Lavas and volcaniclastic units of the CVC are generally a distinct pink-orange colour due to regional scale K-feldspar alteration; grey pervasively chlorite altered units are also present. The CVC is composed predominantly of coherent volcanic units, with volcaniclastic sandstone observed west of Humpty Dumpty (Fig. 3.1). Rhyolites dominate the CVC across the study area; andesites are only recognisable via geochemical analyses due to intense chlorite-sericite alteration. Autobrecciated rhyolites are observed north of Mt Darwin. The CVC is intruded by the Cambrian Darwin Granite (on the Darwin Plateau and west of Humpty Dumpty) and is unconformably overlain by basal conglomerate correlated with the Tyndall Group on Humpty Dumpty (Fig. 3.1). A raft of CVC occurs within the Darwin Granite on the southern Darwin Plateau (Fig. 3.1). The CVC is separated from the Tyndall Group at the northern end of the Darwin Plateau by a major N-S trending dextral fault (Fig. 3.1). Flow banding has been observed within individual volcanic units although an intense spaced cleavage typically obscures primary features. In addition to regional scale K-feldspar and chlorite-sericite alteration, the CVC hosts magnetite, tourmaline and quartz veins within the study area (Chapter 6.0).

Coherent volcanic units of the CVC vary from feldspar-quartz-phyric to quartz-feldspar-phyric lavas. It has not been possible to map individual units over continuous distances, so relative abundances of individual facies could not be accurately established. Units of feldspar-quartz-phyric rhyolite are differentiated from quartz-feldspar-phyric rhyolite on the basis of phenocryst size and relative proportions of quartz to feldspar phenocrysts. Only units that obviously contain quartz in excess of feldspar are defined as quartz-feldspar-phyric. Feldspar-dominated lavas and those with similar proportions of both phenocryst types are grouped as feldspar-quartz-phyric rhyolite.

Volcanic units of the CVC are generally fine grained, altered and (locally) intensely deformed, making accurate petrographic classifications difficult. Strongly deformed schistose regions defined by elongate recrystallised quartz bands and chlorite domains are common; quartz-feldspar-chlorite and sericite comprise the dominant alteration assemblage outside the more intensely deformed zones.

3.2.1 *Feldspar-quartz-phyric rhyolite*

Feldspar-quartz-phyric rhyolites are predominant within the CVC across the Mt Darwin-South

Darwin Peak region (78335). At many localities, only fine feldspar crystals (0.5 to 2mm) and very fine quartz eyes (< 0.5mm) can be recognised within an aphanitic groundmass. These units have suffered regional-scale K-feldspar alteration and have a distinctive pink-orange colour (Plate 3.1). Feldspar and quartz phenocrysts comprise no more than 15% of the rock, and at some localities comprise as little as 3% of the total rock. Proportions of K-feldspar and quartz phenocrysts vary widely, with K-feldspar commonly comprising between 45 to 65% of the total phenocryst content. K-feldspar phenocrysts are commonly weathered and chloritised and range in size up to 2mm. K-feldspar crystals are commonly pseudomorphed by fine grained chlorite and have resorbed grain boundaries. Carlsbad twinning is common and wispy extinction suggests strain. Quartz phenocrysts are generally larger than K-feldspar phenocrysts ranging from < 0.4mm to 2.5mm in size. Quartz grains have euhedral to embayed shapes and are commonly recrystallised. In thin section, quartz crystals display strong undulose extinction, and in some cases recrystallisation has obscured primary features. The groundmass is quartz-rich and typically recrystallised, with fine chloritised feldspars and acicular chlorite crystals locally common within the groundmass. One whole rock geochemical analysis was obtained from a feldspar-quartz-phyric rhyolite (Table 7.1).

3.2.2 *Quartz-feldspar-phyric rhyolite*

Coherent units of quartz-feldspar-phyric rhyolite represent the smallest proportion of CVC rhyolites within the study area. Phenocrysts of quartz, feldspar and minor biotite are locally common, comprising 15 to 25% of the total rock (78336). Quartz-feldspar-phyric rhyolites are hypocrystalline, with phenocrysts varying from (0.5mm to 3mm) in diameter set in a microcrystalline quartz-feldspar-phyric groundmass. Quartz is the dominant phenocryst (up to 60%), varying locally from euhedral to resorbed, and is commonly recrystallised in the more deformed units. K-feldspar phenocrysts (40%) show wispy extinction, suggesting post-depositional strain. Carlsbad twinning is preserved, although crystal boundaries are commonly serrated and individual feldspar crystals are intensely chloritised. Where present, biotite has invariably suffered intense chloritisation+minor sericitisation. In the groundmass, spherulitic textures are defined by chlorite and minor sericite. Fine (< 0.5mm) crystals of magnetite and hematite are disseminated throughout the groundmass, which is typically coarsely recrystallised.

3.2.3 *Volcaniclastic sandstone*

Volcaniclastic sandstone crops out within the CVC west of Humpty Dumpty (Fig. 3.1). This unit is distinct from the volcanic units, having a cream-coloured groundmass in contrast to the dominant pink colour that characterises the majority of the CVC (Plate 3.2; 78340). The volcaniclastic sandstone contains 10 to 20% crystals composed of quartz (35 to 45%), strongly chloritised glass fragments (45 to 55%) and minor feldspar (5 to 10%; Plate 3.2). Euhedral to subhedral quartz crystals are up to 4mm in diameter, and triangular to cuspate glass fragments (possible pyroclastic origin) range up to 2mm in diameter. Glass shards are mostly oriented parallel to the pervasive tectonic cleavage. The sandstone is well sorted, with quartz crystals and glass shards confined to discrete zones within a fine to medium grained sandy matrix. Layers rich in quartz crystals and glass shards are repetitive and semi-parallel, and are separated by 1 to 2cm of sandstone. They may represent crude primary bedding structures.

3.2.4 *Volcanic Setting*

The CVC within the study area is dominated by coherent rhyolite lavas, with subordinate volcaniclastic sandstones. Presence of flow banding in rhyolites, lack of quenching and hyaloclastite textures suggest that volcanism may have occurred within a subaerial environment. Although no volcanic centres are recognisable, the felsic nature of the volcanics suggests that the primary source is likely to have been proximal (Cas & Wright, 1987).

3.3 TYNDALL GROUP

The Tyndall Group was first defined by Corbett *et al.* (1974) near Queenstown, as a Late Cambrian sequence of volcanic and sedimentary rocks. The base of the Tyndall Group is marked by clast-rich volcaniclastic units (Plate 3.3, 3.4), and the top of the group is defined by the contact with the Owen Conglomerate (McNeill & Corbett, 1992). The Tyndall Group is recognised as the last phase of MRV volcanism and lies mostly unconformable on other MRV units (Corbett, 1992). Corbett *et al.* (1993) included the sequence northeast of the Darwin Granite as part of the Eastern Quartz-Phyric Sequence based on a contact metamorphic aureole developed along the contact with the granite (Corbett *et al.*, 1993). Within the study area, the sequence to the east of the Darwin Granite consists of basal conglomerate (Plate 3.3), volcaniclastic lithic conglomerate (Plate 3.6), polymictic lithic volcaniclastic sandstone (Plate 3.4), volcaniclastic sandstone and feldspar-quartz-phyric dacites (Plate 3.5) correlated with the Tyndall Group. The Tyndall Group in the study area rests unconformably upon the Darwin Granite and grading in the basal conglomerate indicates younging to the east. On South Darwin Peak and Humpty Dumpty the Tyndall Group is unconformably overlain by cobble- to boulder-conglomerates of the Owen Conglomerate (Plate 3.6). A stratigraphic section through the Tyndall Group along the access track to the Darwin Plateau is shown in Figure 3.2.

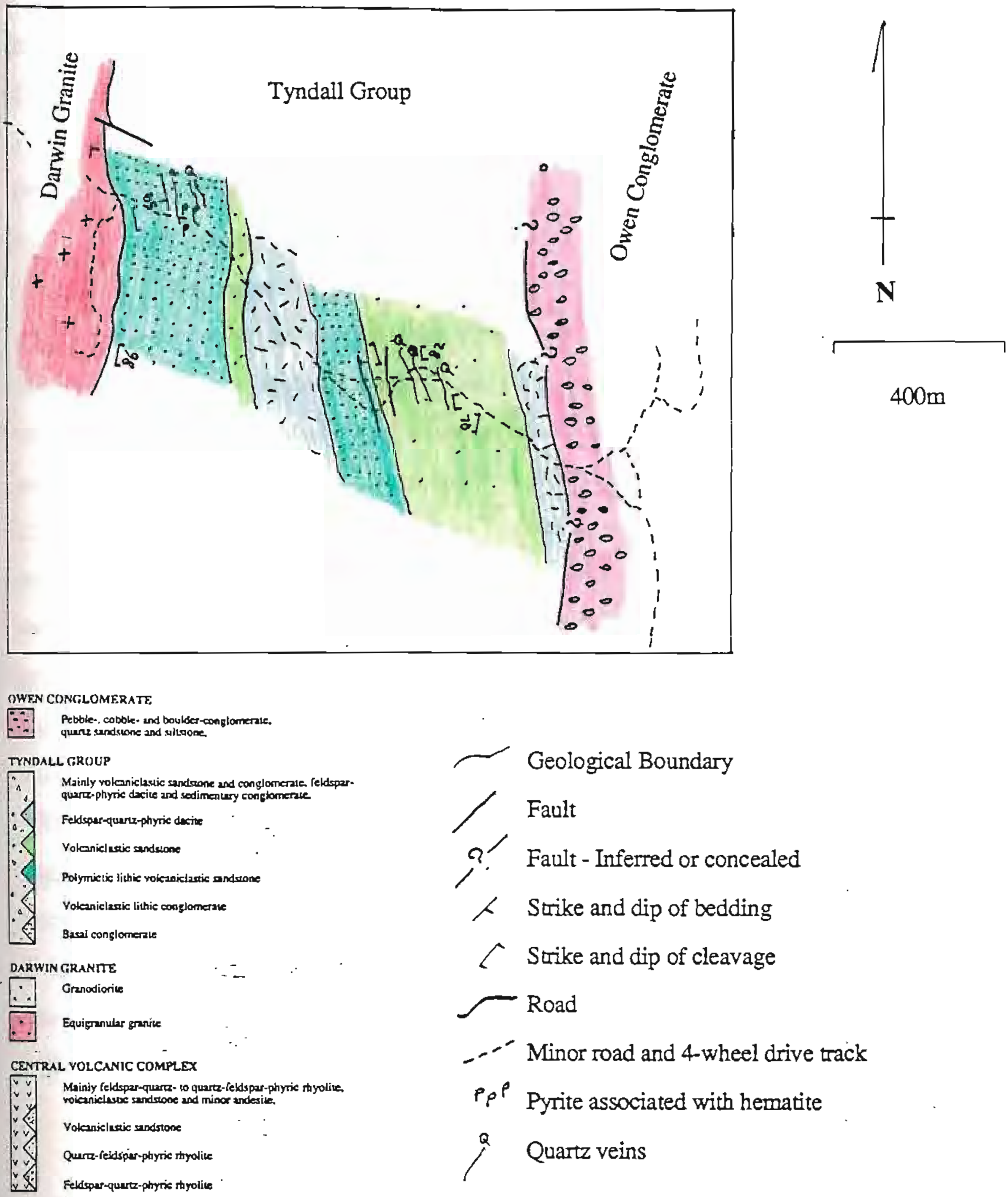


Figure 3.2: Section through the Tyndall Group along the access track to the Darwin Plateau from the Kelly Basin Road.

3.3.1 *Basal conglomerate*

Basal conglomerate (Plate 3.3) crops out in the vicinity of South Darwin Peak (Fig. 3.1). On South Darwin Peak, basal conglomerate is overlain unconformably by the Owen Conglomerate. To the northeast, the basal conglomerate is overlain by younger units of the Tyndall Group (Fig. 3.1). The top of the basal conglomerate on South Darwin Peak is marked by basal scouring where it is overlain by Owen Conglomerate. The conglomerate is well graded, and ranges from clast-supported (up to 90% clasts) at the contact with the Darwin Granite (Plate 3.3) to matrix-supported (up to 85% matrix) higher in the stratigraphy. The matrix-supported facies is predominant, with clast-supported basal conglomerate confined to the contact region with the Darwin Granite. Matrix is composed of coarse quartz-rich sandstone, derived from reworking of granitic clasts, pervasively altered to silica-sericite-chlorite assemblages. The clast-rich facies is massive and varies from 10-60m in width. Clasts are subangular to rounded, cobbles and boulders of granite and felsic volcanics. The largest known granite-derived clast is 30cm in diameter. Both clast types (granitic and felsic volcanic) are typically present, although granitic clasts dominate the unit. Minor quartz and magnetite clasts, possibly vein fragments, are present locally. Clasts are poorly sorted, with boulders randomly interspersed within dominant cobbles. Foliated volcanic clasts thought to be derived from the CVC occur within this unit northeast of South Darwin Peak. Foliation orientation is varied, suggesting formation pre-Tyndall Group deposition. Granitic clasts are sourced from the Darwin Granite, based on textural similarities, whereas the source of volcanic clasts is thought to have been the CVC. The subangular to rounded nature, variation between cobble-boulder size, grading from clast supported to matrix supported, and interspersal of felsic volcanic clasts within the unit indicates that the basal conglomerate has been redeposited.

3.3.2 *Volcaniclastic lithic conglomerate*

Volcaniclastic lithic conglomerate is restricted within the study area to the lower summit of Humpty Dumpty (Fig. 3.1). The volcaniclastic lithic conglomerate can be distinguished from the basal conglomerate by clast composition and stratigraphic position, with the lithic conglomerate composed of felsic volcanic derived clasts with subordinate quartzite and granite clasts. Volcaniclastic lithic conglomerate overlies rhyolites of the CVC above an eroded contact, seen on the lower northern slope of Humpty Dumpty, and is itself overlain unconformably by siliciclastic conglomerates of the Owen Conglomerate (Plate 3.6). Clasts vary between cobble-boulder size (up to 45cm diameter) with an overall boulder size dominant throughout the unit. Felsic volcanic clasts are subangular to subrounded; quartzite clasts range from subrounded to rounded. The volcaniclastic lithic conglomerate is clast-supported (75 to 90% clasts) with a matrix of coarse quartz-rich sandstone, and is strongly silicified. Randomly oriented clasts of foliated felsic volcanics occur on Humpty Dumpty, indicative of a pre-depositional deformation event. Although geochemical analyses have not been undertaken to test the composition of the felsic volcanic clasts, they are likely to be derived from the underlying CVC.

3.3.3 *Polymictic lithic volcaniclastic sandstone*

Units of polymictic lithic volcaniclastic sandstone crop out along the access track to the Darwin Plateau east of the contact between the Darwin Granite and the Tyndall Group (Fig. 3.1). The unit is matrix-supported and polymictic, containing elongate subangular to rounded felsic volcanic clasts (up to 10cm diameter), rounded granite clasts (up to 5cm diameter), rounded quartzite clasts (up to 5cm diameter), and minor clasts of siltstone and chert (Plate 3.4; 78346). Felsic volcanic fragments are dominant, locally constituting up to 40% of the rock. The unit is poorly sorted and typically thinly bedded (3cm to <100cm), with abrupt changes in size and proportion of clasts between and within beds. Low angle cross bedding is common. Matrix is composed of sand to mud sized grains dominated by quartz and feldspar. Bedding is oriented NNW (as determined from thin siltstone interbeds), parallel to the pervasive foliation and predominant clast orientation. Chlorite-sericite alteration is typically present and varies from incipient to pervasive. Weak silicification also occurs, and rare red jasperitic alteration of matrix material has been noted. Fine grained pyrite clusters occur over a 15m interval within this unit along the access track to the Darwin Plateau (Fig. 3.2; Plate 6.2; 78345). The pyrite appears to be related to hematite veining, occurring in a halo around a vein at one locality.

3.3.4 *Volcaniclastic sandstone*

Two separate massive units of volcaniclastic sandstone occur within the Tyndall Group east of the Darwin Plateau (Fig. 3.2). These sandstones contain volcanic-derived quartz and feldspar crystals throughout (10 to 30%), along with minor clasts of granite, quartz-feldspar-phyric volcanics and elongate, chlorite-altered, quartz-feldspar-phyric clasts (possibly flattened pumice). Curved to triangular chlorite-altered fragments occur throughout this unit and are possibly either glass shards from quenched volcanics or from a pyroclastic source. Clasts vary in abundance throughout the volcaniclastic sandstones (5 to 15%) but are typically only a minor component. Quartz and feldspar crystals vary in size from less than 1mm to 2mm and are subhedral-euhedral. Thin bedding structures (1 to 2cm) are present locally, but overall the units are massive and poorly sorted. The matrix is composed predominantly of fine grained reworked volcanic detritus. Volcaniclastic sandstone units are a light grey to pale green colour throughout. Sericitisation is the predominant alteration style within these units.

The two volcaniclastic sandstone units are distinctive markers within the Tyndall Group, and are separated from each other within the stratigraphy by units of polymictic lithic volcaniclastic sandstone and feldspar-quartz-phyric dacite (Fig. 3.2). Volcaniclastic sandstone units are overlain by feldspar-quartz-phyric dacite units (Table 3.1). The presence of possible pumice and glass shards indicates a pyroclastic component for some of the volcanic detritus. Post-depositional deformation has resulted in a pervasive NW-trending foliation throughout the volcaniclastic sandstones.

3.3.5 *Feldspar-quartz-phyric dacite*

Two massive coherent dacites crop out within the Tyndall Group along the access track to the Darwin Plateau (Figure 3.2). The dacites have true thicknesses of 20 to 50m, and are porphyritic (15 to 25% phenocrysts), with quartz and feldspar phenocrysts (up to 2mm) set within a hypocrystalline groundmass (Plate 3.5). In thin section, the phenocrysts can be seen to be comprised of approximately 45% plagioclase, 25% quartz, 25% K-feldspar and 5% biotite + magnetite (78343). The relative abundances of quartz and K-feldspar vary by up to

10% between units. Groundmass is composed of fine grained quartz and feldspar with minor glass and locally abundant magnetite and secondary hematite. Phenocrysts of plagioclase are predominantly euhedral and partially resorbed. Albite twinning is a common feature. Quartz phenocrysts are the largest phenocrysts (1 to 2mm) within the dacites and are invariably embayed and unaltered (Plate 3.5). Quartz has commonly been recrystallised during deformation. Angular K-feldspar phenocrysts are smaller than quartz or plagioclase (<1mm) and have cuspate borders. Subhedral biotite grains are invariably partially to totally chloritised. Monazite occurs as an accessory phase as inclusions within magnetite. Secondary hematite forms partial pseudomorphs after plagioclase phenocrysts although sericite-chlorite alteration of feldspars is more common (particularly along fractures). Euhedral zircons are present as minor inclusions in feldspar.

The dacites typically have a pink colour due to pervasive K-feldspar alteration, although incipient chlorite alteration has produced some light green coloured domains. Both units are feldspar-quartz-phyric, and on petrographic and geochemical grounds (Chapter 7.0) can be classified as feldspar-quartz-phyric massive dacites.

3.3.6 *Depositional Setting*

A proposed depositional setting for the Tyndall Group must be capable of explaining the characteristics of the diverse range of lithologies present. Within the basal conglomerate, the dominance of cobble-boulder clasts from nearby sources (eg. Darwin Granite and possibly CVC volcanics) and the poor sorting suggests that the unit formed from redeposition of material derived from erosional processes and has undergone only minimal transport and reworking. The Darwin Granite and CVC are interpreted to have been partially exposed within a Late Cambrian depositional basin, thus explaining deposition in contact with source material. Grading from clast- to matrix-supported in the granitic conglomerate represents a transition from minimal to highly reworked material.

The polymictic lithic volcaniclastic sandstone unit contains material of extrusive, intrusive, sedimentary and possibly pyroclastic sources. On the basis of the diverse clast types, poor sorting and weakly defined bedding, the unit is thought to have been redeposited predominantly by mass-flow processes. Abundant angular felsic volcanic clasts were probably derived from a proximal source, due to their minimal reworking.

In general, silicic lava flows do not extend large distances from their vent (McPhie *et al.*, 1992b). Therefore it is most likely that the volcanic centre for the feldspar-phyric dacites is intrabasinal, and was probably no more than a few kilometres away from the study area (even though no volcanic centre has been recognised in the vicinity). Evidence for subaqueous deposition (eg. quenching and/or hyaloclastite) has not been observed in the field area, although deformation and limited outcrop may have obscured them.

The massive volcaniclastic sandstones contain quartz and feldspar crystals, possible pumice and glass shards, dominantly of pyroclastic origin. It is interpreted that these materials have been explosively erupted at the same time, or in close association with lava extrusion and were then redeposited into the nearby depositional basin via mass-flow processes. Massive crystal-bearing volcaniclastic sandstones are a common lithofacies within the Tyndall Group across the MRV, and are considered to have been transported and redeposited by high-density turbidity currents in a subaqueous below wave-base setting (White *et al.*, 1993).

It appears during Tyndall Group times, that the study area represented a depositional setting wherein extrusive and explosive volcanism were occurring nearby, forming pyroclastic and extrusive volcanic products. Intrabasinal sedimentary material was generated via erosion and mass flow processes which washed detritus into the basin where the Tyndall Group was depositing.

3.4 OWEN CONGLOMERATE

The siliciclastic Owen Conglomerate is the youngest unit in the Mt Darwin - South Darwin Peak region (Table 3.1). It crops out at three localities: South Darwin Peak, Humpty Dumpty and east of the Tyndall Group (Fig. 3.1). The Owen Conglomerate is typically a distinct pink to dark purple colour, except for thin grey-green siltstone units. Boulder-, cobble-, and pebble-conglomerates, quartz sandstones and minor siltstones are the characteristic facies. The conglomerates are composed of subrounded-rounded, white to pink coloured quartzite clasts ranging in size from 2 to 20cm set in a medium to coarse grained siliceous matrix.

Boulder conglomerate crops out on the summit of Humpty Dumpty, where it overlies an erosional surface marked by basal scouring in volcaniclastic lithic conglomerate of the Tyndall Group (Plate 3.6). Across South Darwin Peak, the Owen Conglomerate consists of thickly bedded pebble-cobble conglomerate with a purple sandy matrix interbedded with cross-bedded quartz sandstones. East of the Darwin Plateau, on the margin of the study area (Fig. 3.1), the Owen Conglomerate is dominated by quartz sandstone, with minor pebble-conglomerate and siltstone units. Pebble sized clasts of siltstone are recognised here, but are subordinate to quartzite clasts. Low angle cross-bedding is observed east of the Darwin Plateau, where the units are more thinly interbedded than those on South Darwin Peak and Humpty Dumpty. Bedding generally strikes N-S to NNW-SSE, parallel to the dominant structural trend. The contact between feldspar-quartz-phyric dacite of the Tyndall Group and quartz sandstones of the Owen Conglomerate to the east of the Darwin Plateau, can only be reconciled to within two metres due to deep weathering. However, the absence of basal boulder- to cobble-conglomerates which are observed on both South Darwin Peak and Humpty Dumpty suggests that a faulted contact exists between Tyndall Group and Owen Conglomerate at this locality (Fig. 3.2).

3.4.1 *Depositional Setting*

The Owen Conglomerate is dominated by pebble-boulder conglomerates and coarse quartz sandstones. Clasts are generally well rounded, and comprised mainly of quartzite clasts.

Cobble-boulder conglomerates are characteristic of basal units on South Darwin Peak and Humpty Dumpty. To the east of the Darwin Plateau, the section of Owen Conglomerate is thought to represent stratigraphically higher units, suggesting that the Owen Conglomerate initially graded from coarse basal conglomerates to more mature sandstones and siltstones. The nature of the Owen Conglomerate in the study area combined with widespread fossil evidence (eg. brachiopods, trilobites, gastropods, cystoids, merostome trails) elsewhere in the MRV (Banks & Baillie, 1989) are indicative of deposition upon alluvial fans in a shallow marine environment.

Plate 3.1: Feldspar-quartz-phyric rhyolite of the CVC. Note the well developed foliation developed by regional scale deformation processes.

Plate 3.2: Volcaniclastic sandstone of the CVC. This rock has abundant volcanic quartz crystals and chloritised glass shards in a fine grained sandy matrix.

Plate 3.3: Basal conglomerate of the Tyndall Group. Basal conglomerate is restricted to the South Darwin Peak area. The unit is dominated by pebble to boulder size, angular to rounded granite clasts with lesser volcanic derived clasts.

Plate 3.4: Polymictic lithic volcaniclastic sandstone of the Tyndall Group. This unit contains volcanic, chert, quartzite and sedimentary clasts. Bedding varies throughout the unit, thinly bedded this sample, and chlorite alteration of matrix is locally intense.

Plate 3.5: Micrograph view of feldspar-quartz-phyric dacite of the Tyndall Group. Two massive dacites outcrop along the access track to the Darwin Plateau and are characterised by a porphyritic texture of euhedral to embayed quartz and euhedral to subhedral plagioclase. (Cross polars; field of view 5mm).

Plate 3.6: Unconformable contact between volcaniclastic lithic conglomerate of the Tyndall Group and overlying siliciclastic conglomerates of the Owen Conglomerate. This contact is exposed on the northern rise to Humpty Dumpty.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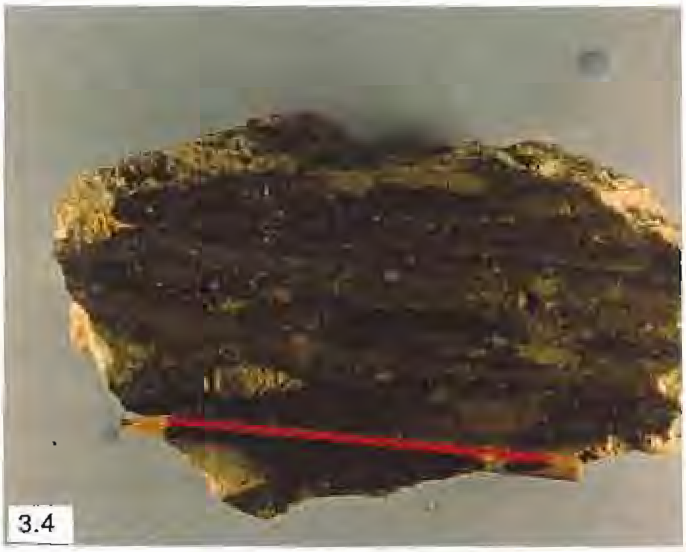
3.4

3.5

3.6

3.5 METAMORPHISM

3.5.1 *Contact Metamorphism*

A biotite-grade contact metamorphic aureole is developed within the CVC adjacent to the Darwin Granite. Biotite is locally abundant, comprising in excess of 40% of the hornfels. Contact metamorphic mineral assemblages are composed of quartz-feldspar-biotite which corresponds with the quartz-albite-epidote hornfels facies of contact metamorphism (Turner & Verhoogen, 1960). Surface weathering has destroyed most of the biotite, leaving residual unconsolidated clay along the CVC / granite contact. Temperatures probably ranged between 300°C and 500°C in the vicinity of the granite contact (Turner & Verhoogen, 1960).

The effects of contact metamorphism within the CVC are only noted adjacent to the granite contact. Away from the contact, the metamorphic effects are probably minor due to the chemical composition of the CVC. Units of the CVC are quartz- and K-feldspar dominated, and contact metamorphism of these rocks would most likely only recrystallise these two minerals, unless significant amounts of other components (such as volcanic glass or mafic minerals) were present. Local silica flooding is noted in the contact aureole. It is probably related to expulsion of magmatic-hydrothermal fluids during granite crystallisation.

3.5.2 *Regional Metamorphism*

Greenschist facies metamorphism has accompanied deformation during the Tabberabberan Orogeny in the Devonian. A prominent spaced cleavage has been developed in the volcaniclastic units that is defined by chlorite and sericite (Chapter 5.0). Chlorite-sericite assemblages are also particularly well developed adjacent to shear zones. Apart from obvious structural controls, it is difficult to discriminate between Cambrian hydrothermal chlorite-sericite alteration in the field area and the effects of greenschist facies metamorphism.

3.6 CONTACT RELATIONSHIPS

Figure 3.3 shows the interpreted lithological relationships within the Mt Darwin-South Darwin Peak area. From field observations, it is concluded that the CVC has been intruded by the Darwin Granite. Evidence includes the presence of an elongate raft of CVC within the granite at the southern end of the Darwin Plateau, and the presence of a granite dyke within the CVC to the west of Humpty Dumpty (Fig. 3.1). Tourmaline veins that radiate out to the west from the granite also cut the CVC. Evidence of contact metamorphism within the CVC surrounding the granite is further support for an intrusive relationship.

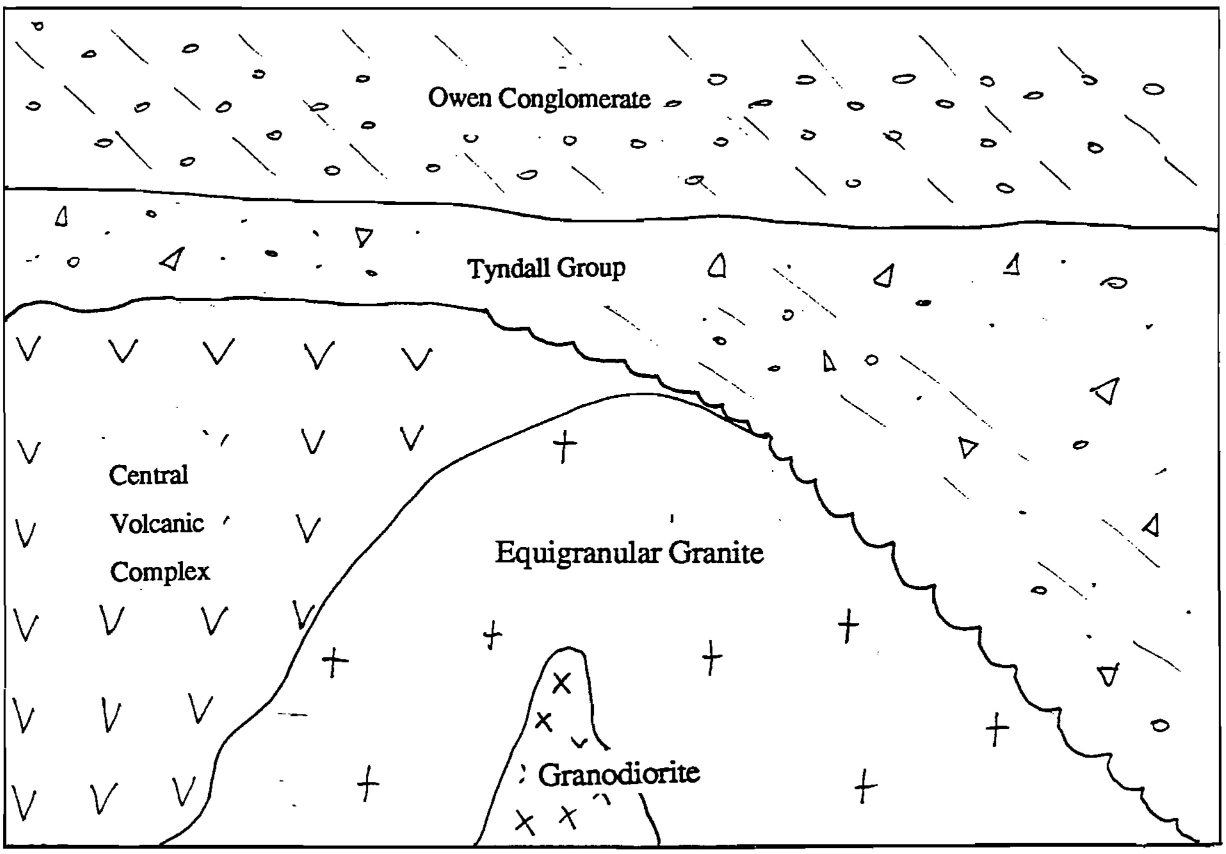

Figure 3.3: Interpreted relationships between stratigraphies in the Mt Darwin-South Darwin Peak area.

The Darwin Granite and the CVC are unconformably overlain by the Tyndall Group. This erosional break is interpreted from the presence of granite and felsic volcanic clasts within basal units of the Tyndall Group at South Darwin Peak, and to the east of the Darwin Plateau. The contact between the Tyndall Group and the Owen Conglomerate on South Darwin Peak is an angular unconformity, with the Tyndall Group dipping steeply to the west and the Owen Conglomerate dipping shallowly to the southeast. An unconformable contact between these units is also recognised on Humpty Dumpty, although the angular discordance is less. The contact between the Tyndall Group and Owen Conglomerate on the eastern side of the field area was not observed due to poor outcrop, but the absence of cobble-boulder conglomerates in the Owen Conglomerate suggests that the contact is fault-controlled.

3.7 DISCUSSION

A variety of lithologies are exposed in the study area. The CVC is dominated by rhyolitic lavas with minor volcaniclastics. The Darwin Granite (Chapter 4.0) is a coarse grained intrusive body. The Tyndall Group is dominated by volcaniclastic units with lesser volcanics, and the Owen Conglomerate is a siliciclastic sedimentary formation.

The erosional unconformity between the Darwin Granite and the Tyndall Group represents a significant hiatus in the development of the MRV. During the period between emplacement of the granite and deposition of the Tyndall Group, the Darwin Granite has been uplifted and eventually unroofed, allowing incorporation of granitic clasts into the basal Tyndall Group. Based on the radiometric age determined for the Darwin Granite (510Ma; Adams *et al.*, 1985), felsic volcanism and sedimentation formed the Tyndall Group in the Late Cambrian-Early Ordovician. The transition from volcanic-dominated to siliciclastic environments (in the Early Ordovician) represents an important change in provenance and cessation of MRV volcanism. Quartzite clasts similar to those which dominate the Owen Conglomerate are present in minor quantities throughout the Tyndall Group within the study area, suggesting that the source of detritus which forms the Owen Conglomerate was exposed to erosion well before the major influx of siliciclastic material. The major influx of transported sedimentary material to form the Owen Conglomerate must have been triggered by an episode of uplift and erosion in the Early Ordovician (Corbett & Solomon, 1989). Therefore, on stratigraphic grounds, two major deformational events are inferred within the field area in the Mid-Late Cambrian (pre-Tyndall Group) and Late Cambrian-Early Ordovician (pre-Owen Conglomerate).

Chapter 4.0 DARWIN GRANITE

Two separate bodies comprise the Darwin Granite, which crops out between Mt Darwin and South Darwin Peak (Fig. 3.1). The larger is approximately 5km long and up to 1km wide, extending in a N-S direction across the Darwin Plateau. The second body crops out west of Humpty Dumpty and has an exposed surface area less than 120m x 50m (Fig. 3.1). The smaller granite body appears to be a dyke. The dominant phase in the Darwin Granite is a homogeneous equigranular pink/green granite. Minor stocks of granodiorite and microgranite are also present. Structurally the granite contains distinct joint sets, and deformation has resulted in numerous N-S trending shear zones, some of which have reactivated older joint surfaces (Chapter 5.0).

Several theories have been proposed concerning the genesis of the Darwin Granite (eg. Solomon, 1960; Crawford, 1987; Corbett & Solomon, 1989). Geochemical analysis is required to judge the strengths of these hypotheses in result of which they are discussed in Chapter 7.0.

4.1 GEOLOGY AND PETROLOGY

The three phases recognised within the Darwin Granite are all classifiable as granitic using modal classification criteria for igneous rocks (Fig. 4.1; Streckeisen, 1974). They are classified, in order of abundance as:

1. Equigranular granite
2. Granodiorite
3. Microgranite.

The equigranular granite and granodiorite have also been classified on geochemical criteria (Chapter 5.0).

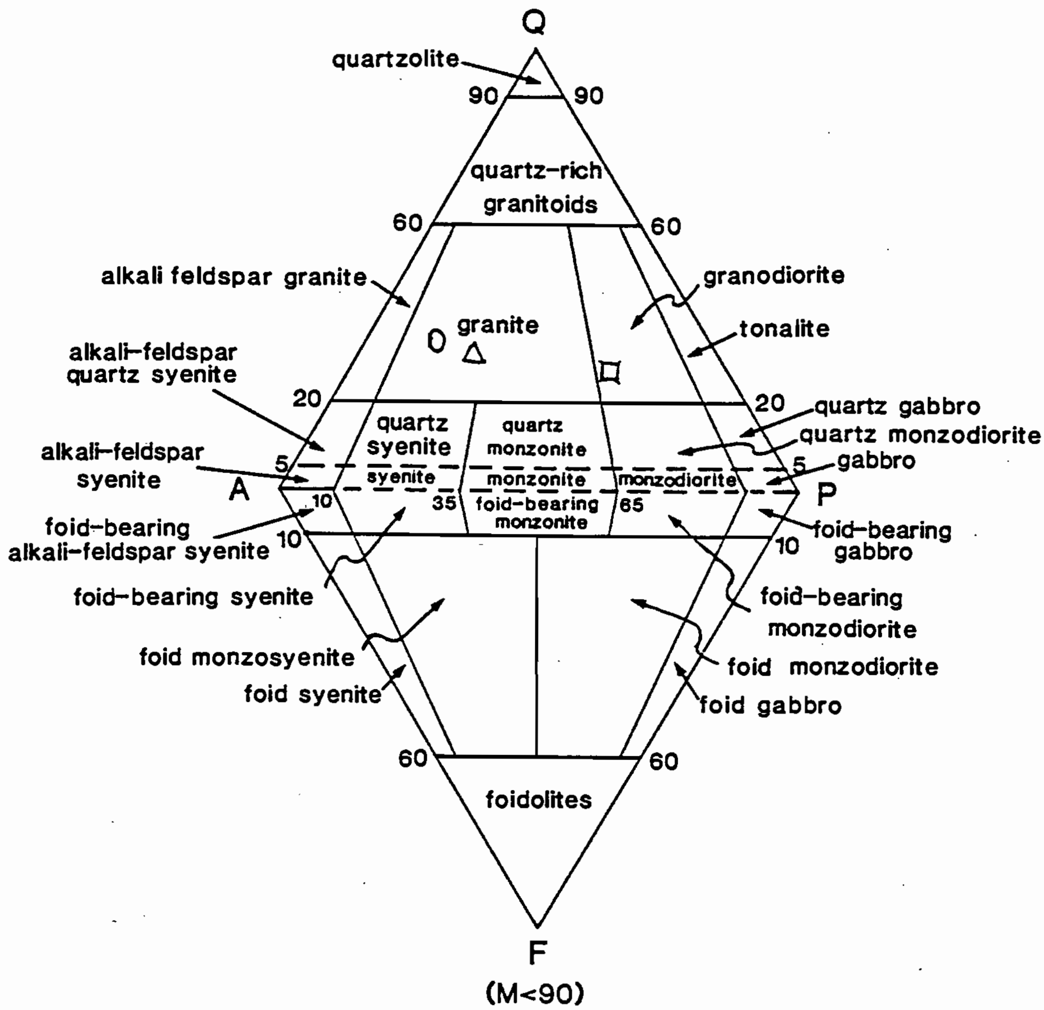

Figure 4.1: Modal classification system of plutonic rocks. Figure shows that both the equigranular granite (0) and microgranite (Δ) plot within the granite field, and the granodiorite (Π) plots in the granodiorite field (after Streckeisen, 1974).

4.1.1 *Equigranular granite*

By far the majority of the Darwin Granite is comprised of a pink-green equigranular granite (Fig. 3.1; Plate 4.1). Pink granite crops out on the Darwin Plateau together with granodiorite and microgranite. This phase is also exposed in a smaller body to the west of Humpty Dumpty (Fig. 3.1; 78320). The granite is easily recognisable when fresh, due to its distinct pink-green colouring, which is imparted by abundant dark pink K-feldspar and green chlorite alteration after plagioclase (Plate 4.1). Previous workers have classified this unit as pink granite (eg. Hills, 1914; Solomon, 1960; White, 1975).

Plate 4.1: Equigranular granite. The colouring (pink-green) is diagnostic of unweathered equigranular granite in the Darwin Granite.

The equigranular texture in the granite is homogeneous throughout the granites body. Equigranular granite is comprised of K-feldspar, plagioclase, quartz, and minor biotite, with accessory magnetite, zircon, apatite and monazite. Plagioclase is pervasively altered, with sericite-chlorite alteration obscuring the majority of primary crystals. Primary biotites have invariably suffered intense sericitisation. Estimated modal composition of the equigranular granite is K-feldspar (45-50%), quartz (25-30%), plagioclase (20-25%) and biotite (5-10%), which plots in the granite field of Streckeisen's (1974) classification (Fig. 4.1). Anhedral quartz crystals typically display undulose extinction, and in some sections are embayed and partially recrystallised (78322). Plagioclase crystals are altered to sericite±chlorite, which in many cases obscures the euhedral character of the relict primary crystals. Subhedral to anhedral K-feldspar dominates the equigranular granite and strong mineral cleavage can generally be observed in thin section. Perthite is common and granophyric texture is locally abundant.

4.1.2 *Granodiorite*

Granodiorite is exposed within equigranular granite on the northern and southern Darwin Plateau (Fig. 3.1). This phase represents only a minor component, by volume, of the Darwin Granite. Granodiorite has been differentiated from the coarse grained granite previously (eg. Hills, 1914; Bradley, 1954; Solomon, 1960; White, 1975) and has been described variously as white granite and as quartz porphyry (Plate 4.2; 78326). In fresh samples, there is a distinct variation between the pink-green equigranular granite and the white granodiorite. However, on weathered surfaces the equigranular granite has a cream colour and is more similar in appearance to the granodiorite. This has lead to some confusion in the past concerning the actual proportion of granodiorite present (Solomon, 1960; White, 1975).

Plate 4.2: Granodiorite. In the Darwin Granite the granodiorite comprises a minor component, by volume, compared with the equigranular granite. Granodiorite is uniformly leucocratic and invariably highly fractured.

The granodiorite varies from coarse to fine grained, and appears to have a fine grained margin. Although the percentage composition of individual minerals can vary substantially generally, plagioclase is the most abundant phase, with lesser K-feldspar and quartz. Modal analysis of granodiorite (Appendix B) indicates plagioclase (50%), K-feldspar (27%), quartz (22%) and sericite (1%). The modal analysis plots within the granodiorite field of Streckeisen's (1974) classification (Fig. 4.1). Euhedral plagioclase crystals are characterised by albite and carlsbad twinning, polysynthetic twinning is rare. Extinction angles between 18-20^o suggest more sodic compositions within plagioclase. Plagioclase crystals have generally suffered intense sericite-chlorite alteration. In some plagioclase crystals, sericite has selectively altered individual twin planes within the crystal. Crystals of K-feldspar are generally euhedral to subhedral, and have only suffered incipient alteration, in direct contrast to plagioclase feldspars. K-feldspar is characterised by carlsbad twinning, and minor perthite is present. Quartz crystals are euhedral in porphyritic samples and subhedral-anhedral in equigranular granodiorite. The grains are generally unaltered and display undulose extinction. Many of the quartz crystals have been recrystallised showing sutured grain boundaries, as does the quartz in the groundmass of porphyritic samples. Rare biotite crystals have invariably suffered partial sericitisation. Opaque minerals are rare and the granodiorite is strongly leucocratic. Texturally, the granodiorite is the most diverse phase within the Darwin Granite varying from equigranular to porphyritic.

At the far northern end of the Darwin Plateau, the contact between the granodiorite and the equigranular granite appears to be gradational. However, the granodiorite is more intensely fractured than the granite, and quartz has been more intensely recrystallised. It is thought that the two regions of granodiorite have intruded the equigranular granite although no blocks of equigranular granite were observed within the granodiorite. The deformation causing fracture is most likely a much later feature. If fracturing was in result of forceful emplacement, the equigranular granite would be deformed; the younger would be hotter and would not fracture.

4.1.3 *Microgranite*

Exposures of pink-cream coloured fine grained microgranite are restricted to the western half of the Darwin Granite. Microgranite crops out over areas of up to 2m and is commonly interspersed within equigranular granite. Microgranite is more common closer to the Darwin Granite / CVC contact, and is believed to represent a chilled margin. The microgranite is discontinuous in nature, and at many localities on the western margin of the Darwin Granite, equigranular granite is in direct intrusive contact with the CVC.

The microgranite is fine grained (< 1 mm), equigranular and holocrystalline (78325). K-feldspar, plagioclase and quartz are predominant with minor opaques and biotite. Plagioclase is intensely altered to sericite-chlorite, and biotite crystals (where present) are sericitised. K-feldspar is the dominant mineral component and perthite is abundant. Crystals of subhedral K-feldspar display post deformation induced sutured contacts with adjacent quartz crystals. Subhedral quartz crystals exhibit undulose extinction and remain unaltered. Even though plagioclase has been highly altered, albite twinning can still be discerned in some crystals. The microgranite contains modal 48% K-feldspar, 27% plagioclase and 25% quartz (Appendix B), which plots in the granite field (Fig. 4.1).

4.2 RELATIONSHIPS BETWEEN THE GRANITIC ROCK TYPES

Intimate spatial, temporal and compositional relationships exist between the coarse grained granite, granodiorite and microgranite. These relationships have been examined in detail by field mapping, petrography and geochemistry.

4.2.1 *Contact Relationships and Xenoliths*

The coarse grained granite and microgranite are the only two units of the Darwin Granite in contact with the CVC. The granodiorite is only in contact with coarse grained granite. Microgranite is restricted mostly to the western margin of the Darwin Granite. It is thought to represent a chilled margin of equigranular granite, based on their similar mineralogies and mostly gradational contact relationships. Granodiorite is highly fractured and strongly silicified throughout. To the east of the Darwin Plateau the Darwin Granite is unconformably overlain by correlates of the Tyndall Group and evidence of an erosion surface is well developed (Chapter 3.0).

White (1975) reported the occurrence of numerous xenoliths along the western margin of the Darwin Granite. A raft of intensely silicified CVC, 600m x 50m, occurs on the southern Darwin Plateau (Fig. 3.1).

4.2.2 *Intrusive Succession*

U-Pb dating of zircons in the Darwin Granite have yielded a Late Cambrian age of 510Ma (Adams *et al.,* 1985). Absolute age data is only available for the equigranular granite, consequently a comparison of absolute ages cannot be used in determining the intrusive succession. Field relationships showing the restriction of granodiorite outcrops to within the coarse grained granite, along with the presence of minor porphyritic texture within the granodiorite, suggest that it has intruded the coarse grained granite. The microgranite and equigranular granite are considered to be coeval.

4.2.3 *Depth of Intrusion*

Determination of depth of intrusion for the Darwin Granite is difficult to establish. Certain features suggest a reasonably deep level (mesozonal) intrusion (eg. coarse grained equigranular texture, semi concordant contacts with the CVC, presence of hydrothermal tourmaline breccias; Charoy, 1982; Middlemost, 1985) while other features are more indicative of a high level (epizonal) intrusion (eg. subvolcanic nature of intrusion, low temperature primary mineral constituents, presence of large xenoliths, small elongate form, narrow low grade contact metamorphic aureole; Middlemost, 1985; Paterson *et al.*, 1991). Previous authors (eg. Solomon, 1981) have suggested that the Darwin Granite is a high level (2 to 3km) intrusion. Textural features do not unambiguously constrain the depth of intrusion. If the granite intruded at a high crustal level (epizonal) then generally a porphyritic texture would be developed, indicating rapid cooling at high crustal levels (Middlemost, 1985). Porphyritic texture is not observed within the equigranular granite. A lack of porphyritic texture in high level intrusions can result from intrusion of a crystal rich magma (Hall, 1987). The Darwin Granite is interpreted to have been highly crystallised upon intrusion; this accounts for the low temperature primary mineral constituents (Hall, 1987). The lack of high grade contact metamorphism within the CVC is in result of similar geochemical compositions between the two formations. The granite was already highly crystallised on intrusion and was not a hot intrusion, capable of melting rocks of similar composition. From the available data it appears that intrusion of the Darwin Granite occurred within the mid to lower epizone (2 to 4km; Middlemost, 1985).

4.3 DISCUSSION

The Darwin Granite is composed of three granitic rocks of two distinct compositions, granite and granodiorite, restricted to the Darwin Plateau and to a small region west of Humpty Dumpty (Fig. 3.1). The Darwin Granite intrudes the CVC and is unconformably overlain by the Tyndall Group (Fig. 3.3). From field relationships and textural characteristics it appears that the equigranular granite has been partly crystallised prior to intrusion to lower epizonal levels. Microgranite formed when liquid magma rose and was chilled. Granodiorite has intruded the equigranular granite at a later stage in the magmatic cycle of the Darwin Granite (Fig. 3.3).

Chapter 5.0 STRUCTURE

This chapter documents the structural setting of the Mt Darwin - South Darwin Peak area. Investigations have involved an initial phase of field mapping and air photo interpretation followed by a detailed analysis of cleavage, vein, joint and fault data, using stereographic projections and rose diagrams. This data set is then compared with the regional structural setting, and stratigraphic relationships, to establish the relative timing and importance of the various fault generations. From this work, it has become evident that at least four stages of deformation affected the area: (1) Mid-Late Cambrian; (2) Late Cambrian - Early Ordovician; (3) & (4) Devonian (Tabberabberan related). Deformation during the Devonian Tabberabberan Orogeny has had the most widespread influence in the region and overprints and obscures effects of the Mid-Late Cambrian and Late Cambrian-Early Ordovician deformations. A trend correlatable with the Late Cambrian-Early Ordovician deformation (Jukesian Orogeny) cannot be distinguished but evidence for its existence is recorded in the stratigraphy (Chapter 3.0).

5.1 CLEAVAGE

A pervasive closely spaced cleavage is well developed throughout the study area and has affected all formations to some extent. There are two preferred orientations recognised within the CVC and the Tyndall Group (NW and N-trending fabrics). Cleavages within the Darwin Granite and the Owen Conglomerate are poorly developed compared to those in the CVC and Tyndall Group. Pervasive fabrics are localised within shear zones, in these two more massive units. Table 5.1 shows the dominant cleavage trends for the CVC and Tyndall Group within the study area.

The lavas of the CVC can exhibit a pervasive spaced cleavage characterised by alignment of sericite and chlorite, and by the segregation of recrystallised quartz bands (Plate 3.1). There are two preferred orientations; N-S and NNW-SSE (Fig. 5.1). No primary bedding is recognisable in the CVC. Joints are also recognised within the CVC units; they probably formed during regional deformation. Volcaniclastic units of the Tyndall Group are the most intensely deformed rocks in the study area, due to their less coherent nature. A pervasive foliation defined by chlorite and sericite increases in intensity towards the Darwin Granite. The fabric has a dominant N-S to NNW-SSE trend (Fig. 5.1). Primary bedding is difficult to recognise at most localities; when present it is parallel to cleavage. Both Figure 5.1 and a contoured plot of poles to Tyndall Group cleavage (Fig. 5.2) show that the foliation in the Tyndall Group is rotated about the vertical axis of the stereonet, indicating a rotation of the regional stress regime. The consistent orientation and similar appearance of the foliations within the CVC and Tyndall Group suggest that the intense tectonic fabric has formed following the deposition of both these groups.

Table 5.1 : Dominant fault and cleavage orientations for the CVC, Darwin Granite and Tyndall Group within the Mt Darwin - South Darwin Peak region. Cleavage in the Darwin Granite is developed in shear zones while cleavage in the CVC and Tyndall Group is a more widespread, closely spaced fabric.

FORMATION	FAULT TRENDS	CLEAVAGE
Central Volcanic Complex	NNW, N	N, NNW
Darwin Granite	NNW, N to NNE	N
Tyndall Group	N, NNW	NNW

5.2 JOINTS

The Darwin Granite is closely jointed (Plate 5.1). Joints from the central region of the granite have apparently random orientations. However a scatter plot (Fig. 5.3) and contour plot of poles to joint planes (Fig. 5.4) indicate the presence of a consistent NNW-SSE joint trend. This NNW-SSE orientation among other various joint orientations suggests that major deformation within the granite is related to a period of WSW-ENE regional compression. Joint surfaces display local small scale movement along joint planes. Cleavage is locally developed within N-S trending shear zones in the granite.

Plate 5.1: Jointing within the Darwin Granite. Two dominant joint orientations are recognisable in this plate and minor movement is visible along some joint surfaces. A magnetite vein has intruded along a joint surface and been displaced later.

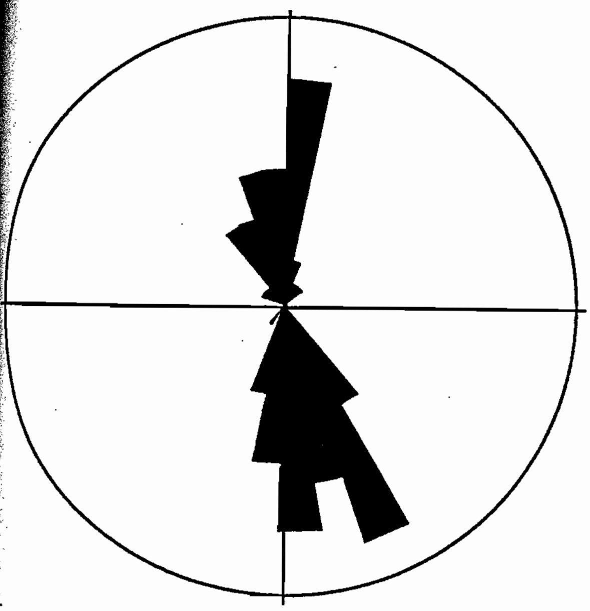

Figure 5.1: Rose diagram of cleavage orientations in the CVC and Tyndall Group. Data was combined for both formations because of the consistency between the two data sets. The rose diagram suggests that there are two main cleavage orientations N and NW to NNW.

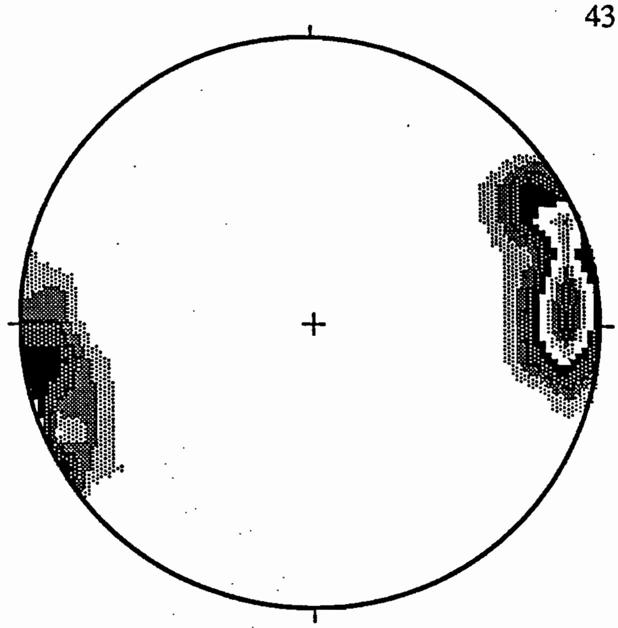

Figure 5.2: Contoured plot of poles to Tyndall Group cleavage.

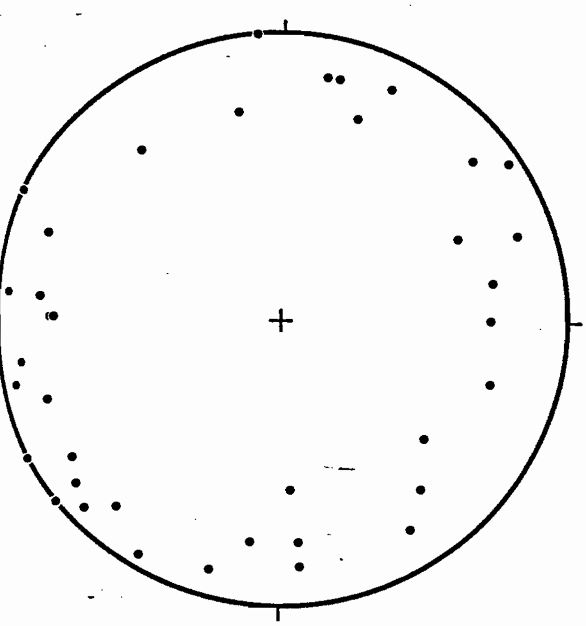

Figure 5.3: Plot of poles to jointplanes in the Darwin Granite. Plot indicates the wide range in joint orientations across the granite.

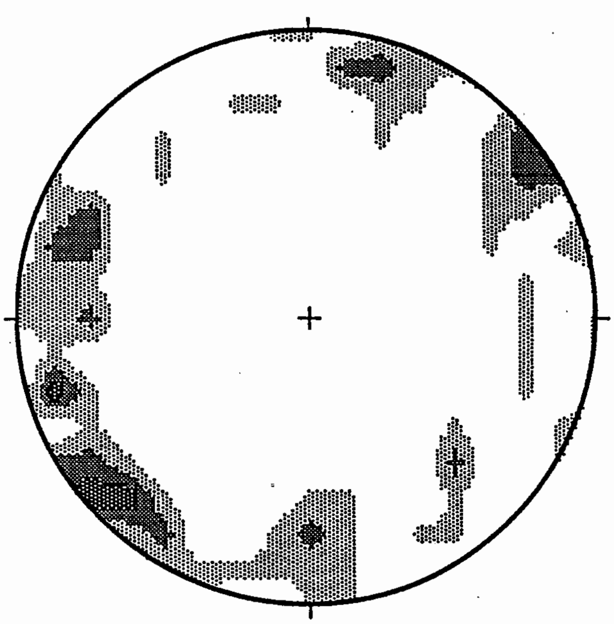

Figure 5.4: Contoured plot of poles to joint planes in the Darwin Granite. Plot shows that joint sets are most commonly oriented between NW and NE orientations.

5.3 FAULTING

Strike-slip faults are recognised in all formations. Displacements range from small scale movements on joints (centimetres) to large (> 5m) movements along shear zones. There are NW-SE and N-S trending dominantly dextral strike-slip faults (Fig. 3.1) that transect the CVC, Darwin Granite and the Tyndall Group.

NW trending faults occur in the CVC along the western edge of the Darwin Plateau and near Mt Darwin. A large N-S trending strike-slip fault of unknown displacement separates units of the CVC from the Darwin Granite at the northern end of the Darwin Plateau (Fig. 3.1). Minor faults display two dominant orientations, N-S and NW-SE (Fig. 5.5, 5.6), that are consistent with dominant orientations in larger faults.

Minor displacement (1 to 5cm) within the Darwin Granite is recorded along many joint planes. Large scale faults are also developed, with a 15m wide N-trending shear zone extending for over 100m along strike near the Tyndall Group contact (Fig. 3.1). Two dominant orientations are recognised in faults in granite; NW-SE to NNW-SSE, and NNE-SSW (Fig. 5.5, 5.6).

Minor faults within the Tyndall Group on the access track to the Darwin Plateau contain pug zones less than 10cm wide, and can be traced for up to 5m along strike. Quartz fibres record both normal and reverse movements on these minor structures. Offsets of up to a few metres are indicated by displacements within polymictic volcaniclastic sandstone.

Within the Owen Conglomerate, significant faulting has been observed at only two localities, east of the Darwin Plateau and on Humpty Dumpty (Fig. 3.1). To the east of the Darwin Plateau, a 15m wide dextral shear zone is recognised in well-bedded quartz sandstone units (Plate 5.2). Figure 5.7 illustrates zones of movement and bedding orientations within this shear zone. On Humpty Dumpty, a NE trending fault within boulder-conglomerate extends 50m and records approximately 5m of dextral offset.

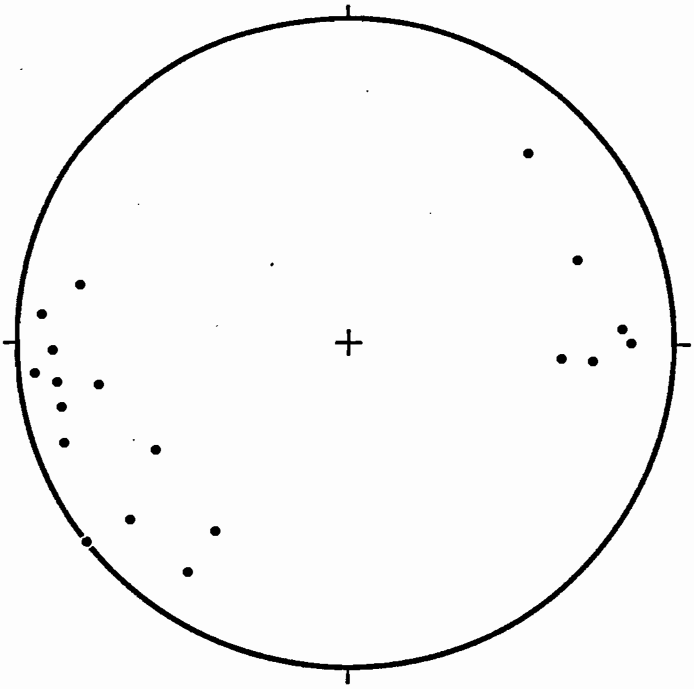

Figure 5.5: Plot of poles to fault planes from the Central Volcanic Complex and Tyndall Group. Plot distinguishes the dominating N and NW fault trends across the Mt Darwin South Darwin Peak area.

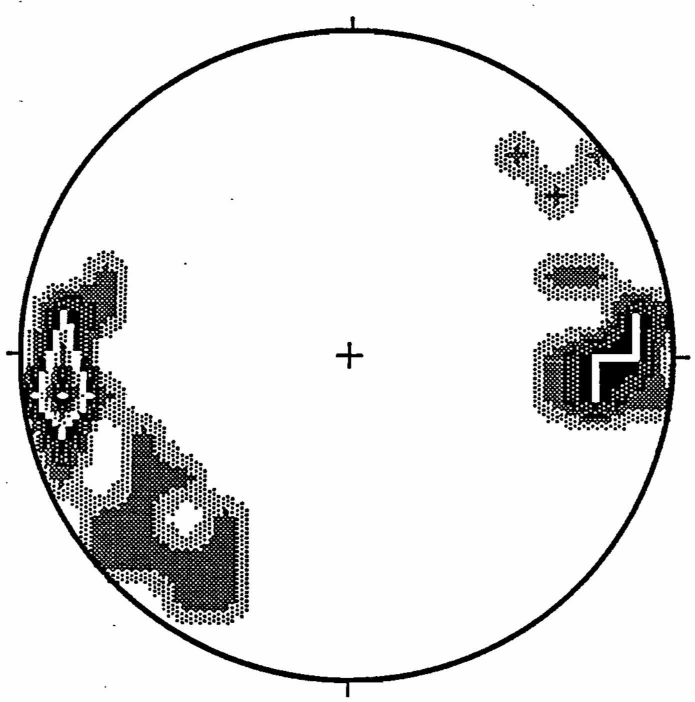

Figure 5.6: Contoured plot of poles to fault planes in the CVC and Tyndall Group. Contoured view distinguishes a N trend and a lesser NW trend. The fault data was obtained from widely spaced localities yet only minor variation is visible.

Plate 5.2: Dextral shear zone developed within quartz sandstones of the Owen Conglomerate. Figure 5.7 highlights the planes of movement and bedding orientations within the shear zone.

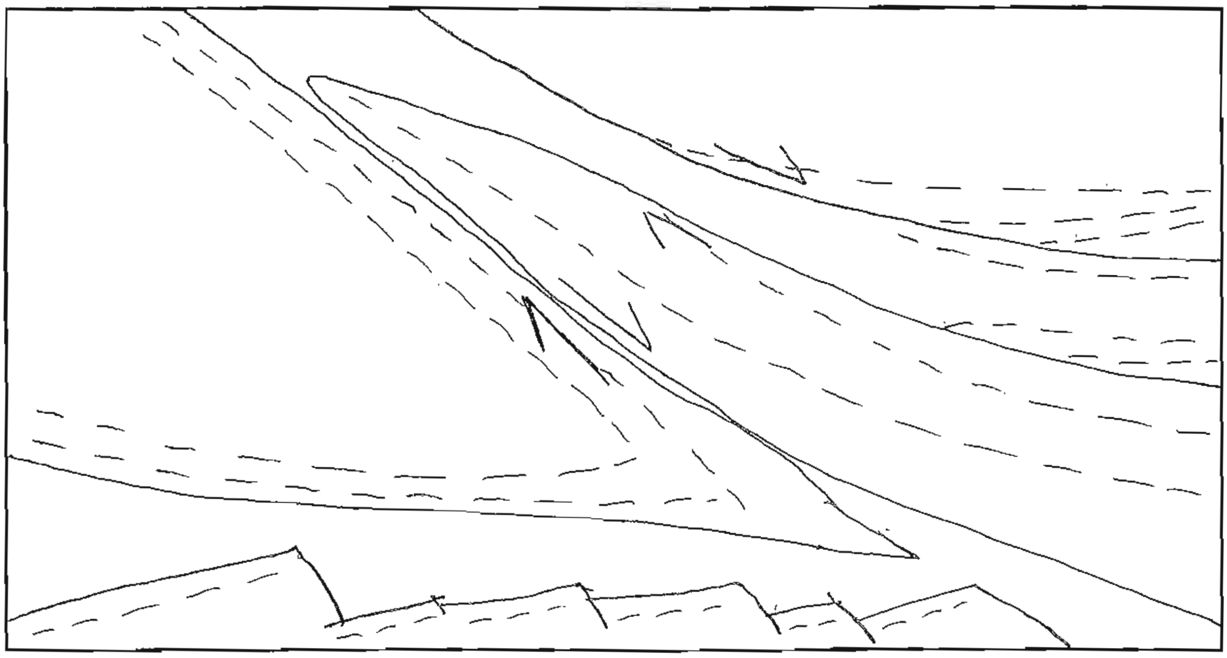

Figure 5.7: Representation of the planes of movement, and bedding orientations, within dextral shear zone developed in the Owen Conglomerate east of the Darwin Plateau. This shear zone is shown in Plate 5.2.

A summary of the dominant fault orientations within the various formations is represented in Table 5.1. It shows the dominant orientations to be NNW-SSE and N-S with a subordinate NE-SW direction also developed. Regional movement along faults is mostly dextral. The dominance of N and NW trends in all units suggests that faulting occurred subsequent to deposition of the Tyndall Group and the Owen Conglomerate, and can be correlated, based on the structural trends, with the Tabberabberan Orogeny (Williams, 1979; Corbett & Lees, 1987).

5.4 VEINING

Four separate vein types are recognised within the Mt Darwin-South Darwin Peak region: magnetite, tourmaline, barite and quartz veins. This section deals specifically with the structural characteristics of vein types while descriptions of vein composition are detailed in Chapter 6.0. Magnetite veins are most common; they are restricted to the CVC and to the Darwin Granite. Tourmaline veins are also restricted to the two oldest lithologies. Only one barite vein was observed within the Darwin Granite, striking N027°, though Hills (1914) has observed E-trending barite veins north of the project area in the CVC. Quartz veins occur within all formations. Structural analysis of vein orientations can reveal the stress regimes present locally during vein formation. Magnetite veins within the CVC and Darwin Granite have similar orientations and are grouped together as one vein population. The dominant orientations of veins from within the respective formations are represented in Table 5.2.

Table 5.2: Dominant trends of the four vein types within the CVC, Darwin Granite and Tyndall Group in the Mt Darwin - South Darwin Peak region.

	VEINS			
FORMATION	MAGNETITE	TOURMALINE	BARITE	QUARTZ
CVC	NW, NE	Varied		NW, E
Darwin Granite	NW, NE	NW	NNE	NW, NNE to E
Tyndall Group				NW

The vein populations, represented in Table 5.2, display some correlation between trends across the region. Two dominant vein trends, NW-SE and NE-SW to NNE-SSW, stand out from Table 5.2 and suggest that veins have formed at times which were dominated by regional compression around an E-W axis.

5.5 MYLONITE ZONES WITHIN THE DARWIN GRANITE

A N-trending mylonite zone (Fig. 3.1) up to 50m wide occurs in equigranular granite and granodiorite towards the northern end of the Darwin Plateau. Deformation is intense relative to the adjacent granite, with reworking of approximately 60-70% of the rock (Plate 5.3). A pervasive N-trending fabric is defined by elongate quartz grains and micas. Angular to rounded porphyroclasts occur throughout the fine grained matrix (Plate 5.3). Zones of recrystallised quartz are interlayered with fine grained biotite, sericite, quartz and feldspar.

Plate 5.3: Mylonite. A zone of mylonite is developed in the equigranular granite at the northern end of the Darwin Plateau. Quartz occurs in elongate bands, feldspar porphyroclasts (rounded to fragmented) are rotated.

The mylonites display characteristics of both simple and pure shear environments (Fig. 5.8; Hobbs *et al.*, 1976). A dextral sense of movement has been recorded by four separate textural relationships which are depicted in Figure 5.9 (Simpson & Schmid, 1983). Plastic deformation of all minerals is accompanied by minor cataclasis of some K-feldspar crystals which were obviously stronger than other primary mineral components. Pressure shadows around K-feldspar porphyroclasts contain aligned elongate secondary sericite. Elements of simple shear and pure shear (Fig. 5.8) suggest that compression and rotation were characteristic features of this intense dextral shear zone.

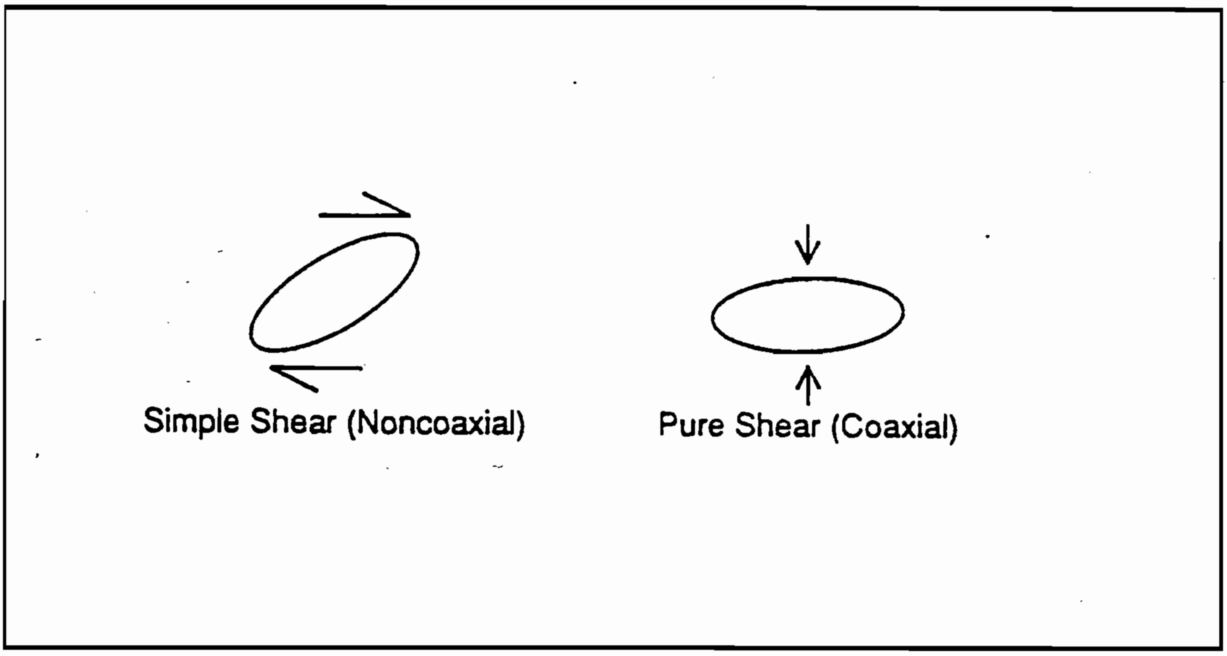

Figure 5.8: Characteristics of pure shear and simple shear. Pure shear involves strain causing the elongation of a body in a single direction. Simple shear is loosely referred to as rotational strain where the body is rotated rather than compressed (after Hobbs *et al.*, 1976; Hanmer & Passchier, 1991).

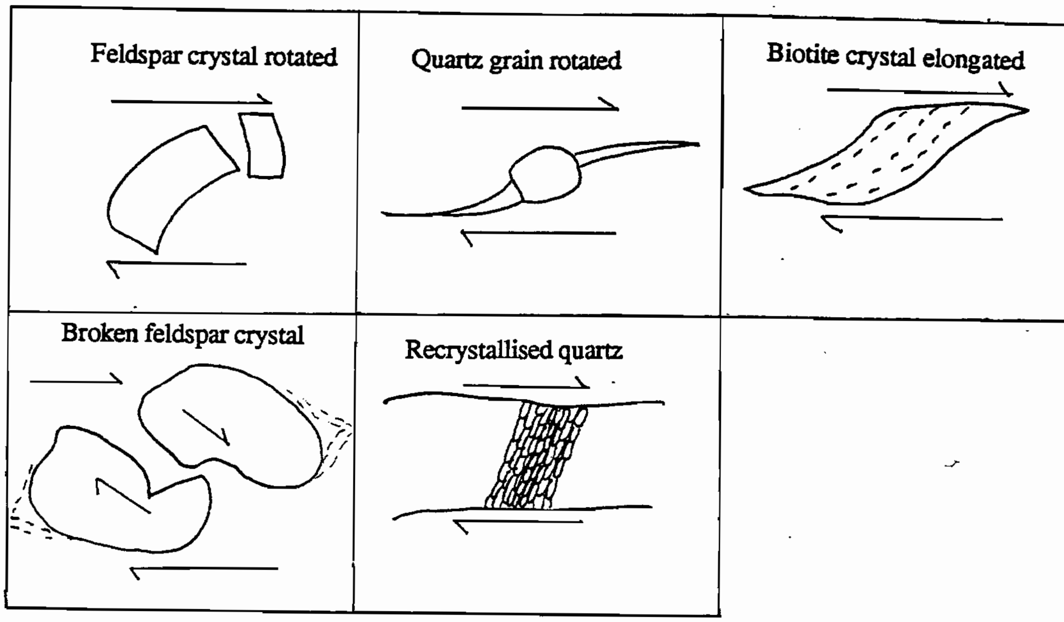

Figure 5.9: Five criteria used to distinguish the sense of movement within the granite mylonite. All criteria are consistent in indicating that movement within the mylonite has been dextral (after Hobbs *et al.*, 1976; Simpson & Schmid, 1983).

5.6 DISCUSSION OF STRUCTURAL RELATIONSHIPS

Analysis of orientations for cleavage, fault and vein populations from stereographic projections and rose diagrams (Fig. 5.1 to 5.6) indicate three dominant structural trends across the region: (1) NNW-SSE to NW-SE; (2) N-S; and (3) NE-SW to NNE-SSW. The NW-SE trend is recorded by fault, cleavage and vein orientations, while the N-S trend is observed in fault trends and by a pervasive cleavage within the CVC. The NE-SW trend is only represented by magnetite, quartz and barite veins within the Darwin Granite.

The NE-SW trend observed within the region is relatively minor, compared to the NW-SE and N-S trends, and is consistent with the major Cambrian trend within the West Coast Range (Corbett & Lees, 1987). It appears that the dominant N-S and NW-SE structural trends within the region are related to post-Cambrian deformation episodes correlatable with the Devonian Tabberabberan Orogeny.

5.7 STRUCTURAL HISTORY

Stratigraphic relationships (Chapter 3.0) provide evidence for at least four stages of deformation. They are: (1) an erosional unconformity between the CVC/Darwin Granite and the Tyndall Group; (2) the angular unconformity between the Tyndall Group and the Owen Conglomerate; (3) N-S fault and cleavage orientations consistent with trends for the first stage of the Devonian Tabberabberan Orogeny (Seymour, 1980); and (4) NW-SE fault and cleavage trends consistent with the second stage of Tabberabberan-related deformation (Seymour, 1980). Deformation related to these four events has dominated the structural development of the region, allowing the structural history of the area to be divided into four definite stages.

<u>1st Stage</u> : An early (Cambrian) deformation is recorded by the presence of randomly oriented cleaved volcanic clasts within basal conglomerate of the Tyndall Group (north of South Darwin Peak) and randomly oriented cleaved volcanic clasts within volcaniclastic lithic conglomerate of the Tyndall Group (on Humpty Dumpty). The erosional unconformity that separates the Darwin Granite and the Tyndall Group represents a period of Mid-Late Cambrian uplift and erosion. The early cleavage preserved in the volcanic clasts most likely formed during this deformational event.

<u>2nd Stage</u> : An Early Ordovician deformational event is represented by the abrupt change in provenance of source materials and the development of an angular unconformity between MRV units and the Owen Conglomerate. This deformation event is interpreted to correspond to the widespread Jukesian Orogeny of Late Cambrian-Early Ordovician age (Solomon & Griffiths, 1974). No fabrics or fault orientations record this event in the study area.

<u>3rd & 4th Stages</u> : Major deformation occurred sometime after the deposition of the Owen Conglomerate, and can be correlated to the two stages of deformation recognised in the Tabberabberan Orogeny elsewhere in the MRV (Seymour, 1980; Corbett & Lees, 1987; Berry & Keele, 1992). These events produced the dominant N-S and NW-SE fault and cleavage trends within the CVC and Tyndall Group, and the N-trending shear zones and faults within the

Owen Conglomerate and Darwin Granite. Initial compression during the Devonian has caused the development of N-S fault and cleavage trends. Following initial compression, stresses rotated to develop the NW-SE cleavage and fault trends across the region. The two phases of Tabberabberan related deformation have modified the morphology of the Darwin Granite. Rotation of stresses during the Devonian accounts for the dextral movement observed along faults within the region.

It is clear from structural relationships within the study region that Tabberabberan-related deformation dominates the structure of the area. Features associated with this event strongly overprint and may also have reactivated features of earlier deformation.

Chapter 6.0 MINERALISATION

Economically, the MRV is the most significant geological feature in Tasmania, hosting the polymetallic VHMS deposits at Que River, Hellyer, Rosebery and Hercules, and the Cu-Au VHMS Mt Lyell deposits (Corbett & Solomon, 1989; Large, 1989). The mineralisation in the Jukes-Darwin region represents one of several clusters of minor mineralisation occurrences within the MRV. Cu-Au mineralisation predominates within the Jukes-Darwin region, where there is a spatial relationship between copper mineralisation and the Darwin Granite (Fig. 1.2). This chapter describes the characteristic sulphide mineralisation and vein types encountered within the study area. Sulphur isotopic data is used to trace possible sulphur sources, and mineralisation in the study region is compared to the characteristics of classic porphyry copper deposits to assess potential for classic porphyry-style mineralisation immediate to the Darwin Granite. Because of the unsafe nature of many of the adits within the study area, descriptions of old workings are mostly summarised from the available literature (eg. Hills, 1914; White, 1975; Green *et al.*, 1988).

6.1 SULPHIDE MINERALISATION

The Jukes-Darwin Mining Field (Fig. 1.2) has yielded several discoveries of Cu±Pb±Ag±Au, some of which have been worked intermittently in the past. Old mines and prospects close to or within the study area include Prince Darwin, Tasman Darwin, East Darwin and several unnamed prospects (Fig. 1.2). Magnetite-pyrite veins and disseminations are common throughout the CVC, which hosts the major mineralisation occurrences. Pyrite is restricted to veins and breccias within the Darwin Granite, and is known from only one locality within the Tyndall Group (Fig. 3.2).

6.1.1 *Prince Darwin*

The old Prince Darwin workings are to the west of the central Darwin Plateau, within massive rhyolites of the CVC (Fig. 1.2; White, 1975). Prince Darwin consists of two adits within a belt of magnetite-hematite veins extending along a N-S trend over a distance of some 2km (White, 1975). Copper and silver were mined at Prince Darwin in the early 1900's, where pyrite and chalcopyrite occur within a stockwork of magnetite - hematite ± tourmaline veins (White, 1975; Green *et al.*, 1988). The intensity of magnetite-hematite veining increases in proximity to the adit at Prince Darwin (White, 1975). Grab samples from Prince Darwin have yielded assay results of up to 7% Cu and 60g/t Ag (Hills, 1914); no data is available on average grades.

6.1.2 *East Darwin*

Four adits represent the East Darwin workings (Fig. 1.2) which intersect Cu-Ag-Au(±Pb) mineralisation (Corbett & Cuffley, 1970; Green *et al.*, 1988). The host volcanics are strongly foliated and altered to a pervasive quartz-sericite-chlorite assemblage. Outside the adits, the volcanics contain abundant disseminated medium-coarse grained cubic to subrounded pyrite grains with minor hematite and chalcopyrite. Pyrite varies from coarse cubes in less deformed regions to fine anhedral aggregates within strongly deformed sections. Groundmass quartz is fine and recrystallised, and sericite forms aggregates of aligned crystals. The mineralisation at East Darwin occurs along a fault surface, striking NNW and dipping steeply to the east, between the CVC and the Tyndall Group (White, 1975). This contact occurs approximately 100m to the west along the adit drives at East Darwin (Hills, 1914).

Mineralisation occurs in both vein and disseminated forms (Hills, 1914). Pyrite-chalcopyrite ±covellite veins up to 15cm wide (assaying to 31% Cu) are the most important vein type. Minor copper mineralisation is also hosted within quartz veins (White, 1975). Assays on vein mineralisation have yielded significant Ag and Au values, up to 660g/t and 20g/t respectively (Hills, 1914). The largest disseminated ore zone covers 25m within highly cleaved country rocks; it has not been assayed (Hills, 1914). More than ten tonnes of ore at 9% Cu were mined at East Darwin (Hills, 1914), making it the richest known mineralisation occurrence within the

Jukes-Darwin Mining Field, although its extent has not been adequately defined by drilling.

6.1.3 *Tasman Darwin*

The trench at the Tasman Darwin prospect, west of Humpty Dumpty (Fig. 1.2), is around 3m long and 2m deep. The ore body at Tasman Darwin is approximately 8m wide and is comprised of disseminated magnetite-hematite with pyrite and minor chalcopyrite (Hills, 1914). Assays have yielded between 0.5-1.0% Cu (Hills, 1914). This prospect lies within the belt of iron oxide veins extending south from Prince Darwin. There are many smaller magnetite-hematite bodies nearby.

6.1.4 *Minor Sulphide Occurrences*

Pyrite has a wide distribution within the CVC and the Darwin Granite, and has also been observed in the Tyndall Group. Pyrite generally occurs with magnetite in veins and as disseminations in alteration halos. Pyrite within the Tyndall Group is associated with hematite veining.

Magnetite-pyrite veins occur within the CVC along the western edge of the Darwin Plateau. They commonly contain coarse grained pyrite and magnetite that has been partially oxidised to hematite. Vuggy quartz veins also contain minor disseminated magnetite-pyrite. Massive disseminations of magnetite+pyrite are restricted to only a few localities, including Tasman Darwin and the exploration trench dug within a raft of CVC in the Darwin Granite (Fig. 1.2). Disseminated magnetite-pyrite zones can extend over several square metres and have been a focus for copper exploration in the past. There is no obvious fault control on disseminated mineralisation.

Within the Darwin Granite, veins of pyrite have been observed at the southwest corner and the eastern margin. Pyrite also occurs as disseminations within the granite at several localities (Plate 6.1), with the largest occurrence on the northern side of the circuit track within the granite, covering an area of approximately 3m x 2m. Disseminated occurrences contain coarse to fine broken feldspar and quartz crystals in a matrix of pyrite-hematite-magnetite with no preferential crystal alignment. Pyrite crystals (in thin section) appear to have been partially replaced by magnetite. Elsewhere, minor disseminated pyrite also occurs within the granite but is difficult to distinguish in hand specimens.

Plate 6.1: Pyrite within the Darwin Granite. Mineralisation is associated with magnetite in this breccia.

Pyrite has been observed on the access track to the Darwin Plateau within polymictic lithic volcaniclastic sandstones of the Tyndall Group (Fig. 3.2; Plate 6.2). There are several occurrences of disseminated pyrite, containing pyrite cubes up to 1mm in diameter, that occur over a 15m x 2m region. The largest occurrence of disseminated pyrite covers an area approximately 15cm x 8cm. Weathering and a strongly developed foliation within the Tyndall Group help to obscure the nature of pyrite mineralisation, with the exception of one locality within the zone where pyrite occurs in a halo around a 3cm wide hematite vein. Hematite is abundant throughout the zone of polymictic lithic volcaniclastic sandstone which hosts pyrite mineralisation.

Plate 6.2: Pyrite is restricted to one locality where it occurs across a 15m interval in polymictic lithic volcaniclastic sandstone of the Tyndall Group, in association with hematite veining.

6.2 VEINING

Four distinct vein types are recognised in the study area. They are: (i) magnetite±pyrite, (ii) tourmaline, (iii) barite and (iv) quartz veins. The last three vein populations are restricted to specific lithologies thus providing an indication as to their time of formation. Figure 6.1 depicts the formation of the four vein types. Only the composition and basic structural characteristics of vein populations are discussed here. A comprehensive structural interpretation of vein relationships is presented in Chapter 5.0.

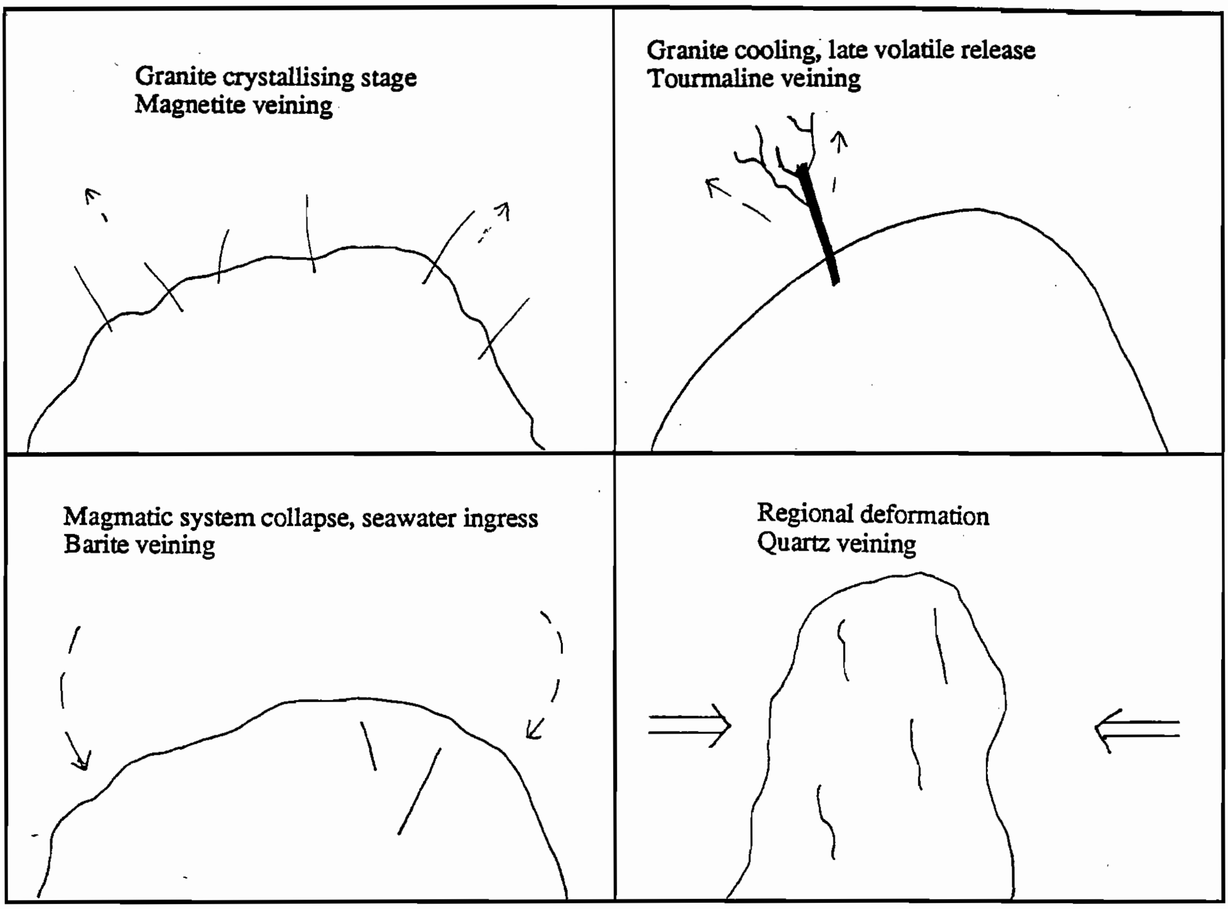

Figure 6.1: Diagramatic representation of magnetite±pyrite, tourmaline, barite and quartz vein formation within the study area.

6.2.1 *Magnetite(±Pyrite) Veins*

Magnetite veins are the most abundant vein type in the study area. They are restricted to the CVC and the Darwin Granite. Two magnetite vein trends are recognised in the CVC and Darwin Granite, NW-SE and NE-SW. Magnetite veins occupy joints across the Darwin Granite and range in width from 1-9cm (Plate 5.1). In the southwest region of the Darwin Granite, several veins of massive to euhedral pyrite occur together with minor magnetite. Magnetite veins in the CVC are generally wider than in the Darwin Granite, with the largest vein (1m x 4m) occurring 400m south of Mt Darwin trending 270/65°W. In thin section, fine grained magnetite has been partially replaced by acicular hematite, locally, with thin needle-like grains grown semi-parallel to the vein margins. Hematite is characterised by strong red internal reflections, and interstices between individual hematite crystals are filled by chlorite.

The absence of magnetite veins from both the Tyndall Group and the Owen Conglomerate suggests that this vein population formed prior to deposition of either of these two groups. Based on the close spatial relationship between magnetite veining and the Darwin Granite, a magmatic-hydrothermal origin related to granitic emplacement is considered likely (Fig. 6.1), although detailed fluid inclusion and stable isotope analyses are required to confirm this hypothesis.

6.2.2 *Tourmaline Veins*

Veins of black, fine grained tourmaline containing abundant clasts of broken quartz crystals occur within the CVC and Darwin Granite (Plate 6.3). The tourmaline veins range from 1cm to 20cm wide and can be traced along strike for over 5m. Tourmaline occurs with magnetite and pyrite in one vein within the CVC, but this mineral association is rare. In thin section, tourmaline crystals are tabular, while quartz appears finely recrystallised. Within the Darwin Granite, tourmaline veins trend NW-SE, whereas in the CVC they have more varied orientations.

Plate 6.3: Tourmaline vein with angular white quartz crystals from the western margin of the Darwin Granite. The angular nature of clasts supports the hypothesis that tourmaline veining is related to hydrothermal brecciation.

Tourmaline veins within the study area are believed to represent hydrothermal intrusive breccias (Fig. 6.1). Within the tourmaline veins, numerous angular quartz clasts incorporated from the surrounding wall rocks are set in a fine grained tourmaline matrix. There is no preferred orientation of clasts, and jigsaw-fit textures are rare. Tourmaline crystals in the breccia matrix do not exhibit any preferred orientation. The lack of any preferred orientations in the matrix or clasts is suggestive of a hydrothermal, rather than tectonic origin. Tectonic breccias should exhibit some evidence of structural controls, such as millings of quartz fragments or alignment of tourmaline crystals within the breccia matrix. Magmas rich in boron have increased H_2O solubilities compared to fluorine-rich magmas (Pollard *et al.*, 1987). This generally causes boron-rich magmas to have a higher volatile content, leading to greater mechanical energies being present during crystallisation, and allowing the development of hydrothermal intrusive breccia pipes of tourmaline (Fig. 6.1; Pollard *et al.*, 1987).

Microprobe analyses of tourmaline from Prince Darwin (Eastoe *et al.*, 1987), Jukes Proprietary Prospect (Doyle, 1990) and the Darwin Granite (Appendix C) indicate that tourmaline across the region is iron rich (FeO / FeO+MgO = 0.66-0.84) and aluminium-poor (FeO+MgO / FeO+MgO+Al_2O_3 = 0.33-0.4) and is of the iron-rich form, schorl (Table 6.1). Tourmaline of the schorl-elbaite series is characteristic of peraluminous leucocratic granites (Deer *et al.*, 1966; Bernard *et al.*, 1985).

Table 6.1: Data obtained from tourmaline veins in the Jukes-Darwin Mining Field using the electron microprobe. FeO / FeO+MgO values indicate the iron richness of the veins, while FeO+MgO / FeO+MgO+Al_2O_3 values indicate that the veins are aluminium poor (Data this study; Eastoe *et al*, 1987; Doyle, 1990)

TOURMALINE LOCALITY	FeO / FeO+MgO	FeO+MgO / FeO+MgO+Al_2O_3
Darwin Granite	0.66	0.35
Prince Darwin	0.77	0.4
Jukes Proprietary	0.84	0.33

Tourmaline generally crystallises during the late- to post-magmatic stages of granite emplacement (Charoy, 1982). Within the study area, tourmaline veins are only recognised in the Darwin Granite and the CVC along the western edge of the Darwin Plateau. They are absent from the Tyndall Group and the Owen Conglomerate. Therefore, based on stratigraphic evidence, geochemical evidence and comparisons with tourmaline veins from other granites, it is concluded that tourmaline veins formed during or immediately after emplacement of the Darwin Granite.

6.2.3 *Barite Veins*

White (1975) described the occurrence of minor irregular barite veins within the Darwin Granite to the north of South Darwin Peak. Within the study area only one barite vein (25cm x 2m) was observed during this study, striking N027° within the Darwin Granite in the central region of the Darwin Plateau (Fig. 3.1). The barite ranges from coarse to fine grained, with crystals varying in colour from milky white to light grey (78334).. In thin section, elongate tabular phenocrysts are present within a granular crystalline groundmass of barite with minor quartz. There is a preferred orientation of crystals within the granular groundmass. Lamellar twinning is common and a strong mineral cleavage is observed in thin section. Minor hematite grains and quartz crystals occur throughout the barite vein. Geochemical data from White (1975) and Crawford (1987) show that the Darwin Granite contains up to 1396ppm Ba. However sulphur isotope signatures from the barite vein give $\partial^{34}S$ values of +29.01‰ suggesting a seawater sulphate source. This suggests that barite veining has developed following collapse of the magmatic system which allowed the ingress of seawater into the granite (Fig. 6.1).

Within the Jukes-Darwin Mining Field the major occurrence of barite is at Taylours Prospect (Fig. 1.2; Hills, 1914). Barite occurs as a series of en echelon veins, up to 1m wide and 10m long, within a 400m long east-trending fault zone in the CVC northeast of Mt Darwin (Hills, 1914; White, 1975). There has been no report of barite veining within the Tyndall Group or the Owen Conglomerate close to the study area. Due to the restriction of barite veining to the granite body it is assumed that vein emplacement is related to increased volumes of seawater moving through the granite as it cooled.

6.2.4 *Quartz Veins*

Quartz veins are present within the CVC, Darwin Granite, Tyndall Group and Owen Conglomerate. In the CVC, rare quartz veins mostly do not exceed 5cm in width. The largest quartz vein in the CVC has a strike length of 25m and at one locality, a quartz vein striking N336^{o} cross-cuts an earlier tourmaline vein striking N319^{o}. In the Darwin Granite, quartz veins are randomly oriented and range between 1-10cm in width. In the Tyndall Group, vuggy quartz veins up to 20cm x 5m are well-developed parallel to the NW-SE cleavage. Quartz veining within the Owen Conglomerate is common across all outcrops, and quartz fills tension gashes on South Darwin Peak.

The presence of a quartz vein cross-cutting an earlier formed tourmaline vein indicates that at least some quartz veins formed after the tourmaline veining event. Furthermore, the presence of quartz veins in the Tyndall Group and Owen Conglomerate, and their close alignment with the dominant Devonian (Tabberabberan) structural trend suggests a structural origin for quartz veining (Fig. 6.1).

6.3 SULPHUR ISOTOPES

Sulphur isotope analyses of barite from a vein within the Darwin Granite (1 analysis) and pyrite from East Darwin (2 analyses), veins within the Darwin Granite (2 analyses) and disseminated within the Tyndall Group (2 analyses) have been obtained using laser ablation techniques on sulphide grains at the University of Tasmania (Huston *et al.*, 1992): Results are listed in Table 6.2. These results are used in conjunction with existing sulphur isotope data (Fig. 6.2) from Prince Darwin, East Darwin, the Darwin Granite and Findons within the vicinity of Mt Darwin (Fig. 1.2; Eastoe *et al.*,1987) to identify the likely sources for sulphur, and to establish any sulphur isotopic zonation around the Darwin Granite.

Table 6.2 Sulphur isotope signatures obtained on sulphides (3 localities) and sulphates (1 locality) from within the field area.

SAMPLE	MINERAL	$\partial^{34}S$ VALUES (‰)
Darwin Granite (vein)	Pyrite	+8.97, +14.45
Darwin Granite (vein)	Barite	+29.01
East Darwin (disseminated)	Pyrite	+13.41, 14.33
Tyndall Group (vein)	Pyrite	+11.01, 12.63

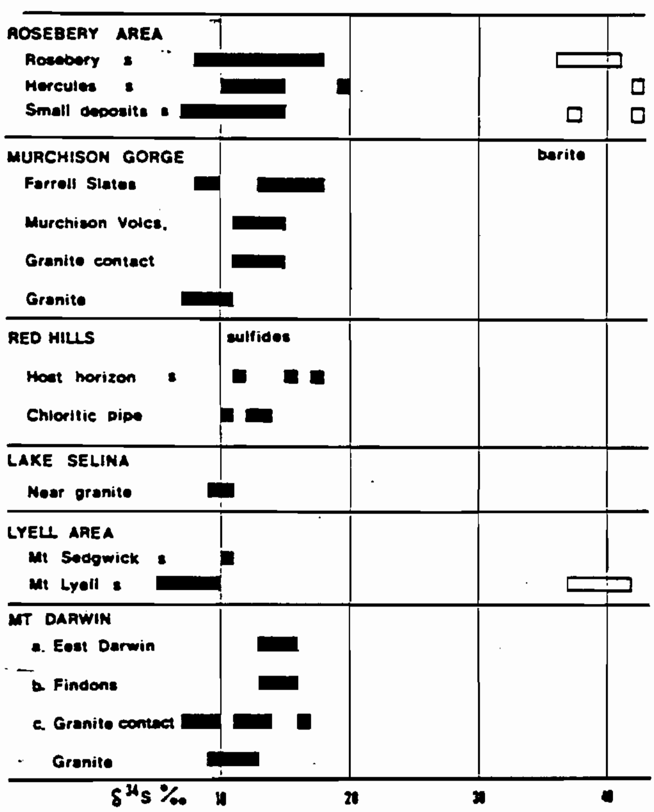

Figure 6.2: Sulphur isotope signatures from the Mt Darwin-South Darwin Peak area and from elsewhere in the Mount Read Volcanics (after Eastoe *et al.*, 1987).

$\partial^{34}S$ values from pyrite in the Mt Darwin region range from +7 to +16.5‰ (Eastoe *et al.*, 1987). The lowest $\partial^{34}S$ values have been recorded from Prince Darwin and the Darwin Granite, but Prince Darwin displays a wide range in $\partial^{34}S$ values (from +7 to +16.5‰). The heaviest $\partial^{34}S$ values were obtained from East Darwin and Findons. Figure 6.3 shows the spatial variation of the sulphur isotopes away from the Darwin Granite. Due to the large range in $\partial^{34}S$ values within the region, the median $\partial^{34}S$ value has been plotted using data from this study, Polya *et al.* (1986), Eastoe *et al.* (1987) and Solomon *et al.* (1988; Fig. 6.3). Figure 6.3 indicates an increase in median $\partial^{34}S$ values with distance from the granite. A similar increase also occurs out from the Murchison Granite (Polya *et al.*, 1986).

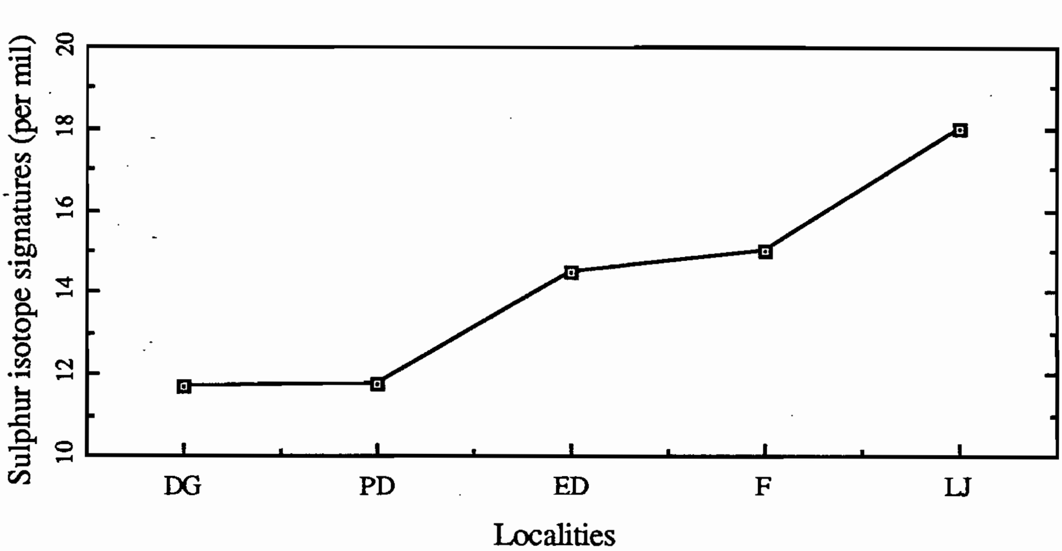

Figure 6.3: Plot of median $\partial^{34}S$ values from localities within the Jukes-Darwin Mining Field. The prospects are with increasing distance from the Darwin Granite (DG), Prince Darwin (PD), East Darwin (ED), Findons (F) and Lake Jukes (LJ) (after this study; Polya *et al.*, 1986; Eastoe *et al.*, 1987; Solomon *et al.*, 1988).

Sulphur isotope analyses of pyrite from the Tyndall Group (+11.01 to +12.63 ‰) are lighter than those from East Darwin, and are more similar to signatures from the Darwin Granite. The increasing trend in $\partial^{34}S$ values (Fig. 6.3) indicates a zonation to heavier $\partial^{34}S$ away from the Darwin Granite. The increase in $\partial^{34}S$, with distance from the granite, indicates that seawater sulphate has comprised an increasing proportion of hydrothermal fluids; low $\partial^{34}S$ values close to the granite represent the maximum proportions of magmatic sulphur within the fluids. The trend to heavier $\partial^{34}S$ away from the Darwin Granite indicate that heat from the granite has affected circulating fluids, and consequently that mineralisation is related to granite emplacement.

The trend to heavier sulphur isotope values away from the Darwin Granite (Fig. 6.3) are consistent with mixing of Cambrian seawater sulphate ($\partial^{34}S$ +30‰) and either magmatic or leached rock sulphur (average $\partial^{34}S$ 0±5‰; Ohmoto & Rye, 1979; Ohmoto, 1986). The input from Cambrian seawater sulphate increases with distance from the Darwin Granite, explaining the trend to progressively higher values. This scenario is consistent with the genetic models of Solomon (1981) and Large (1989), which propose the Darwin Granite as the heat source for a regionally convecting hydrothermal cell. Sulphur isotope values from within the region are similar to values obtained on granite-related mineralisation at Lake Selina (+8 to +12‰; Solomon *et al.*, 1988). The values also fall within the range of values from the Rosebery deposit (+6 to +16‰; Large, 1992). Sulphur isotope trends around the Darwin Granite suggest the presence of a sub-seafloor hydrothermal convection cell that developed during emplacement of the Darwin Granite in the Cambrian.

6.4 TIMING OF MINERALISATION

Mineralisation within the Jukes-Darwin Mining Field is thought, based on geological and sulphur isotope evidence, to be of Cambrian age and to predate deposition of the Tyndall Group and Owen Conglomerate (Eastoe *et al.*, 1987; Doyle, 1990). At Prince Darwin mineralisation is related to magnetite-hematite±tourmaline veining which most likely occurred synchronously with or closely following granite intrusion, based on the restriction of this vein type to the CVC and Darwin Granite. Clasts of magnetite vein material occur within the basal conglomerate of the Tyndall Group (Chapter 3.0) and has been recorded by Doyle (1990) within basal Owen Conglomerate at Jukes Proprietary Prospect (Fig. 1.2), indicating that magnetite veining predates Tyndall Group and Owen Conglomerate deposition. At Jukes Proprietary Prospect and at East Darwin, mineralisation occurs at the boundary of the CVC and Tyndall Group correlates (White, 1975; Doyle, 1990), again suggesting a pre-Owen age for mineralisation. Remobilisation of sulphide mineralisation during Tabberabberan-related deformation appears to have occurred at East Darwin, based on an absence of sulphides from the Tyndall Group in the study region and the strongly cleaved character of the host rocks. Age constraints on time of deposition for the Tyndall Group and Owen Conglomerate (Chapter 3.0), and the sulphur isotope zonation surrounding the Darwin Granite, indicate that sulphide mineralisation within the Jukes-Darwin Mining Field is of Cambrian age and has been generated by hydrothermal processes driven by heat related to emplacement of the Darwin Granite.

6.5 COMPARISON OF STUDY AREA TO PORPHYRY COPPER REGIONS

Several authors (eg. Hunns, 1987; Doyle, 1990; Large, 1992) have recognised similarities between certain regions within the MRV, such as Jukes-Darwin and Lake Selina-Murchison Gorge, and porphyry copper districts. These workers have hypothesised that potential for porphyry style mineralisation (Fig. 6.4) exists in the MRV, and that the Jukes-Darwin copper occurrences represent subeconomic examples of this mineralisation type. Despite several similarities between the MRV copper shows and porphyry copper deposits, there are also marked differences (Table 6.3), raising doubts about the possibility that copper mineralisation around the Darwin Granite is of the porphyry copper variety.

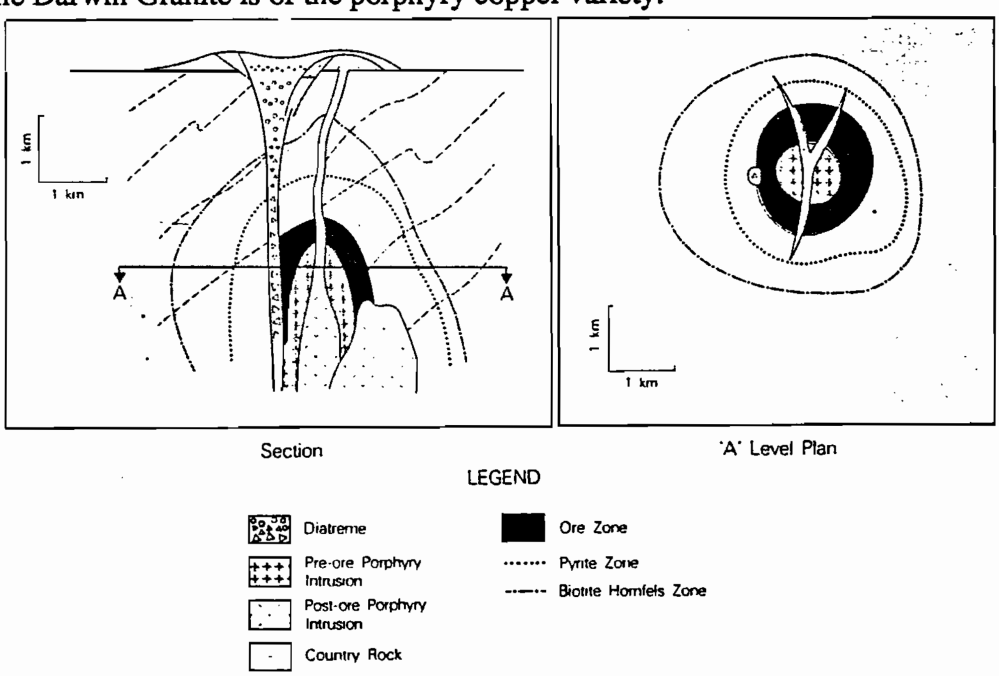

Figure 6.4: Model of a classic-type porphyry copper deposit (after Sutherland Brown, 1976).

Table 6.3: Similarities and differences between the Mt Darwin region, and characteristics of classic porphyry copper deposits.

SIMILARITIES	DIFFERENCES
K-feldspar, phyllic, argillic alteration	Bulk of Darwin Granite is equigranular
Early magnetite veins host Cu-Au mineralisation	Heavy sulphur isotope signatures
Porphyritic texture in granodiorite	SiO_2 rich granite dominant
Multiple veining events (magnetite,tourmaline,barite)	Poorly developed quartz veining
Proximity of mineralisation to intrusives	
Cu-Au mineralisation dominant	
Presence of hydrothermal tourmaline breccias	

Alteration within the granite and CVC includes pervasive K-feldspar and more selective sericite and chlorite alteration (Chapter 6.0) which are representative of potassic, phyllic and phyllic-argillic alteration assemblages, recognised at porphyry copper deposits (Sillitoe, 1972; Titley & Beane, 1981; Sillitoe, 1984). Hydrothermal tourmaline breccias similar to those recognised on the Darwin Plateau are known from several porphyry copper deposits (eg. Los Bronces-Rio Blanco and El Salvador, Chile), and boron complexes may play an important role in the transportation of metals in these systems (Gustafson & Hunt, 1975; Charoy, 1982; Warnaars *et al.*, 1985).

Differences between the MRV copper mineralisation and porphyry copper deposits include a lack of porphyritic intrusives, absence of stockwork zones, and heavy sulphur isotope signatures (+7 to +16‰) from the Darwin Granite and associated mineralisation occurrences compared to porphyry copper deposits (-3 to +1‰; Ohmoto & Rye, 1979; Heithersay & Morrison, 1992). It therefore is concluded that the Darwin Granite is unlikely to be related to (traditional) porphyry copper style mineralisation.

The Cu-Au mineralisation in the Mt Darwin region is granite-related and sulphur isotopes indicate a large seawater sulphate input. In classic porphyry copper systems a convecting meteoric hydrothermal cell is generated surrounding an inner magmatic-hydrothermal zone (Gustafson & Hunt, 1975). The setting of the CVC at the time of granite emplacement is thought to have been submarine, based on the occurrence of VHMS deposits (in the CVC) that were deposited onto the seafloor (Large, 1992). A submarine setting would lead to seawater dominating the volcanic pile and cause a seawater hydrothermal convection cell to be generated upon granite emplacement, rather than a meteoric convection cell. This could significantly alter the characteristics of a porphyry system and would form a hydrothermal system more consistent with those of VHMS deposits.

6.6 DISCUSSION

Mineralisation occurrences are relatively common within the Jukes-Darwin Mining Field, and some mines (eg. East Darwin) have produced significant mineralisation at economic grades (although low tonnages), indicating the exploration potential of the area. Although the region is unlikely to contain classic porphyry copper style mineralisation, evidence of a Cambrian age for Cu mineralisation and the spatial association of Cu mineralisation to the granite raise the prospect of granite-related mineralisation, possibly at depth, or obscured beneath younger Tyndall Group cover.

The restriction of magnetite and tourmaline veining to the CVC and Darwin Granite, and presence of magnetite vein fragments within basal conglomerate of the Tyndall Group (Chapter 3.0), suggest these vein sets formed prior to the deposition of the Tyndall Group, while widespread quartz veins within all lithologies suggest a later (possible Tabberabberan) age for quartz veining (Fig. 6.1). Cu-Au mineralisation is only known to be associated with magnetite veins; all other populations are barren. Two dominant structural orientations, NW-SE and NE-SW, control magnetite veining within the study area.

Doyle (1990) suggested that the Jukes Proprietary Prospect (Fig. 1.2) represents a hybrid between a porphyry copper deposit and a massive sulphide deposit. The presence within the

CVC of the Mt Lyell Cu-Au VHMS deposits, less than 20km north of the Jukes-Darwin region, indicate that hydrothermal processes capable of producing large economic deposits existed in the region. Furthermore, mineralisation at Jukes-Darwin is similar to mineralisation lower in the sequence at Mt Lyell (Collins & Williams, 1986). The Cambrian granites were potentially excellent heat sources, capable of driving the hydrothermal processes within the CVC that are recognised through sulphur isotope zonation (Solomon, 1981). Sulphur isotope signatures in the CVC and Darwin Granite are indicative of a high input from seawater sulphate and are more consistent with sulphur values from Cambrian VHMS deposits (+5 to +12‰; Large, 1991) than with porphyry copper style mineralisation (0 ± 5‰; Ohmoto, 1986). Magnetite-pyrite veins are recorded beneath VHMS deposits (Large, 1977) and mineralisation in the Jukes-Darwin Mining Field represents high temperature mineralisation generated through emplacement of the Darwin Granite.

Chapter 7.0 GEOCHEMISTRY

7.1 INTRODUCTION

Major element and trace element analyses have been carried out on seven samples of the Darwin Granite, two coherent volcanic units within the CVC and a dacite from the Tyndall Group in order to geochemically classify and contrast the rock units, and to assess the degree and nature of alteration within the various groups. Sample locations in the study area are shown in Appendix D. Because hydrothermal alteration can significantly modify primary lithologies, classifications of primary lithologies and comparisons between units are based primarily on the immobile elements. Rare Earth Element (REE) analyses have also been undertaken to aid geochemical comparisons within the study area and with units elsewhere in the MRV. Geochemical data for the samples analysed during this study is listed in Table 7.1.

7.1.1 *Analytical Methods*

Ten rock samples were analysed using the University of Tasmania's XRF Spectrometry facilities. Sample sizes varied from 5-10kg for the Darwin Granite, and 0.5-1kg for coherent volcanic units of the CVC and Tyndall Group. Samples were crushed using a steel jaw crusher and then ground to powder in a tungsten carbide disc mill. Major elements were determined on fusion discs (3.75g borate glass flux, 0.7g sample-rock powder, 0.05g $LiNO_3$), whereas trace elements were determined upon pressed powder pills (6g sample-rock powder, boric acid). Loss on ignition (L.O.I.) analyses were undertaken to determine the volatile content; this involved heating 1-2g of sample in a furnace at 1000°C overnight. Two standards, Tasbas and Tasgran, were analysed concurrently to assess the precision of the analyses. REE contents of igneous units within the study area were determined using the ion-exchange XRF procedure of Robinson *et al.* (1986).

	Equigranular Granite		Darwin Granite			Granodiorite		CVC Rhyolite	Alt. Rhyolite	Tyndall Group Dacite
	GS1	GS2	GS3	GS6	GS7	GS4	GS5	W6	5	GST
(Wt%)										
SiO2	74.56	76.93	75.38	74.83	75.79	76.51	76.23	75.2	60.15	71.79
TiO2	0.22	0.19	0.19	0.19	0.21	0.2	0.26	0.11	0.57	0.45
Al2O3	12.83	12.45	12.57	13.6	13.63	13.96	13.54	11.72	10.6	15.39
Fe2O3	1.72	2.71	1.86	1.95	1.54	0.39	2.35	0.79	9.84	2.71
MnO	0.01	0.01	0	0	0	0.01	0.1	0	0.07	0
MgO	0.33	0.35	0.32	0.4	0.33	0.21	0.3	0.2	8.6	0.28
CaO	0.04	0.05	0.02	0.09	0.1	0.28	0.18	0.01	0.29	0.07
Na2O	1.14	0.19	1	2.2	2.43	3.62	2.95	0.24	0.17	6.3
K2O	6.38	7.84	6.96	6.77	6.58	1.87	2.23	9.21	5.86	3.49
P2O5	0.03	0.05	0.04	0.05	0.04	0	0	0.03	0.31	0.1
L.O.I.	1.75	1.76	2.13	1.36	1.47	2.29	2.57	0.79	2.98	1.21
Total	97.26	100.77	98.34	100.08	100.65	97.05	98.14	97.51	96.46	100.49
Trace Elements (ppm)										
Ni	2	3	2	5	5	2	3	2	18	3
Cr	3	2	2	2	3	3	4	1	13	8
V	19	20	18	16	17	2	4	5	186	47
Sc	3	4	3	2	3	<2	<2	4	89	8
Zr	134	124	134	128	137	134	190	156	159	234
Nb	13	11	12	12	13	14	20	19	16	13
Y	18	22	18	12	14	2	7	46	27	30
Sr	48	59	52	67	58	115	75	80	7	85
Rb	196	211	190	200	195	74	116	224	494	77
Ba	1240	3152	1941	1348	1151	416	444	3133	314	674
Th	31	35	34	38	43	40	44	21	97	13
Pb	50	327	196	6	6	14	19	4	10	3
Ti/Zr	9.84	9.19	8.5	8.9	9.19	8.95	8.2	4.23	21.49	11.53
Zr/TiO2	0.1	0.11	0.12	0.11	0.11	0.11	0.12	0.24	0.05	0.09
Nb/Y	0.69	0.49	0.66	0.98	0.93	6.04	2.66	0.42	0.6	0.43
Rare Earth Elements (ppm)										
La	69.8	80.2	55.8	57.9	65.2	3.9	4.7	23.4	49	59.5
Ce	115.1	132.9	99.9	96.4	106.3	6.4	8.5	48	89.9	120.6
Pr	11.63		9.98				1.26	5.25		12.02
Nd	32.4	34.5	30.4	27.5	30.8	1.8	4	19.9	41	53.4
Sm	5.15		5.04				1.1	3.37		7.47
Eu	1.27		1.19				0.77	0.64		1.68
Gd	3.11		3.39				0.93	3.86		5.67
Tb	0.56		0.65				0.18	0.95		0.91
Dy	3		3.21				1.12	6.87		4.39
Ho	0.72		0.75				0.46	1.75		0.93
Er	2.1		2.16				1.41	5		2.57
Yb	2.04		2.08				0.92	5.79		2.29

Table 7.1: Whole rock and REE data for the Darwin Granite, CVC and Tyndall Group within the Mt Darwin - South Darwin Peak area.

7.2 IGNEOUS ROCKS WITHIN THE STUDY AREA

Igneous rock units analysed from within the study area include two phases of the Darwin Granite (equigranular granite and granodiorite) along with coherent units from both the CVC and the Tyndall Group. These samples were classified petrographically in Chapter 3.0 and Chapter 4.0 and are classified here on geochemical criteria. From petrographic observations (Chapter 3.0, 4.0) it is clear that the CVC, Darwin Granite and Tyndall Group have been subjected to varying degrees of hydrothermal alteration and metamorphism. Alteration has caused sericitisation and chloritisation of primary plagioclase feldspars and biotites. Primary quartz and K-feldspar have generally proved resistant to alteration within the granite, although K-feldspar in the CVC has been partially altered to chlorite-sericite.

7.2.1 *Element Mobility Determination*

For rocks that exhibit petrographic evidence of hydrothermal alteration, geochemical classification should only be based on those elements that remained immobile during alteration. A graph of TiO_2 vs Zr (Fig. 7.1) for the Darwin Granite is plotted to show that these elements act relatively coherently; seen from the straight plot of values. One value is observed not to conform to the overall trend of the granites. Coherent behaviour within the plot indicates element immobility (Stolz, 1992). This procedure is most suited to suites of cogenetic igneous rocks. However, the Darwin Granite, CVC and Tyndall Group, have been suggested to be unrelated (Solomon, 1960; Crawford, 1987) making mobility determinations based on elemental discrimination diagrams of limited value. Consequently, only those elements widely accepted as being immobile within the MRV (eg. Ti, Zr, Y, Nb, REE; Crawford *et al.*, 1992) are used here for geochemical classification.

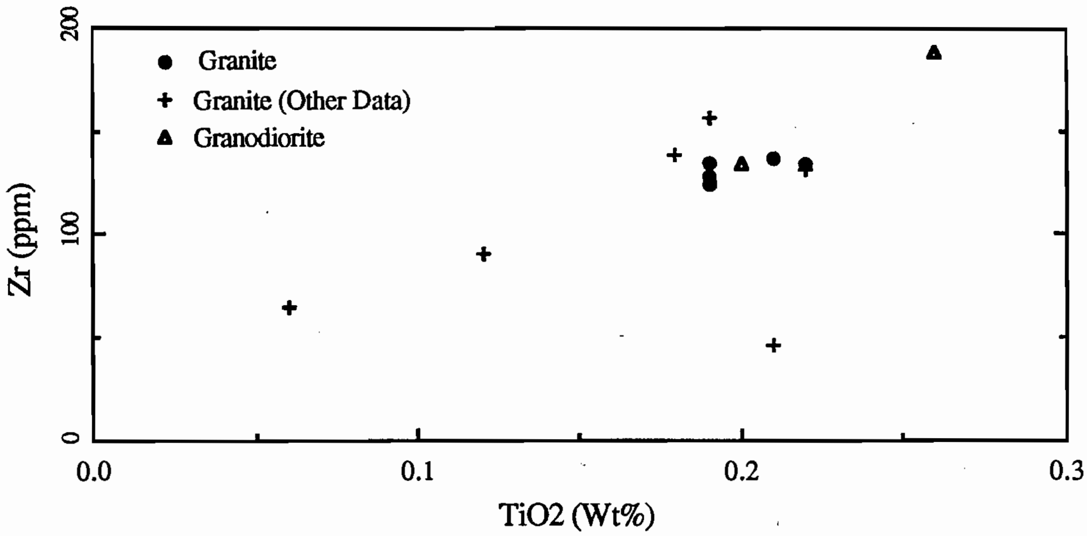

Figure 7.1: Plot of TiO_2 vs Zr for the Darwin Granite. Plot shows relatively coherent behaviour between TiO_2 and Zr suggesting that these elements have remained immobile throughout alteration.

7.2.2 *Geochemical Classification*

Volcanic and plutonic rock types can be classified on whole rock compositions (eg. Cox *et al.*, 1979), trace elements (eg. Winchester & Floyd, 1977; Hallberg, 1984) or a combination of several geochemical characteristics (eg. Ishihara, 1981; White & Chappell, 1983). In consequence of the effects of hydrothermal alteration in the study area, volcanic rocks are classified using immobile trace elements while the Darwin Granite is classified using the systems of Ishihara (1981) and White & Chappell (1983). A ternary AFM plot of Na_2O+K_2O, MgO and FeO (Fig. 7.2) shows that the equigranular granite and granodiorite have calc-alkaline affinities.

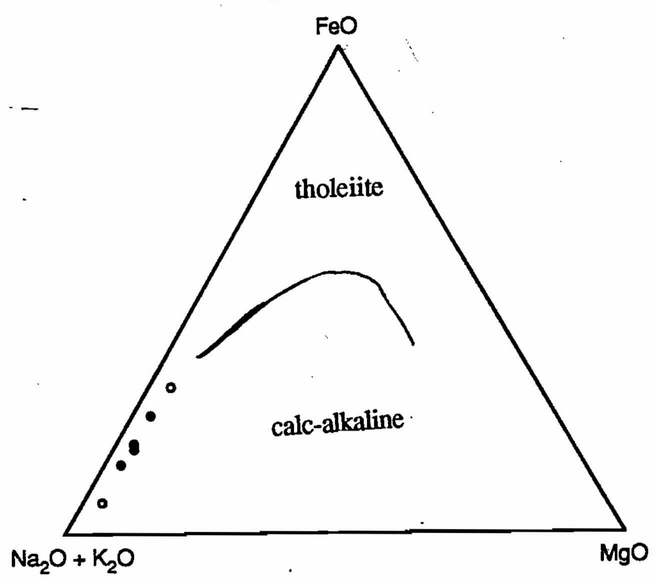

Figure 7.2: Ternary AFM diagram indicating the calc-alkaline affinities of the equigranular granite (closed circles) and the granodiorite (open circles). (after Irvine & Baragar, 1971).

Volcanic Rocks (CVC and Tyndall Group)

Because Nb, Y, Zr and TiO_2 have remained relatively immobile (section 7.2.1), the volcanic units of the CVC and Tyndall Group are classified using the Nb/Y vs Zr/TiO_2 method of Winchester & Floyd (1977; Fig. 7.3). Variations in Zr/TiO_2 define the compositional range from basalt to rhyolite, whereas variations in Nb/Y distinguish subalkaline and alkaline volcanic suites. Of the coherent units analysed from the study area, one of the CVC units plots in the rhyolite field and one in the rhyodacite/dacite field while the Tyndall Group volcanic plots in the rhyolite field (Fig. 7.3). Petrographically, CVC units were identified as rhyolites and the Tyndall Group unit as a dacite (Chapter 3.0).

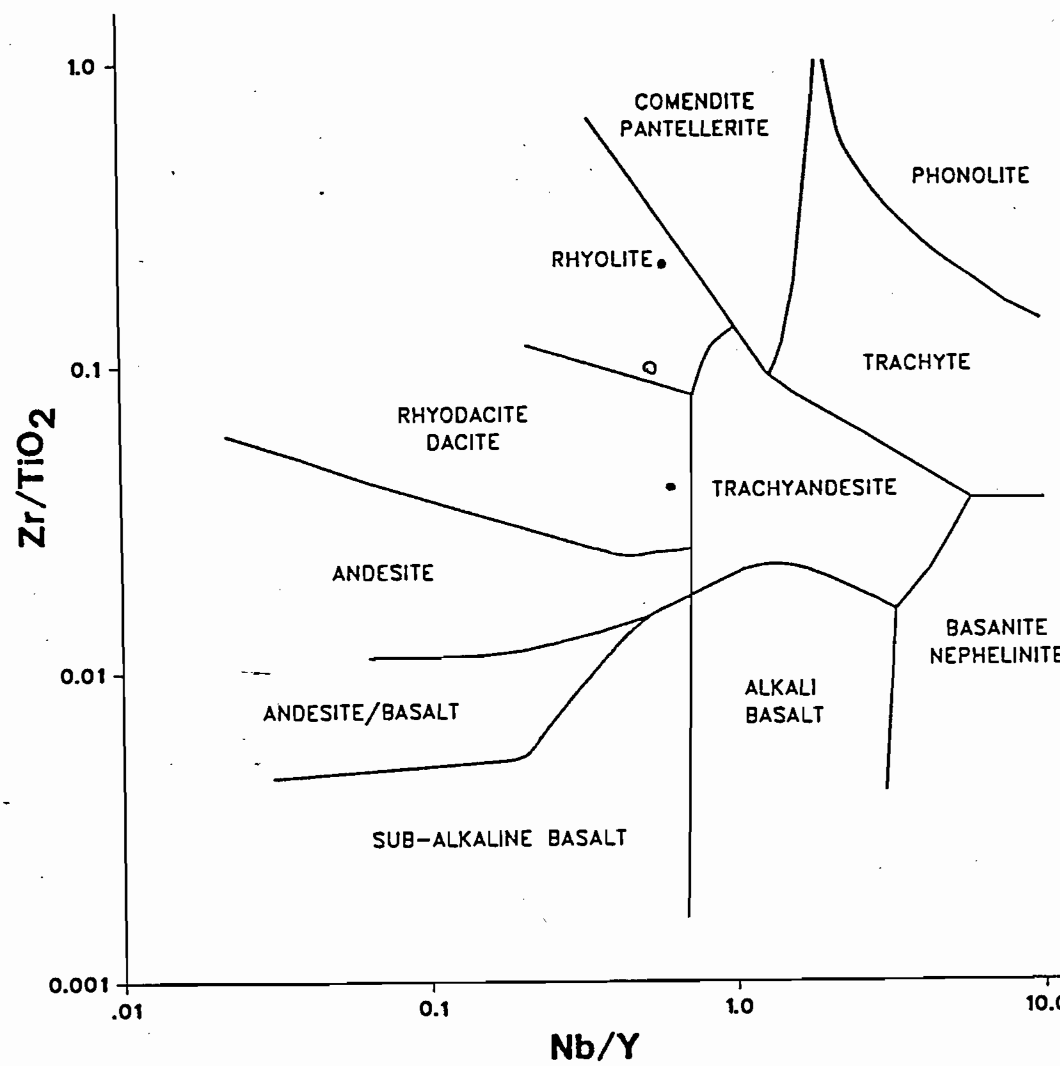

Figure 7.3: Plot of Nb/Y vs Zr/TiO_2 for two volcanic units of the CVC (closed circle) and one volcanic unit of the Tyndall Group (open circle).(after Winchester and Floyd, 1977).

Darwin Granite

Classification systems for granitic rock types are generally based upon whole rock geochemical data combined with normative mineral calculations and stable isotope determinations. The two most widely used classification systems for granitic rocks are the I- and S-type scheme (White & Chappell, 1983) and the magnetite and ilmenite series classification of Ishihara (1981). These two systems have been developed to classify granitic rocks in specific regions (eg. Tasman Fold Belt, Australia and circum-Pacific orogenic belt, Japan respectively) and may not always be applicable in other terrains (White & Chappell, 1983).

Field mapping, petrographic and geochemical studies indicate that there are two separate granitic phases within the Darwin Granite, equigranular granite and granodiorite (Chapter 4.0). Whole rock geochemistry data (Table 7.1) for the Darwin Granite indicates that both phases are SiO_2 rich, with a range between 74.56 - 76.93%. Both the equigranular granite and granodiorite are peraluminous, with Al_2O_3 / (Na_2O+K_2O+2CaO) > 1.1 (ratios range from 1.19 - 1.39 for equigranular granite and 1.56 - 1.70 for granodiorite). Difficulties arise when comparing the two phases on the basis of differences in major element chemistries due to the effects of alteration and metamorphism (discussed in section 7.3.2). The two phases can be discriminated on plots of SiO_2 vs Na_2O+CaO (Fig. 7.4) and SiO_2 vs K_2O (Fig. 7.5) and show that the granodiorite is enriched in CaO and Na_2O and depleted in K_2O relative to the equigranular granite. From studies of the effects of alteration on the equigranular granite it is found that the granite is depleted in CaO and Na_2O and enriched in K_2O overall. Alteration thus makes discrimination of the two phases based on widely used methods (Figs. 7.4, 7.5) unreliable (Turner & Verhoogen, 1960).

REE are generally considered immobile, and Figure 7.6 indicates that the granite is higher in total REE compared to the granodiorite. The granodiorite displays a distinctive positive Eu anomaly, consistent with plagioclase fractionation, that is not noted from the granite (Fig. 7.6). From REE data comparisons, the two granite phases are different. The markedly depleted REE data from the granodiorite is consistent with values expected from an SiO_2 enriched, differentiated, residual melt.

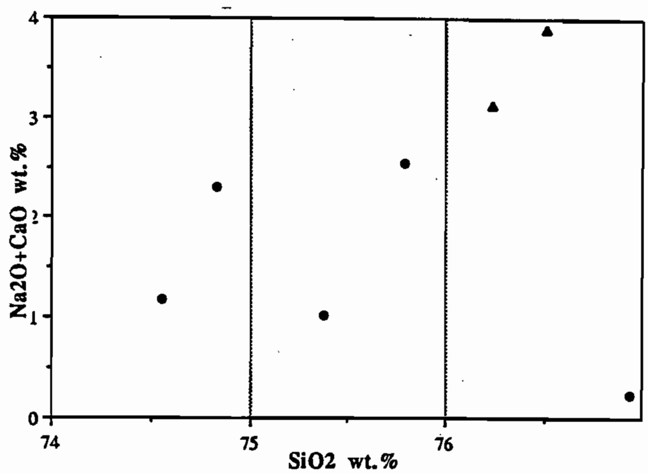

Figure 7.4: Plot of SiO_2 vs Na_2O+CaO for the equigranular granite (circles) and granodiorite (triangles).

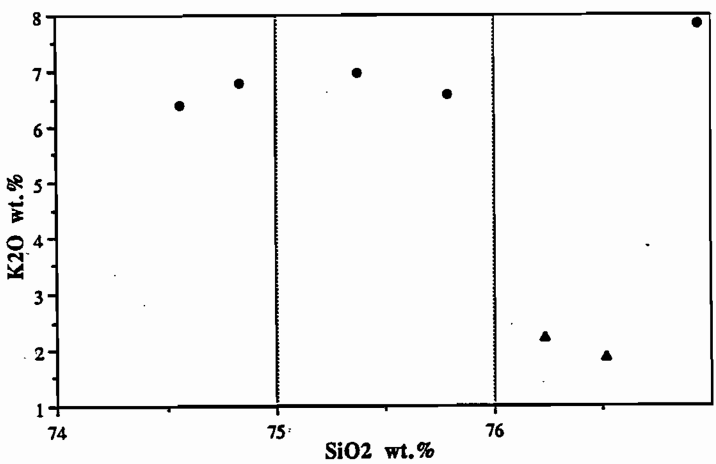

Figure 7.5: Plot of SiO_2 vs K_20 for equigranular granite (circles) and granodiorite (triangles).

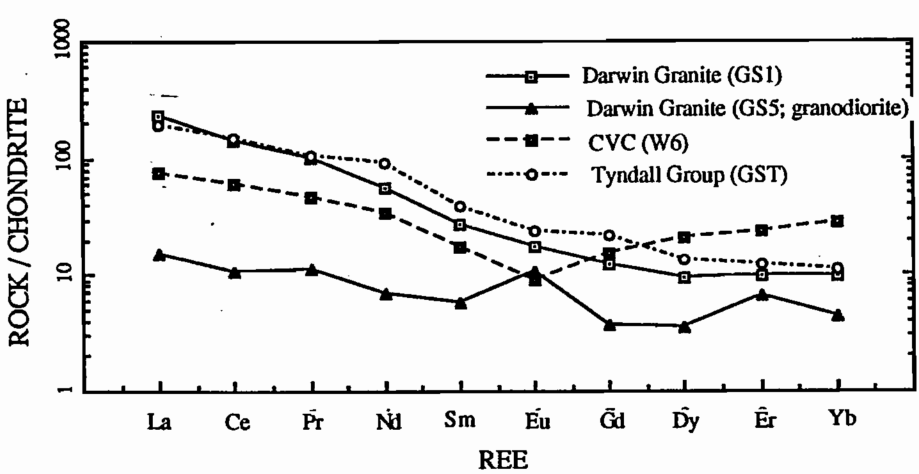

Figure 7.6: Plot of REE for the Darwin Granite (GS1=equigranular granite; GS5=granodiorite), CVC and Tyndall Group from within the study area.

Normative calculations for the equigranular granite and granodiorite (Appendix B) may not be representative of the primary lithologies due to effects of alteration. The norm shows that the granodiorite has more normative quartz, albite and corundum than the granite. Granites usually contain greater normative quartz than granodiorites (Middlemost, 1985). Both the units are corundum normative, with > 1% corundum in the norm. The I- and S-type classification scheme of White & Chappell (1983) relies heavily upon the contents of major and trace elements, and normative calculations for classification. The mobility of Na_2O, CaO, K_20, Sr and Rb can particularly affect the I- and S-type classification.

The Darwin Granite is associated with sulphide mineralisation (Chapter 6.0) which is a characteristic feature of magnetite-series granites elsewhere (Ishihara, 1981). Presence of abundant magnetite veining and disseminated magnetite across the granite are also features consistent with granites of the magnetite-series as are high magnetic susceptibilities (Ishihara, 1981).

Geochemical data for the Darwin Granite classifies it as S-type in the scheme of White & Chappell (1983; Table 7.2) and as magnetite-series by Ishihara's (1981) scheme (Table 7.3). Magnetite-series granites are equivalent to I-type granites, whereas ilmenite-series granites can be equivalent to I- or S-type granites (Ishihara, 1981; White & Chappell, 1983). The degree of alteration within the granite is sufficient to make classification using White & Chappell's (1983) scheme unreliable. The magnetite-ilmenite series classification is more consistent with the available data as it does not rely so heavily upon major element abundances which are no longer representative of the primary rock composition. Significant alteration denies use of the I- and S-type scheme whereas the magnetite-ilmenite system appears valid. Magnetite-series granites are generated at depth in the upper mantle or lower crust by the melting of rocks of characteristically igneous affinity. Based on the observed unreliability of the I- and S-type classification of White & Chappell (1983) and on the good fit of data using the magnetite- and ilmenite-series classification of Ishihara (1981), the Darwin Granite can be classified as a magnetite-series granite.

Table 7.2: Characteristics of the Darwin Granite that are compatible with I- and S-type granites as defined by White & Chappell (1983). Note that classification using this system relies heavily on use of major and trace elements that have been determined to have been mobilised.

S - TYPE GRANITES	I - TYPE GRANITES
K_2O/Na_2O high for equigranular granite	K_2O/Na_2O low for granodiorite
$Al_2O_3/Na_2O+K_2O+2CaO > 1.05$	Contains magnetite
>1% normative corundum	Related to sulphide mineralisation
<200ppm Sr	
$Na_2O<3.3$ (except is 3.62 in one sample)	
No hornblende	
Low CaO (0.04 to 0.10)	
Accessory monazite and apatite	

Table 7.3: Characteristics of the Darwin Granite that are consistent with magnetite- and ilmenite-series granites as defined by Ishihara (1981). Note that no characteristics were recognised in the Darwin Granite that were diagnostic of an ilmenite series granitoid.

MAGNETITE SERIES	ILMENITE SERIES
Contains magnetite	
Granite is magnetically susceptible (>1 x 10^{-4}emu/g)	
Positive sulphur isotope signatures	
Fe_2O_3 / $FeO > 0.5$	
Related to sulphide mineralisation	

7.3 ALTERATION GEOCHEMISTRY

Hydrothermal alteration may lead to elemental depletion or enrichment, significantly modifying the primary whole-rock composition (Stolz, 1992). Within the study area, primary lithologies have been subjected to near-surface weathering, hydrothermal alteration (potassic and chloritic) and regional metamorphism. All units have suffered at least partial alteration, so geochemical analyses no longer truly represent primary compositions. This section discusses the effects of hydrothermal alteration, weathering and regional metamorphism based on field observations and petrographic analyses, then evaluates the geochemical effects of each alteration style.

7.3.1 *Styles of Alteration*

The various alteration processes recognised in the study area have marked differences in their effects on rock compositions. Near-surface weathering and oxidation causes argillisation of feldspars and micas, and oxidation of magnetite and sulphides to hematite. Stratigraphic relationships (Chapter 3.0) indicate that the Darwin Granite was unroofed soon after emplacement in the Mid-Late Cambrian, exposing rock units to weathering processes at this time. The effects of oxidation are clearly visible in the study area, with magnetite partially to completely replaced by hematite in veins within the Darwin Granite and the CVC. Sample selection and preparation has removed weathered material, thus removing the effects of near-surface weathering from geochemical analyses.

Hydrothermal alteration is common surrounding granites (Gustafson & Hunt, 1975) and development of potassic and chlorite-sericite assemblages within the CVC and throughout the granite are interpreted to be granite-related. The Tyndall Group was deposited post-granite emplacement and the chlorite-sericite alteration which dominates the matrix throughout the Tyndall Group is thought to be dominantly of sub-seafloor hydrothermal origin with effects of Devonian regional metamorphism overprint. Hydrothermal alteration can lead to enrichment and depletion of varied elements depending on the character of the hydrothermal fluids (Heithersay & Morrison, 1992; Stolz, 1992).

Contact metamorphic processes have caused growth of secondary biotite and silica mobilisation within the CVC, with biotite hornfels restricted to the CVC adjacent to the contact with the Darwin Granite. Chlorite alteration has also developed adjacent to shear zones within the granite (Chapter 3.0).

7.3.2 *Geochemical Effects of Alteration*

The effects of hydrothermal alteration and metamorphism have been assessed for the CVC, Darwin Granite and Tyndall Group within the study region using data from this study, White (1975), Stolz & Large (1988) and Crawford *et al.* (1992), Appendix D. The alteration index (AI) of Ishikawa *et al.* (1976) is a measure of the intensity of alteration and is calculated by:

$$AI = 100(MgO+K_2O) / (MgO+K_2O+CaO+Na_2O)$$

The alteration index increases with increasing alteration intensity. Alteration index data for the study region is displayed in Appendix D and shows that values range from 85 to 97 (coarse grained granite), 34 to 44 (granodiorite), 45 to 99 for rhyolites within the CVC, and 37-90 for volcanics of the Tyndall Group. These values indicate that the effects of chlorite-sericite-K-feldspar alteration are strongest within the coarse grained granite and CVC rhyolites. Alteration is less intense within the granodiorite and Tyndall Group volcanics.

The AI values, petrographic studies and examination of whole-rock geochemical data (Table 7.1) indicate that the Darwin Granite is strongly altered. Crawford *et al.* (1992) have analysed unaltered Darwin Granite. This unaltered sample (Appendix D; Crawford *et al.*, 1992) will be used as the standard sample for the isocon method of comparing relative element mobilities between an unaltered sample and altered equivalents (Fig. 7.7; Grant, 1986; Huston, 1993). Trace elements which have been immobile within the granite (Y, Zr, TiO_2, Nb) are interspersed among other elements along the x-axis (Fig. 7.7). The trace elements are scaled relative to one another in order to form a straight line through the origin. A scaling factor can then be obtained for all of the elements plotted on the x-axis (Fig. 7.7) to bring them onto the straight line. This scaling factor is applied to the corresponding elements within the altered samples and plotted, thus giving the concentrations of altered samples relative to the standard sample. The isocon plot (Fig. 7.7) indicates that all samples of the Darwin Granite are enriched in Ni, Cr, Fe, K, Rb, P and depleted in Na, Sr and Ca (Fig. 7.7). Variations between the standard unaltered sample and the altered samples show that alteration effects are strong. The observed depletion in Na, Sr and Ca is consistent with alteration of plagioclase, while enrichment in K and Rb indicate sericitic alteration of plagioclase and K-feldspar alteration. A slight increase in some samples, of Fe, Cr and Ni, suggest chloritisation has also affected the rocks. The geochemical data is consistent with petrographic data (Chapter 4.0) which indicates sericite-chlorite alteration throughout the granite. It is difficult to distinguish sericitic from potassic alteration based on there compositional similarities, but the high whole rock geochemistry values obtained for K_2O (Table 7.1) and field observations, suggest that potassic alteration is developed.

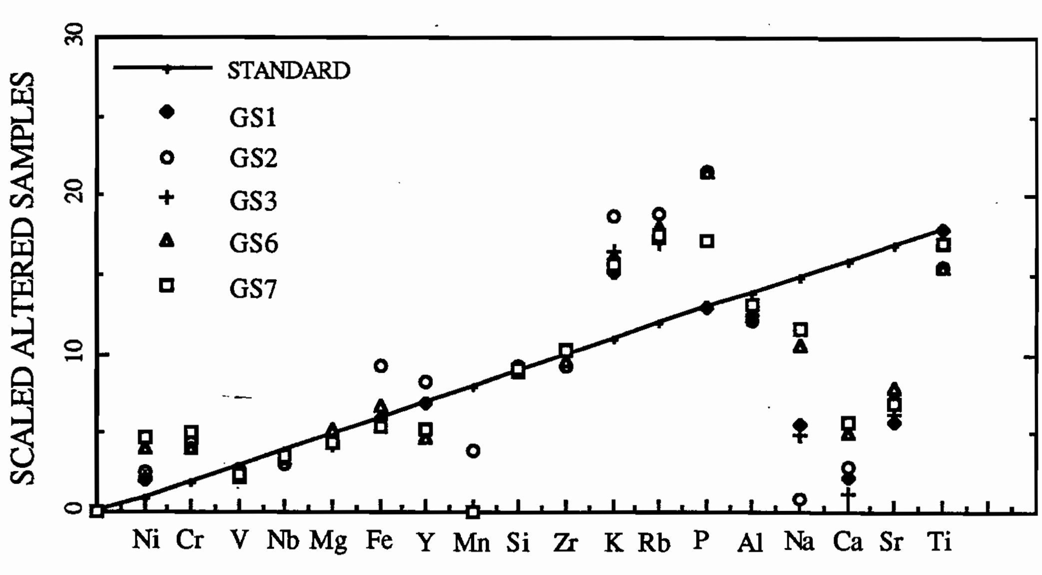

Figure 7.7: A plot of an unaltered sample of Darwin Granite (standard) against scaled altered samples of Darwin Granite (GS1, GS2, GS3, GS6, GS7) using the isocon method (after Grant, 1986; Huston, 1993).

7.4 GEOCHEMICAL COMPARISON WITH THE MRV

The coherent volcanic units comprising the MRV have been geochemically subdivided into five distinct suites (I-III calc-alkaline and IV-V tholeiitic) based upon their major element, trace element and REE compositions (Crawford *et al.*, 1992). These geological suites and the geological formations in which they occur are summarised in Table 7.4.

Table 7.4 : Geochemical suites of the MRV and the geological formations which comprise them (source Crawford *et al.*, 1992).

SUITES	CORRESPONDING MRV UNITS
I (calc-alkaline affinities)	CVC, Tyndall Group, Cambrian Granites, Eastern Quartz-Phyric Sequence
	Andesites of the Que-Hellyer Footwall Sequence
II (calc-alkaline affinities)	Andesites of the Southern Upper CVC
III (calc-alkaline affinities)	Basaltic and andesitic lavas of the Que-Hellyer Hangingwall Sequence
	Lynch Creek Basalts, Intrusive Basalts of Howards Plains area
IV (tholeiitic affinities)	Tholeiitic basalts of Henty Fault Wedge and Henty Dike Swarm
V (tholeiitic affinities)	Miners Ridge Basalts

Geochemical analyses from this study have been combined with data from White (1975) and Crawford *et al.* (1992; Appendix D), to compare igneous rocks in the study area with the MRV suites via major and trace element variation diagrams; specifically SiO_2 vs Fe_2O_3 (Fig. 7.8), SiO_2 vs TiO_2 (Fig. 7.9), SiO_2 vs Ti/Zr (Fig. 7.10) and REE patterns (Fig. 7.6). The Darwin Granite and volcanic units of the CVC and Tyndall Group in the study area plot in the field of suite I rocks on every major element variation diagram (Figs. 7.8-7.10) . REE patterns for the Darwin Granite, CVC and Tyndall Group within the study area are also consistent with suite I lithologies from other localities (Crawford *et al.*, 1992), showing enrichment in REE with distinct negative Eu anomalies within the CVC (Fig. 7.6). However, the granodiorite is depleted in LREE relative to other suite I units (Fig. 7.6). Crawford *et al.* (1992) classification is based on analyses of unaltered rocks, while data from this study is entirely derived from altered rocks. Despite differences in relative degrees of alteration, the immobile elements Ti/Zr fit with the ratio defined for suite I. All data indicates that rocks of the Mt Darwin-South Darwin Peak region are a part of suite I within the MRV.

Solomon (1980) suggested that the Darwin Granite is co-magmatic with lavas of the CVC, whereas Crawford (1987) proposed the Darwin Granite to be co-magmatic with lavas of the Tyndall Group. Possible genetic relationships can only be addressed by combining geochemical information with observed field relationships. The Darwin Granite clearly intrudes the CVC and is unconformably overlain by the Tyndall Group (Chapter 3.0). The unconformity between the Tyndall Group and Darwin Granite and the incorporation of eroded granite blocks into basal Tyndall Group indicate that the Tyndall Group was deposited after granite emplacement, crystallisation, and erosion to expose the granite. Thus, despite geochemical similarities, the Darwin Granite cannot be co-magmatic with volcanics of the Tyndall Group.

Major, trace and REE data for the Darwin Granite and CVC (this study; White, 1975; Crawford *et al.*, 1992; Appendix D), indicate that the CVC and Darwin Granite share some geochemical similarities, but some significant differences can also be noted. The Darwin Granite and CVC are both members of suite I within the MRV so are overall geochemically similar (Crawford *et al.*, 1992). The CVC volcanics are generally enriched in TiO_2 relative to the Darwin Granite and slightly depleted in SiO_2, and the chondrite-normalised plot of REE data (Fig. 7.6) illustrates that the negative Eu anomaly characteristic of the CVC is not recognised in the Darwin Granite.

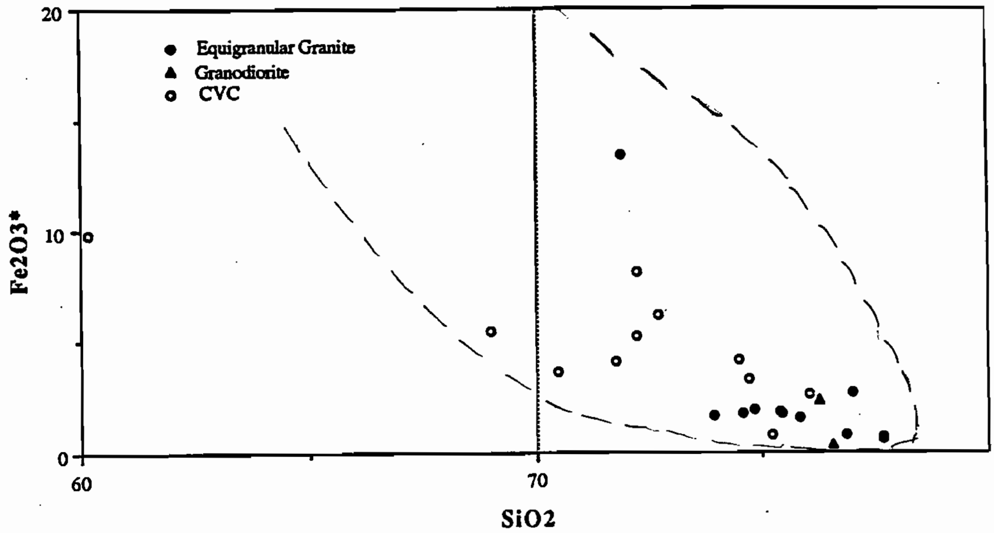

Figure 7.8: Plot of SiO_2 vs Fe_2O_3*(total iron) for units of the Darwin Granite and CVC across the study region. The field transposed onto the graph (dashed lines) represents Crawford *et al.*, (1992) range of values for suite I rock types in the MRV (data this study; White, 1975; Crawford *et al.*, 1992)

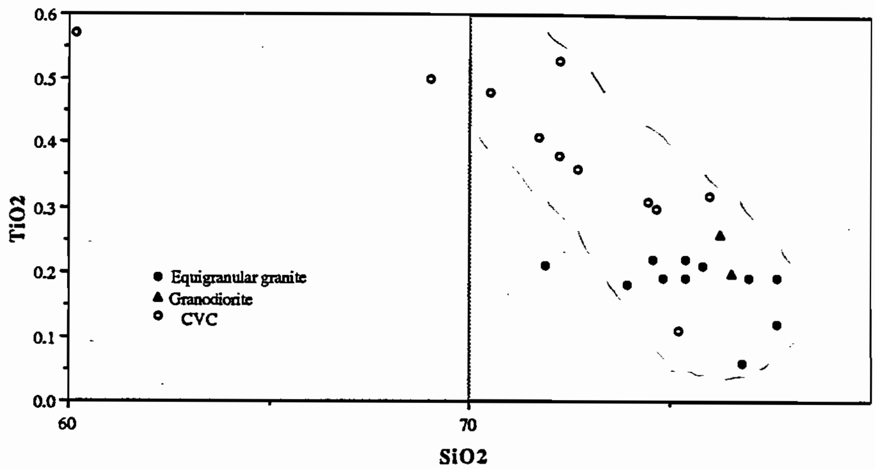

Figure 7.9: Plot of SiO_2 vs TiO_2 for analyses of the Darwin Granite and the CVC within the Mt Darwin region. The field (dashed lines) represents the range of values recognised for suite I rock types across the MRV (data this study; White, 1975; Crawford *et al.*, 1992).

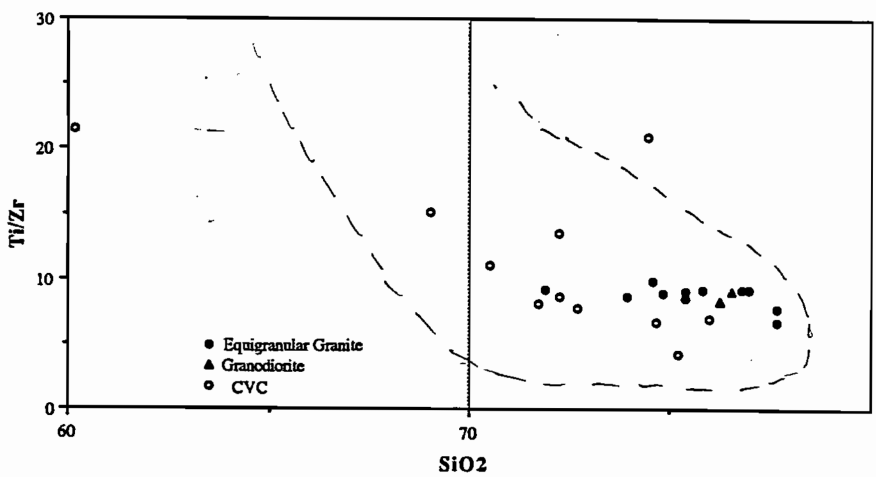

Figure 7.10: Plot of SiO_2 vs Ti/Zr. Units analysed are all from the Darwin Granite and volcanics of the CVC from within the study region. A field (dashed lines) corresponding to the range of values in suite I of the MRV is transposed onto the graph to determine the study regions relation to suite I rock types (data this study; White, 1975; Crawford *et al.*, 1992).

The similarities between the Darwin Granite and the CVC volcanics in the study area present the possibility that they are co-magmatic and that the Darwin Granite has intruded its own volcanic pile. Co-magmatic units of the CVC which may have been extruded at the time of granite intrusion could lie stratigraphically some distance above the CVC units that have been intruded. Units which could have formed by magma of similar or the same composition as the Darwin Granite being extruded at the surface would be less evolved than the granite. If the CVC volcanics within the study area are co-magmatic with the Darwin Granite then they could be expected to be less fractionated equivalents. The CVC and Darwin Granite are both highly altered and geochemical data can not reliably be compared to assess the degree of differentiation using the differentiation index of Thornton & Tuttle (1960).

After analysis of available geochemical data and stratigraphic data (Chapters 3.0, 4.0) it can be concluded that the Darwin Granite is not co-magmatic with the Tyndall Group. Comparisons between the CVC and the Darwin Granite show that the overall compositions are similar though differences in REE occur (Fig. 7.6). Based on the REE data it appears that the CVC has not formed by eruption of a magma with equivalent composition to the Darwin Granite. A more likely scenario is that the two units had the same parent magma. The Darwin Granite is a highly evolved remnant of this magma and fractionation has lead to marked changes in magmatic compositions between the CVC and Darwin Granite.

7.5 GEOCHEMICAL COMPARISON OF CAMBRIAN GRANITES

Leaman & Richardson (1989) suggest that a number of Cambrian granites lie unexposed within the MRV and belong to the same granitic suite as the Murchison and Darwin Granites (Fig. 2.2). In this section, geochemical data (Table 7.1; Appendix D), absolute age data (Table 2.1) and field relationships are compared between the Cambrian Darwin and Murchison Granites, Tasmania to assess their potential relationships. The Darwin and Murchison granites are also contrasted with Cambrian granites of Northern Victoria Land, Antarctica, to assess tectonic hypotheses that these regions were continuous across an old intercontinental suture (Fig. 7.16; Quilty, 1985).

7.5.1 *Tasmania : Darwin Granite vs Murchison Granite*

The Darwin and Murchison granites form a minor component, by volume, of the MRV belt, outcropping over 5km x 1km and 7km x 2km respectively. Absolute age determinations give ages of 524±15Ma (K-Ar) and 498Ma (U-Pb) for the Murchison Granite and 510Ma (U-Pb) for the Darwin Granite (Table 2.1; Adams *et al.*, 1985). Both granites crop out in the central MRV, with the Darwin Granite intruding the CVC and Murchison Granite intruding the Eastern Quartz Phyric Sequence (Fig. 2.1; Corbett, 1992). Pemberton & Corbett (1992) have demonstrated that the CVC and Eastern Quartz Phyric Sequence are at several localities laterally equivalent, so it is likely that the granites were emplaced to similar stratigraphic levels.

Geochemical data used in comparisons between the Darwin and Murchison Granites (this study; White, 1975; Stolz & Large, 1988; Abbott, 1992; Crawford *et al.*, 1992) is tabulated in Appendix D. Plots of Nb/Y vs Zr/TiO_2 (Fig. 7.11), SiO_2 vs Ti/Zr (Fig. 7.12), SiO_2 vs Fe_2O_{3total} (Fig. 7.13), SiO_2 vs Al_2O_3 (Fig. 7.14) and REE (Fig. 7.15) display many marked similarities for the two granitic suites. The plot of SiO_2 vs Fe_2O_3 (Fig. 7.13) displays a well defined trend which encompasses the analyses from both granites. The situation is similar for the Nb/Y vs Zr/TiO_2 (Fig. 7.11) and SiO_2 vs Ti/Zr (Fig. 7.12), where data from the Darwin Granite falls within the field of values encompassed by the Murchison Granite. The major differences between the two granites (Fig. 7.14) are the large variations in SiO_2 and Al_2O_3

recognised from the Murchison Granite; the Darwin Granite has a much more restricted range. REE patterns (Fig. 7.15) for the Darwin and Murchison Granites show similarities in LREE abundances but differences in HREE. The Murchison Granite is enriched in HREE relative to the Darwin Granite and the Murchison Granite displays a negative Eu anomaly which is not observed in REE data from the Darwin Granite. The granodiorite phase of the Darwin Granite is markedly different from the Murchison Granite (Fig. 7.15). REE data from the Murchison Granite (Fig. 7.15) is very similar to REE data from the CVC (Fig. 7.6), both being enriched in the HREE and displaying a negative Eu anomaly.

The Murchison Granite displays wide compositional variations, whereas the Darwin Granite is relatively homogeneous. The strong similarities in major and trace elements for the two granites suggest a similar source. Compositional modelling studies have shown that it would be possible to evolve the Darwin Granite by fractionation of plagioclase, hornblende and minor apatite from an initial less evolved Murchison Granite melt. The Darwin Granite is more evolved than the Murchison Granite, with the most fractionated Murchison Granite samples most closely resembling the Darwin Granite. Limited REE data suggests some differences between the two suites, but origin of the two granitic suites through partial melting of the same lower crustal source is suggested. The variation in REE data between the two granites can be explained through fractionation of plagioclase (causing a negative Eu anomaly in the Murchison Granite). The differences between the Murchison and Darwin Granites are not geochemically distinct but are thought to be significant enough to suggest that these two granites are separate bodies, and do not represent apophyses of a single batholith beneath the MRV.

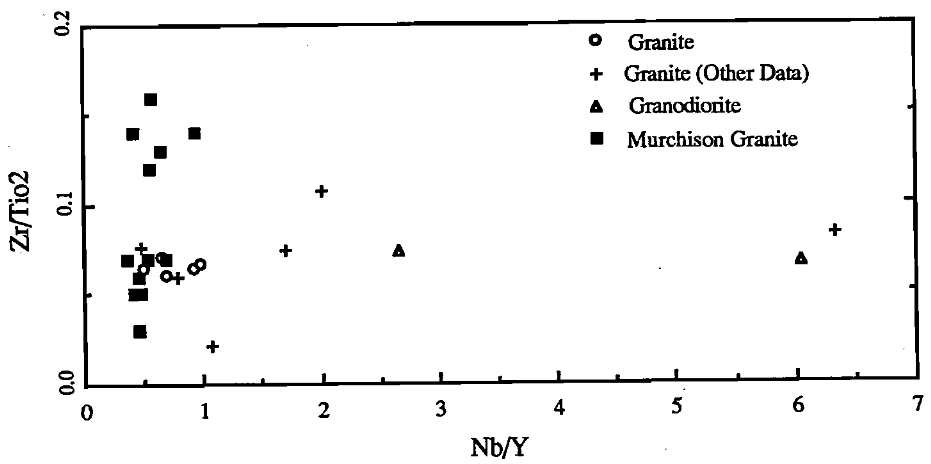

Figure 7.11: Plot of Nb/Y vs Zr/TiO_2 between the Darwin Granite and Murchison Granites, Tasmania. The term granite on the graph refers to the Darwin Granite (data from this study and other sources are plotted separately as granite and granite (other data) respectively. The term granodiorite refers to the granodiorite phase of the Darwin Granite analysed as a part of this study. The Murchison Granite was not analysed as a part of this study (data this study; White, 1975; Stolz & Large, 1988; Abbott, 1992; Crawford *et al.*, 1992).

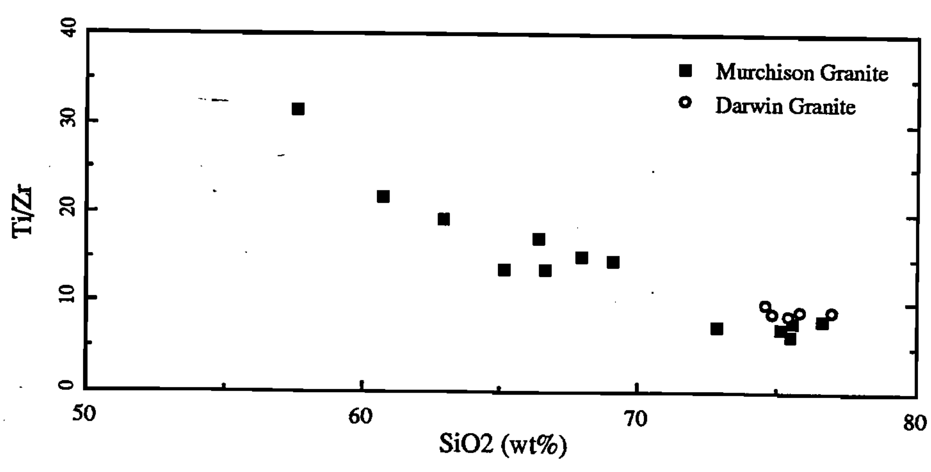

Figure 7.12: Plot of SiO_2 vs Ti/Zr for the Tasmanian Darwin and Murchison Granites (data this study; White, 1975; Stolz & Large, 1988; Abbott, 1992; Crawford *et al.*, 1992).

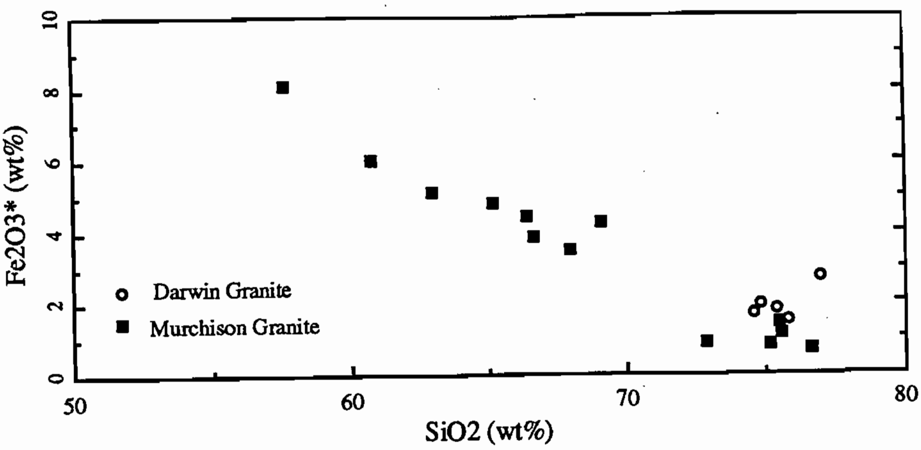

Figure 7.13: Plot of SiO_2 vs Fe_2O_{3total} for the Darwin and Murchison Granites, western Tasmania (data this study; White, 1975; Stolz & Large, 1988; Abbott, 1992; Crawford *et al.*, 1992).

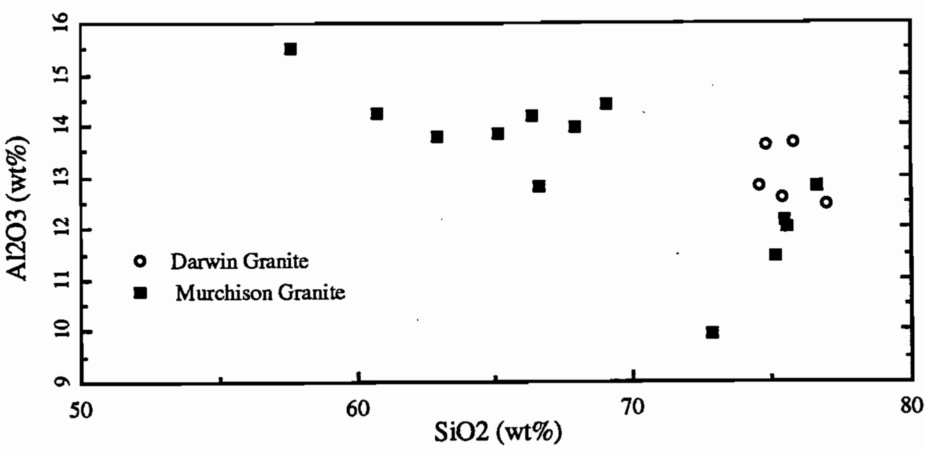

Figure 7.14: Plot of SiO_2 vs Al_2O_3 for the Tasmanian Darwin and Murchison Granites (data this study; White, 1975; Stolz & Large, 1988; Abbott, 1992; Crawford *et al.*, 1992).

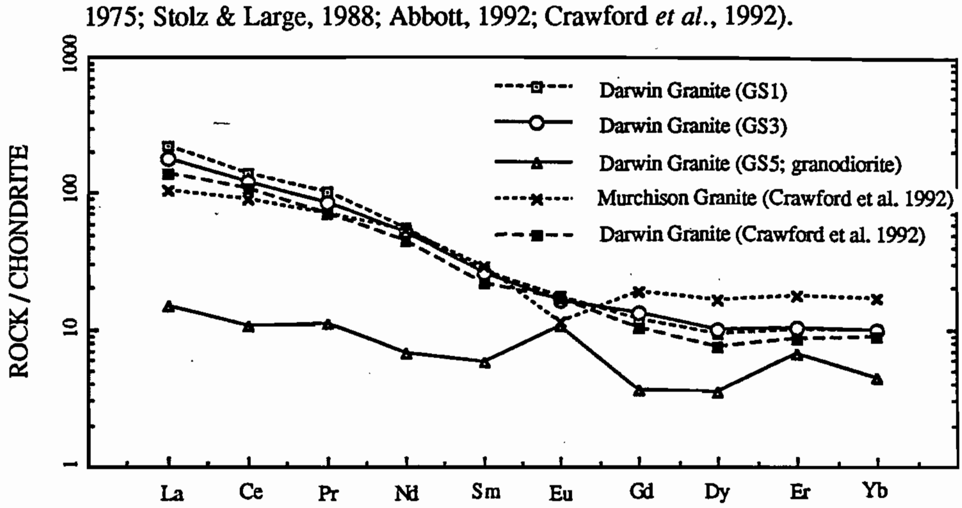

Figure 7.15: Plot for the Darwin and Murchison Granites, Tasmania of the REE (data this study; Crawford *et al.*, 1992).

7.5.2 *Tasmania vs Antarctica*

Tectonic reconstructions between Australia and Antarctica by previous workers (eg. Laird *et al.*, 1977; Burrett & Findlay, 1984; Quilty, 1985; Stump *et al.*, 1986) have linked Northern Victoria Land, Antarctica variously with the Adelaide Geosyncline, South Australia, basement terrains in Victoria and with the Dundas Trough, Tasmania. This section will use elemental discrimination diagrams to test the correlation between the Granite Harbour Intrusives, Northern Victoria Land and the Darwin Granite, western Tasmania. The regional geology of Northern Victoria Land is subdivided into the Wilson Terrane, Bowers Terrane and the Robertson Bay Terrane (Fig. 7.17; Borg *et al.*, 1986). Granites and granodiorites of the Granite Harbour Intrusives are dominantly S-type, with tonalites dominantly I-type (Vetter *et al.*, 1983).

Absolute age determinations on the Granite Harbour Intrusives, Antarctica yield K-Ar and Rb-Sr ages in the range of 460Ma to 550Ma (Stump *et al.*, 1986; Borg *et al.*, 1987). The wide spread of ages for these granites makes age comparisons with the 510Ma Darwin Granite of little value (Adams *et al.*, 1985). However, granitic bodies that were once emplaced into mountain ranges that have since been separated, as hypothesised for the Dundas and Bowers Troughs (Fig. 7.16), could display similar geochemical characteristics which would allow igneous units from these regions to be correlated with some degree of confidence (Quilty, 1985).

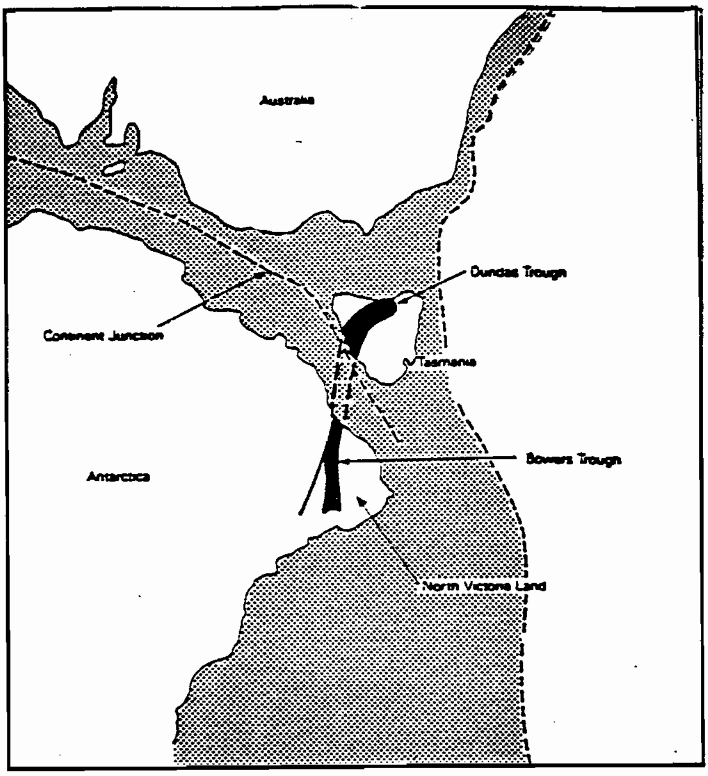

Figure 7.16: Proposed reconstruction linking the Dundas Trough, Tasmania with the Bowers, Trough of North Victoria Land, Antarctica (after Quilty, 1985).

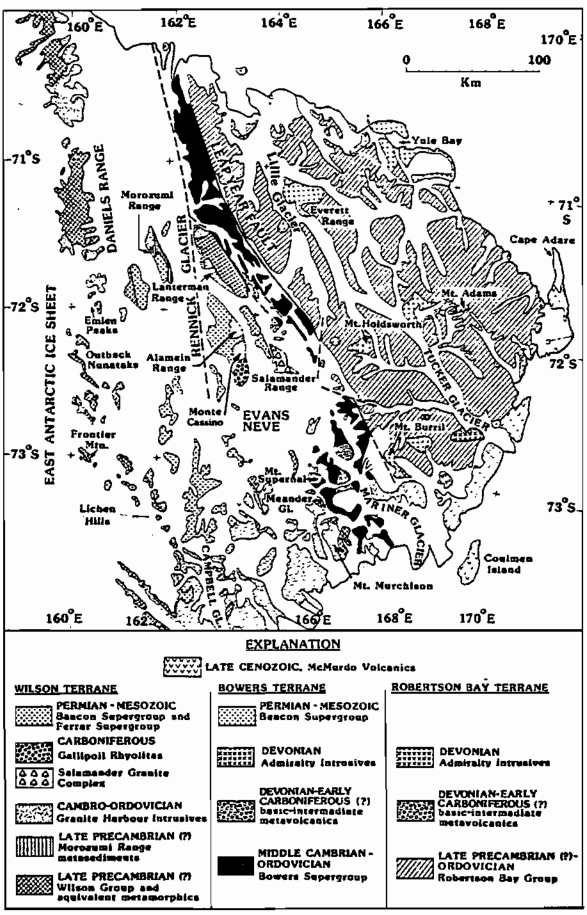

Figure 7.17: Geology of Northern Victoria Land, Antarctica. The map shows the Cambro-Ordovician Granite Harbour Intrusives in relation to the Bowers Terrane which has been proposed to have previously been linked with the Dundas Trough, Tasmania.

Geochemical data from the Darwin Granite (this study; White, 1975), the Alamein Range, Monte Cassino and Mt Murchison regions of Antarctica (Fig. 7.17; Borg *et al.*, 1986) have been compared using plots of SiO_2 vs Ti/Zr (Fig. 7.18) and SiO_2 vs Y (Fig. 7.19). On Figure 7.18 the Darwin Granite falls on the silica-rich end of a trend defined by the Granite Harbour Intrusives trend. A similar situation is recognised on Figure 7.19 (SiO_2 vs Y), with the Darwin Granite plotting at the SiO_2-rich end of the trend defined by the Granite Harbour Intrusives. Overall, Yttrium values from both granite provinces are similar, although the Antarctic granites cover a wider range. The Granite Harbour Intrusives range in composition from 61.56 to 76.56% SiO_2 while the Darwin Granite defines a much smaller compositional range, between 71.90 - 76.93% SiO_2. The Darwin Granite is highly evolved and is a single outcrop. Granites of the Granite Harbour Intrusives cover a wide compositional range. This range is to be expected when analysing granites covering an area in excess of $100km^2$. Because the Darwin Granite falls within or close to the compositional fields defined by the most evolved Antarctic granites (Figs. 7.18, 7.19) it is possible that the two granitic provinces are related. However, a much larger database of whole-rock geochemical data and REE data is required to fully assess any genetic relationships. Better constrained ages for the Antarctic granitoids is also required to check the feasibility of any correlation. Further assessment should be on a granite to granite level with the Cambrian granites of Tasmania compared individually against single plutons in Antarctica, and not with the Antarctic plutons as a whole.

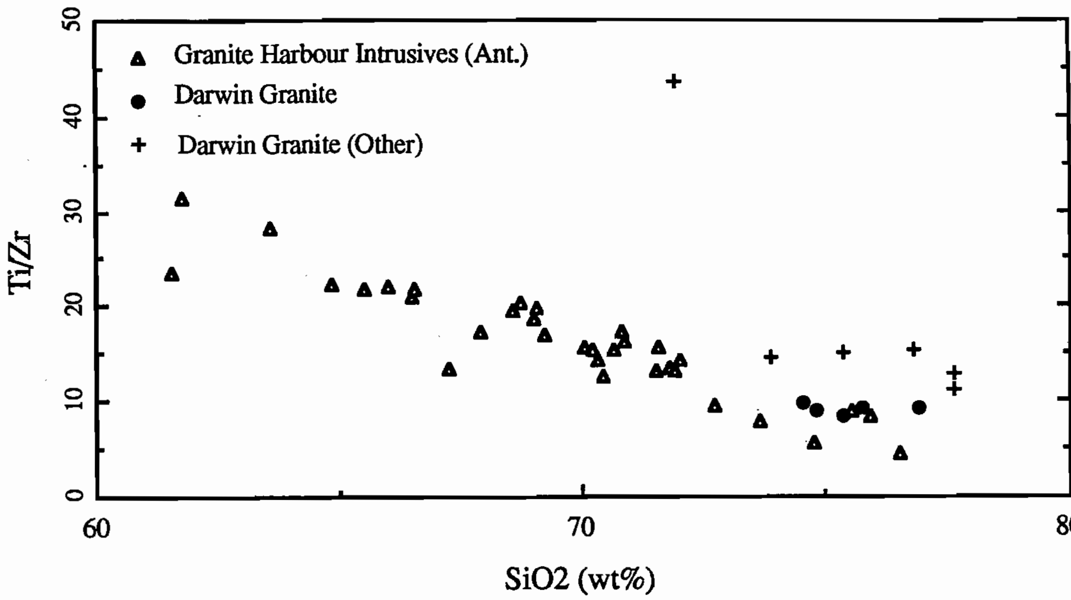

Figure 7.18: Plot of SiO_2 vs Ti/Zr comparing the Darwin Granite, Tasmania and the Granite Harbour Intrusives, Antarctica. In the plot, data referred to as Darwin Granite has been analysed as a part of this study while data referred to as Darwin Granite (Other) is from White, (1975).(data this study; White, 1975; Borg *et al.*, 1986).

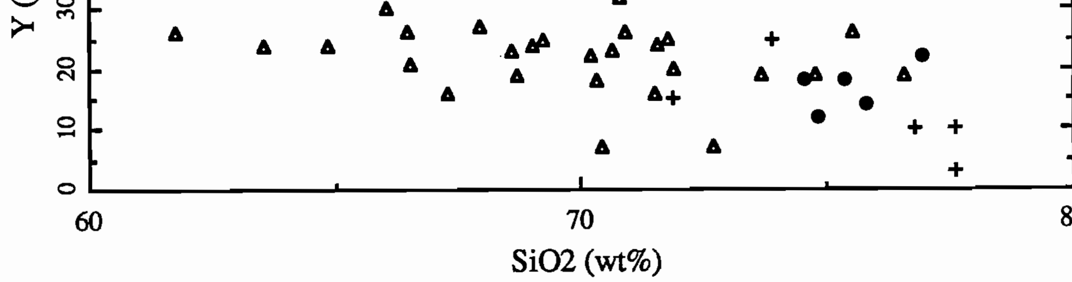

Figure 7.19: Plot of SiO_2 vs Y data from the Darwin Granite, Tasmania and the Granite Harbour Intrusives, Antarctica (data this study; White, 1975; Borg *et al.*, 1986).

7.6 TECTONIC SETTING OF WESTERN TASMANIA

The tectonic scenario leading to the development of western Tasmania is a controversial issue. In order to be acceptable to the geological community, any proposed model must explain the geological aspects observed across western Tasmania and fit with time constraints set by stratigraphic studies and absolute dating. In this section previous hypotheses will be summarised and geochemical evidence from the study area will be analysed to suggest a possible tectonic setting to explain the development of the study area.

7.6.1 *Hypotheses to Date*

Numerous tectonic models have been put forward for western Tasmania. These have been categorised by Corbett (1989) into rift models, plate tectonic models and the allochthon model. A fourth model type, suggested by Leaman (1992), is referred to here as the extension model.

Rift models (Fig. 7.20) have been used to explain the evolution of western Tasmania by Campana and King (1963), Corbett *et al.*, (1972, 1977), Williams (1978) and Collins and Williams (1986). A failed-rift setting, developed above a rising mantle diapir has been proposed by Brown *et al.*, (1980) and Brown (1986). In contrast Corbett (1979) and Large *et al.* (1986) envisage the MRV as a rift-caldera association.

Plate tectonic models explaining development of the Dundas Trough and MRV in both east and west-dipping subduction settings (Fig. 7.20) have been suggested by Solomon and Griffiths (1972, 1974), Corbett (1981), Varne and Foden (1987), Crook (1980a,b) and Corbett and Lees (1987). Green (1984a,b) proposed an oceanic island arc setting with initial west-dipping subduction. A major point of disagreement between these models has been the positioning of the subduction trench.

The allochthon model (Fig. 7.20), proposed by Berry & Crawford (1988), Berry (1989) and Crawford and Berry (1992) suggests that western Tasmania evolved due to collision of a rifted passive continental margin with an oceanic island arc. This collision occurred above an east-dipping subduction zone and emplaced one or more sheets of fore arc ultramafics into the underthrusting western Tasmanian block, while later extension developed graben-like troughs (Dundas Trough) and lead to eruption of the MRV belt. Woodward *et al.* (1993) supported the view that western Tasmania's ultramafic complexes are allochthonous and suggested that west-directed Cambrian and Devonian thrusting, with imbrication of the Precambrian basement, Cambrian oceanic suite and Ordovician sequences, could account for the geological features observed across western Tasmania.

The extension model of Leaman (1992) portrays western Tasmania as one part of a much larger basin within which extensional gashes developed, becoming half-graben structures upon continued extension. The Crimson Creek Formation was deposited prior to wrenching of the crust, which lead to the emplacement of ultramafic slices. The MRV formed as a result of localised volcanism related to an extension structure, and trough associates (Dundas Group) were deposited closeby. Upper Cambrian times saw deformation and the reshuffling of basement units leading to emergence of the Precambrian Tyennan Region along with further extension until the sag-phase of basin development was reached in the Early Ordovician.

Despite continual attempts, no model can fully explain all aspects of western Tasmanian geology, such as the geochemical composition of the MRV, the presence and composition of ultramafic complexes and the restriction of the MRV to the western edge of the Tyennan Region. Problems with rift, plate tectonic and allochthon models are discussed in detail by Corbett (1989).

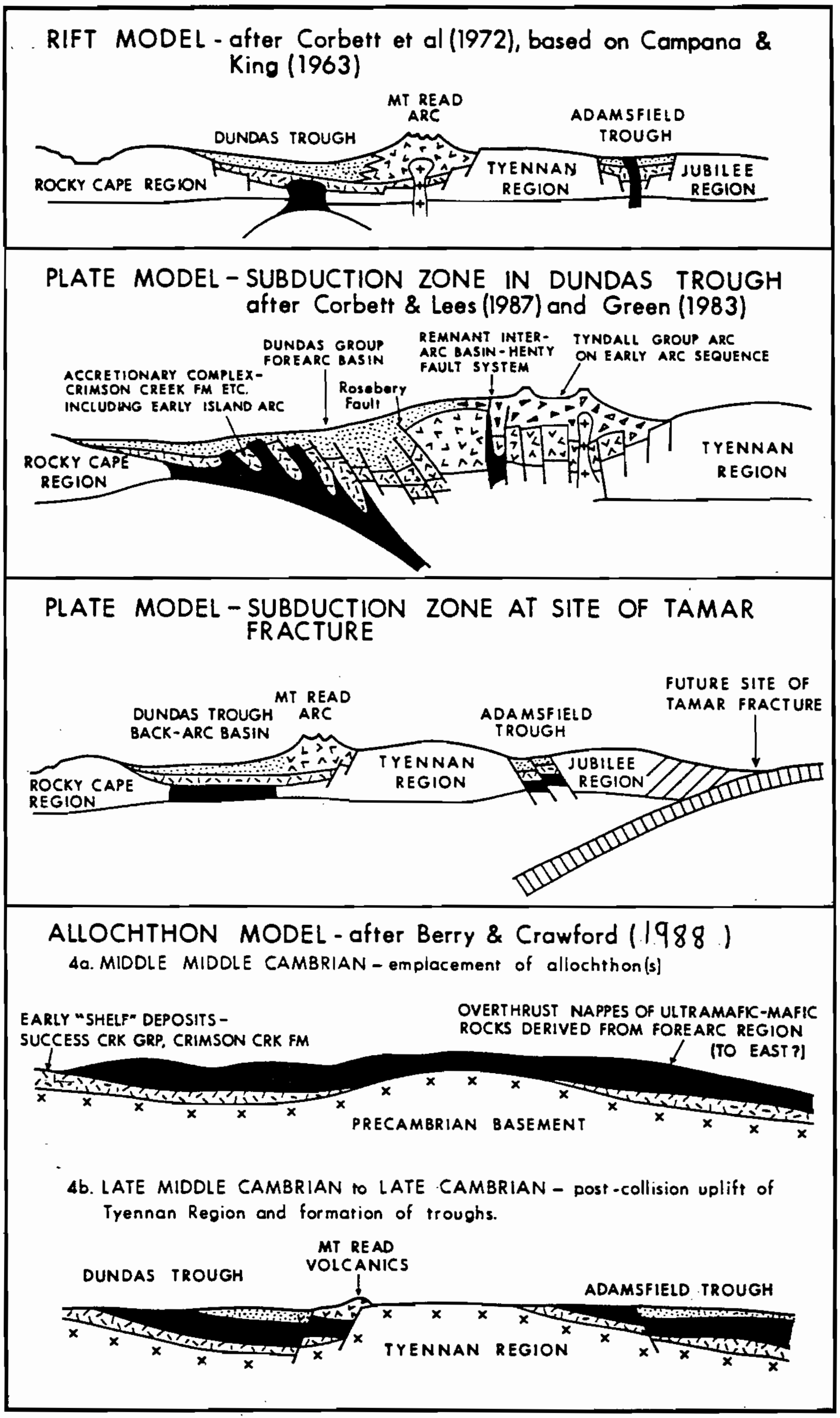

Figure 7.20: Previously proposed tectonic scenarios for the development of western Tasmania (after Corbett & Turner, 1989).

7.6.2 *Geochemical and Field Evidence: Indications of Tectonic Environment*

The geochemical composition of lithologies from the study area together with an interpretation of deformational events and contact relationships can provide information on the regional tectonic setting during the Cambrian. The key factors to consider are: the geochemistry of the CVC and the Darwin Granite, mineralisation within the MRV, uplift and unroofing of the Darwin Granite, the nature of volcanism during Tyndall Group times and influx of siliciclastic material represented by the Owen Conglomerate.

The CVC is dominated by medium- to high-K calc-alkaline rhyolites and lesser dacites with SiO_2 contents between 66 - 75%, 6 - 10% K_2O and a peraluminous composition. There are also significant volumes of andesite in the CVC (Pemberton & Corbett, 1992). Field relationships demonstrate that lavas of the MRV erupted onto or through the Precambrian Tyennan Region (Corbett & Solomon, 1989). The eruption of such large volumes of rhyolite onto continental crust constrains the number of possible tectonic settings. In order to have felsic-volcanic dominated sequences, a continental crustal source is required (Hall, 1987). In oceanic island arcs (eg. western Aleutian Islands), volcanism is characterised as mafic and intermediate rocks with less than 3% rhyolites by volume (Hall, 1987). In the South American Andes (active continental margin) and eastern Aleutian Islands (active continental margin) there is abundant felsic volcanism typically associated with andesitic volcanism (Christiansen *et al.*, 1986; Hall, 1987). Based on the characteristics of modern continental margins, and on the extrusion of the MRV onto Precambrian continental crust, it can be assumed that the CVC formed at an active continental margin setting.

The magnetite-series Darwin Granite intruded the CVC within the Mt Darwin - South Darwin Peak area prior to a significant deformation event leading to 3 to 5km of uplift. Whole rock geochemistry has been used by several authors (eg. Pearce *et al.*, 1984; Cobbing, 1990) to discriminate four tectonic settings for the emplacement of granites, oceanic ridge granites (ORG), volcanic arc granites (VAG), within-plate granites (WPG) and collision granites (COLG). Plots of SiO_2 vs Y (Fig. 7.21) and Nb+Y vs Rb (Fig.7.22) for the Darwin Granite define ranges corresponding to the fields defined for volcanic arc granites, implying that the granite has formed at a volcanic arc (subduction setting) from either (1) melting of subducted oceanic crust, (2) melted lower continental crust or (3) an assimilated melt comprising both (1) and (2). The magnetite-series Darwin Granite was probably emplaced in an extensional tectonic setting; ilmenite-series granites are characteristic of compressional tectonic settings (Ishihara, 1981). The Darwin Granite could have been generated in an extensional environment at an active continental margin, possibly towards the back-arc basin although this can not be stated conclusively. In Japan this scenario occurs where magnetite-series granitoids predominate towards the back-arc (Ishihara, 1981).

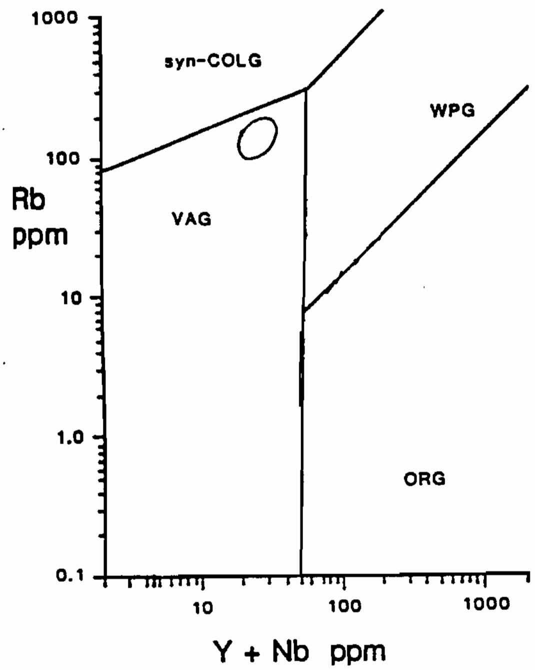

Figure 7.21: Plot of field defined by SiO_2 vs Y for the Darwin Granite. The plot is separated into two fields related to tectonic setting of emplacement, WPG = Within Plate Granite, ORG = Oceanic Ridge Granite, VAG = Volcanic Arc Granite, COLG = Collisional Granite, ORG (d) = Oceanic Ridge Granite (Supra-subduction).(after Pearce *et al.*, 1984).

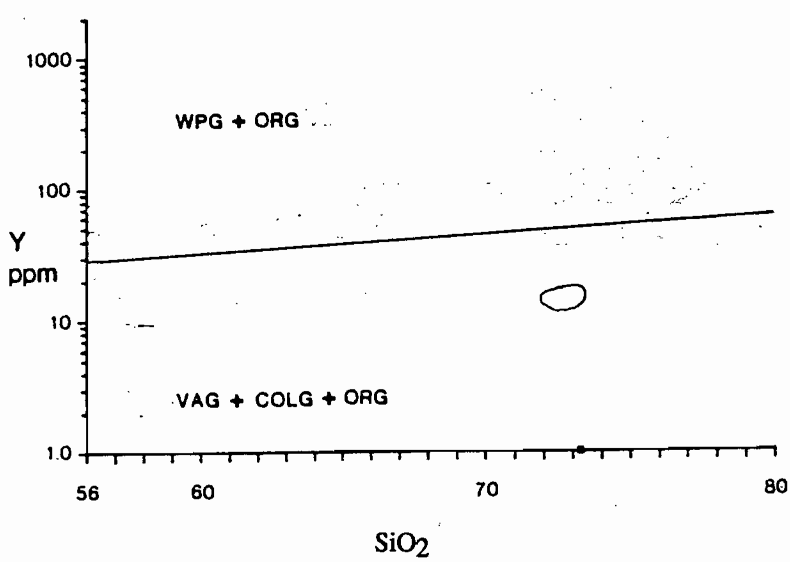

Figure 7.22: Plot of Y+Nb vs Rb field defined by the Darwin Granite. The fields defined relate to the tectonic setting of emplacement. VAG = Volcanic Arc Granite, WPG = Within Plate Granite, ORG = Oceanic Ridge Granite, syn-COLG = Collisional Granite (after Pearce *et al.*, 1984).

VHMS mineralisation occurs across the MRV arc and is interpreted to have formed in a subduction-related setting with mineralisation restricted to local rift structures (Large, 1992). These deposit types form in submarine settings and are present within the CVC in the MRV, indicating a probable submarine setting for the study region upon granite emplacement (Corbett, 1992; Large, 1992)

The Darwin Granite was intruded prior to deformation leading to major uplift and exposure of the granite in the Mid-Late Cambrian. A time break of several millions of years is represented by the unconformity at the base of the Tyndall Group. When volcanism and sedimentation resumed, volcanism was on a much smaller scale and was short lived. Volcanism leading to formation of the Tyndall Group lithologies within the study area is thought to have been at least partially subaerial. Transition from the Tyndall Group to Owen Conglomerate is a major event within the MRV causing cessation of volcanism locally, and significant uplift elsewhere to cause influx of the Owen Conglomerate source material.

7.6.3 *Summary*

Data (geochemical and stratigraphic) from within the field area and elsewhere in western Tasmania suggests an active continental margin tectonic setting for the formation of the MRV and the emplacement of the Darwin Granite. The felsic-dominated CVC was erupted onto or through the continental margin (Crawford *et al.*, 1992). Subduction caused partial melting of the subducting slab and the lower crust, leading to intrusion of the Darwin Granite and other Cambrian granites on the back-arc side of the continental margin. A major tectonic disturbance, possibly collision of the continental margin with an island arc (Crawford & Berry, 1988; Crawford *et al.*, 1992), caused uplift of the MRV, leading to significant erosion and unroofing of the Darwin Granite. From the available data, it appears that the Darwin Granite is a pre-collisional intrusion developed in a subduction-related setting.

7.7 DISCUSSION

The strong effects of hydrothermal alteration on primary rock compositions within the study area make classification of lithologies difficult. The isocon plot of altered vs unaltered equivalent samples for the equigranular granite displays depletion in Na_2O, CaO and Sr, and enrichment in K_2O, Rb, P_2O_5, Cr, Fe and Ni. These changes in composition, due to alteration, are consistent with sericitic, potassic and chloritic alteration styles. Despite alteration volcanic units can still be classified using immobile elements (Winchester & Floyd, 1977). Volcanic units from the CVC are classified as rhyolite and rhyodacite/dacite and the Tyndall Group volcanic is classified as a rhyolite. Alteration has made the use of the I- and S-type granitic classification system of White & Chappell (1983) unreliable. Classification of the Darwin Granite is well more acceptable (due to the level of alteration) using the magnetite and ilmenite series system of Ishihara (1981) and shows that the Darwin Granite is of the magnetite series.

Major, trace and REE comparisons between the CVC and Tyndall Group with the Darwin Granite display marked overlaps in the data. Stratigraphic relationships discount possibilities of the Darwin Granite being co-magmatic with the Tyndall Group. Although differences do occur between the CVC and the Darwin Granite it is possible that they have been differentiated from a similar parental source. Comparisons of the Darwin Granite with the Murchison Granite suggest that these granites are not the same but have formed via partial melting of the same upper mantle to lower crustal source. Granites of Northern Victoria Land, Antarctica, share age similarities with the Cambrian granites of Tasmania although their ages are poorly constrained at this time. Plots of SiO_2 vs Ti/Zr (7.18) and SiO_2 vs Y (7.19) indicate that the Darwin Granite is compositionally heterogeneous while the Northern Victoria Land granites display a fractionation trend across a wide compositional range. The Darwin Granite plots with the most evolved Northern Victoria Land granites as it does with the Murchison Granite.

Geochemical criteria from the study area and wider MRV suggest that the study area developed at an active continental margin. The Darwin Granite has possibly intruded on the back-arc side of the margin. A major tectonic event caused several kilometres of uplift in the Cambrian and no volcanism is recorded within the study region through this time. After this time gap, dacitic dominated volcanism of the Tyndall Group began, but on a smaller scale than volcanism that formed the CVC. Cessation of MRV volcanism is marked by another tectonic event (Chapters 3.0, 5.0). This event caused erosional breaks to develop between the Tyndall Group and the Owen Conglomerate and has been responsible for significant uplift of quartz dominated units to source the Owen Conglomerate.

Chapter 8.0 SYNTHESIS

The Mt Darwin - South Darwin Peak region contains lithologies of the CVC, Darwin Granite, Tyndall Group and Owen Conglomerate. Feldspar-quartz-phyric rhyolites dominate the CVC, while the Tyndall Group is comprised mainly of volcaniclastic debris flows and coherent dacite lavas. The Darwin Granite can be classified within the magnetite series of Ishihara (1981) and is composed of two geochemically and petrographically distinct phases, equigranular granite and granodiorite. A biotite-grade contact metamorphic aureole is developed adjacent to the contact with the CVC on the western side of the Darwin Plateau, and granite-related magnetite and tourmaline veins occur in the Darwin Granite and in the CVC. Pervasive K-feldspar, and chlorite-sericite alteration are widespread, and have locally caused significant enrichment in K and Fe, and depletion in Na and Ca. Quartz veining is recorded in the Tyndall Group and Owen Conglomerate, indicating a post-granite veining event. Quartz veins occur in all lithologies, parallel to the NW Devonian foliation in the Tyndall Group, indicating a Tabberabberan age of formation.

Stratigraphic and structural relationships indicate that three periods of deformation have affected the study area: (1) Mid - Late Cambrian (pre-Tyndall Group); (2) Late Cambrian - Early Ordovician (pre-Owen Conglomerate); and (3) Devonian (Tabberabberan Orogeny). The erosional unconformity between the Darwin Granite and the Tyndall Group represents a significant period of non deposition in the Late Cambrian. The angular unconformity between the Tyndall Group and Owen Conglomerate on South Darwin Peak and elsewhere in the MRV (Corbett & Turner, 1989) suggests that cessation of MRV volcanism was tectonically controlled.

The CVC rhyolites, Darwin Granite and Tyndall Group dacites are all geochemically compatible with suite I calc-alkaline rocks of the MRV recognised by Crawford *et al.* (1992). Comparison of the Darwin and Murchison granites using major, trace and REE, and compositional modelling suggests a similar source regime. Despite this, the similarities between the two granites are not distinct enough as to indicate that they have evolved from the same parental magma. Comparisons between the small body of the Darwin Granite and the widespread granites of Northern Victoria Land, Antarctica is difficult due to poorly constrained crystallisation ages for the Antarctic granites.

Cu-Au mineralisation is spatially and genetically related to the emplacement of the Darwin Granite. Mineralisation is inferred to have formed within a submarine magmatic - seawater convection cell based on the influence of seawater sulphate upon mineralisation. $\partial^{34}S$ signatures indicate the increased involvement of seawater sulphate with distance from the granite.

8.1 EVOLUTION OF THE DARWIN PLATEAU

A six stage model for the evolution of the study area has been formulated. This model involves:

(1) Volcanism of the felsic-dominated CVC in an Andean-type setting in the Middle Cambrian.

(2) Generation of the magnetite series Darwin Granite in an extensional environment by the partial melting of an upper mantle - lower crustal source, and subsequent emplacement into the volcanic pile of the CVC.

(3) Cataclysmic upheaval of the study area in the Mid - Late Cambrian and unroofing of the Darwin Granite in the Cambrian. A significant break in deposition has occurred.

(4) Deposition of the Late Cambrian Tyndall Group. Basal mass flows have incorporated detritus derived from the Darwin Granite and CVC.

(5) A significant regional uplift event that exposed the Precambrian source of the Owen Conglomerate in western Tasmania during the Ordovician, leading to influx of detritus which deposited the Owen Conglomerate in a shallow marine alluvial fan setting.

(6) Post-Owen Conglomerate deformation, metamorphism and quartz veining correlated with the Devonian Tabberabberan Orogeny.

8.2 CONCLUSIONS : EXPLORATION POTENTIAL OF THE DARWIN PLATEAU AND THE IMPORTANCE OF THE CAMBRIAN GRANITES TO MRV MINERALISATION

The Darwin Plateau is one of only a handful of localities where Cambrian granites crop out in western Tasmania, and the genetic relationship between the Darwin Granite and Cu-Au mineralisation has important exploration implications. Even though the Cu-mineralisation is granite related, the Darwin Granite is unlikely to be related to classic porphyry copper-style mineralisation due to the equigranular texture of the Darwin Granite, heavy sulphur isotope signatures of related mineralisation and a lack of several generations of quartz veining. Despite these differences between the study region and classic porphyry copper deposits, the potential for variations of porphyry style mineralisation generated in relation to emplacement of the Darwin Granite is a real possibility. Sulphur isotope signatures are more consistent with those of the Cambrian VHMS deposits than with those of porphyry copper deposits. $\partial^{34}S$ values suggest mixing of Cambrian seawater sulphate and magmatic sulphur around the Darwin Granite, consistent with a convection cell developed during granite emplacement. Cambrian faults in the region were possible pathways along which hydrothermal fluids could have moved away from the granite. The occurrence of granite-related mineralisation, and presence of a Cambrian regionally convecting hydrothermal cell generated through granite emplacement raises the possibility that mineralisation has formed not only proximal to but may also be present distal to the Darwin Granite. Mineralisation related to the Darwin Granite may lie covered by deposits of the Tyndall Group or buried at depth within the CVC.

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APPENDICES

Appendix A - Departmental Rock Catalogue Numbers

	A	B	C	D	E	F
1	CATALOG #	FIELD #	DESCRIPTION	FORMATION	CO-ORDS	PREPS
2	78320	29	Equigranular Granite	Darwin Granite	516850N/382650E	RS
3	78321	GS1	Equigranular Granite	Darwin Granite	318600N/384100E	TS
4	78322	GS2	Equigranular Granite	Darwin Granite	318605N/384100E	TS
5	78323	GS7.1	Equigranular Granite	Darwin Granite	318650N/382700E	TS
6	78324	GS6.1	Equigranular Granite	Darwin Granite	318650N/382710E	TS
7	78325	3	Microgranite	Darwin Granite	318400N/383100E	TS
8	78326	GS4	Granodiorite	Darwin Granite	318500N/383500E	RS
9	78327	40	Granodiorite	Darwin Granite	318500N/383500E	TS
10	78328	S4	Granodiorite	Darwin Granite	318510N/383510E	TS
11	78329	M	Mylonite	Darwin Granite	319500N/383600E	TS
12	78330	F3	Mylonite	Darwin Granite	319520N/383610E	TS
13	78331	30	Mag. Vein in Granite	Darwin Granite	317350N/382500E	PTS
14	78332	34	Magnetite-pyrite brecci	Darwin Granite	318600N/383800E	PTS
15	78333	TV	Tourmaline Vein	Darwin Granite	317500N/383000E	RS
16	78334	B	Barite Vein	Darwin Granite	318400N/383800E	RS
17	78335	W6	Feld-qtz-phyric rhyolite	CVC	318850N/383000E	TS
18	78336	W10	qtz-feld-phyric rhyolite	CVC	317900N/383100E	TS
19	78337	92	foliated qtz-phyric rhy.	CVC	319500N/383000E	TS
20	78338	5	Andesite/Rhyolite	CVC	317350N/382500E	TS
21	78339	83	Magnetite-pyrite vein	CVC	316800N/382500E	PTS
22	78340	55	Volcaniclastic sandston	CVC	315900N/382200E	TS
23	78341	W5	Mag-tour-breccia	CVC	318000N/383800E	PTS
24	78342	GST2	Qtz-feld-phyric dacite	Tyndall Group	318000N/385150E	TS
25	78343	GST	Qtz-feld-phyric dacite	Tyndall Group	318005N/385150E	RS
26	78344	Y7	Qtz-feld-phyric dacite	Tyndall Group	318005N/385160E	TS
27	78345	X10	Pyrite in Poly. L. V. Sst	Tyndall Group	318500N/384250E	RS
28	78346	T3	Polymictic lithic volc. s	Tyndall Group	318500N/384300E	TS
29	78347	ED	East Darwin - pyrite	Tyndall Group	323000N/384300E	PTS
30	78348	O	Quartz sandstone	Owen Cong.	317900N/385500E	TS

Appendix B - Modal and Normative Calculations

Modal analyses were carried out on microgranite (78325) and granodiorite (78327).

	Microgranite		Granodiorite	
	(points counted)	(%)	(points counted)	(%)
Quartz	372	25.4	363	21.48
Plagioclase	396	27.1	841	49.76
K-feldspar	659	47.47	460	27.22
Opaques	35			
Sericite			26	1.5

	1	2	3	4	5	6	7	8	9	10	11
1	(norm %)	GS1	GS2	GS3	GS4	GS5	GS6	GS7	GST	W6	5
2	MINERAL										
3	Quartz	42.54	44.89	42.3	47.47	49.09	34.83	35.75	21.27	38.1	21.81
4	Orthoclase	37.86	46.21	41.2	11.13	13.36	40.08	38.97	20.6	55	34.52
5	Albite	9.44	1.57	8.39	30.42	25.18	18.88	20.46	53.5	2.1	1.57
6	Anorthite	0.28	0.28		1.39	0.84	0.56	0.56			
7	Corundum	3.98	3.57	3.37	5.51	5.5	2.35	2.35	1.22	1.33	3.98
8	Hypersthene	1.07	1.7	1.33	0.5	2.96	1.4	0.8	0.7	0.63	26
9	Magnetite	1.39	2.08	1.39		1.62	1.62	1.39	2.08	0.69	6.95
10	Ilmenite	0.46	0.3	0.3	0.46	0.46	0.3	0.46	0.91	0.15	1.06
11	Hematite				0.16				0.16		
12	Apatite								0.1		0.16
13											
14	TOTAL	97.02	100.6	98.28	97.04	99.01	100.02	100.74	100.54	98	96

Calculations of the CIPW norm were carried out using the methods of Iddings (1909).

Appendix C - Results of Microprobe Analyses of Tourmaline

Analyses were undertaken at the University of Tasmania, Central Science Laboratory using a Cameca Electron Microprobe.

-	Tourmaline 1	Tourmaline 2	Tourmaline 3	Tourmaline 4	Tourmaline 5
(Wt%)					
SiO2	36.54	35.39	35.92	36.03	36.12
TiO2	0.48	0.71	0.49	0.34	0.4
Al2O3	30.84	30.81	30.02	31.08	30.7
MgO	5.51	5.7	5.29	5.51	5.74
CaO	0.57	0.64	0.54	0.37	0.58
MnO	0	0	0.01	0.02	0
FeO	10.68	10.48	11.85	10.54	11.03
Na2O	2.24	2.05	2.26	2.23	2.25
K2O	0.13	0.06	0.02	0.04	0.04
H2O	4.04	3.99	3.85	4	3.99
F	0	0	0.29	0	0.07
Cl	0	0	0	0.04	0.01
Total	91.03	89.83	90.54	90.18	90.9

Appendix D - Whole Rock Geochemical Data and Alteration Index Calculations

Data from White, (1975); Stolz & Large, (1988); Abbott, (1992); Crawford *et al.* (1992)

	Murchison Granite												Eastern Quartz-phyric Sequence					
Sample No.	AT053	AT052	AT050	AT047	AT064	AT028	AT027	AT025	AT020	AT016	AT017	AT013	AT002	AT001	AT031	AT033	AT037	AT044
Compounds %																		
SiO2	75.51	76.61	57.65	66.36	75.54	60.76	62.95	66.61	65.13	72.90	75.17	67.93	61.23	75.13	64.79	69.62	68.85	70.10
Al2O3	12.16	12.82	15.53	14.18	12.02	14.22	13.79	12.81	13.84	9.93	11.44	13.97	14.30	11.15	12.51	13.98	14.41	13.88
TiO2	0.27	0.27	0.87	0.53	0.25	0.69	0.61	0.50	0.55	0.12	0.16	0.45	0.72	0.16	0.45	0.45	0.57	0.43
Fe2O3	1.48	0.72	8.11	4.40	1.16	6.01	5.15	3.84	4.79	0.87	0.83	3.46	10.97	1.71	5.84	3.02	2.06	2.42
MnO	0.07	0.02	0.21	0.22	0.03	0.24	0.24	0.18	0.24	0.26	0.08	0.09	0.54	0.21	0.26	0.15	0.20	0.14
MgO	0.47	0.41	3.73	2.02	0.36	3.53	2.63	1.21	1.93	0.34	0.32	1.28	2.60	0.59	1.13	1.02	1.13	1.07
CaO	0.94	1.16	5.14	2.55	0.30	3.11	2.65	2.79	2.59	3.77	1.30	1.16	1.06	2.25	1.87	1.55	3.45	2.47
K2O	4.64	1.81	3.54	5.30	7.46	4.00	4.61	5.64	5.96	5.89	7.70	7.68	3.39	3.67	8.39	4.90	3.06	3.22
Na2O	2.97	4.90	3.32	2.58	1.85	2.94	3.25	1.99	0.67	1.55	0.98	0.89	3.21	1.64	0.59	2.69	3.91	3.47
P2O3	0.03	0.05	0.23	0.13	0.04	0.18	0.16	0.14	0.13	0.03	0.03	0.11	0.16	0.04	0.12	0.09	0.10	0.09
L.O.I.	1.15	1.36	2.24	2.66	0.94	3.73	3.55	3.78	4.27	3.78	2.17	2.59	2.92	3.32	3.21	3.80	3.15	2.86
Total	99.68	100.13	100.58	100.91	99.95	99.40	99.59	99.48	100.10	99.44	100.18	99.62	101.10	99.87	99.15	101.21	100.88	100.17
Elements ppm																		
Y	18	38	29	40	31	31	37	28	44	23	20	31	32	46	57	33	51	28
Sr	183	212	421	211	116	276	240	207	179	177	148	98	142	105	307	275	301	240
Zr	258	199	166	184	188	190	189	218	240	99	133	179	256	180	250	254	242	250
Rb	139	93	145	225	287	178	163	254	300	162	210	336	145	205	210	225	171	192
V	11	10	188	96	13	144	120	87	78	6	6	81	158	8	37	37	57	49
Nb	11	21	13	18	20	15	16	15	16	10	19	21	13	16	14	16	18	15
Ba	1578	311	1087	914	739	1015	1516	2299	1662	1647	1982	3191	985	615	3845	1207	478	616
Pb	3	12	51	7	6	137	293	183	103	156	23	87	24	1022	47	15	107	23
Zn	42	18	203	189	28	337	304	70	184	119	25	121	290	127	130	93	148	88
Cu	3	11	26	5	4	11	4	15	5	152	4	21	6	15	9	9	8	5
As	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd
Ni	1	2	9	6	2	9	9	5	6	2	1	5	3	2	3	3	4	3
Cr	bd	3	40	21	bd	32	29	18	22	2	bd	18	20	2	9	3	21	7
Ti	1619	1619	5216	3177	1499	4137	3657	2998	3297	719	959	2698	4316	959	2698	2698	3417	2578
Ratios																		
Ti/Zr	6.27	8.13	31.42	17.27	7.97	21.77	19.35	13.75	13.74	7.27	7.21	15.07	16.86	5.33	10.79	10.62	14.12	10.31
Zr/TiO2	0.16	0.12	0.03	0.06	0.13	0.05	0.05	0.07	0.07	0.14	0.14	0.07	0.06	0.19	0.09	0.09	0.07	0.10
Nb/Y	0.58	0.55	0.46	0.46	0.65	0.47	0.43	0.54	0.36	0.43	0.93	0.68	0.41	0.34	0.24	0.47	0.35	0.55

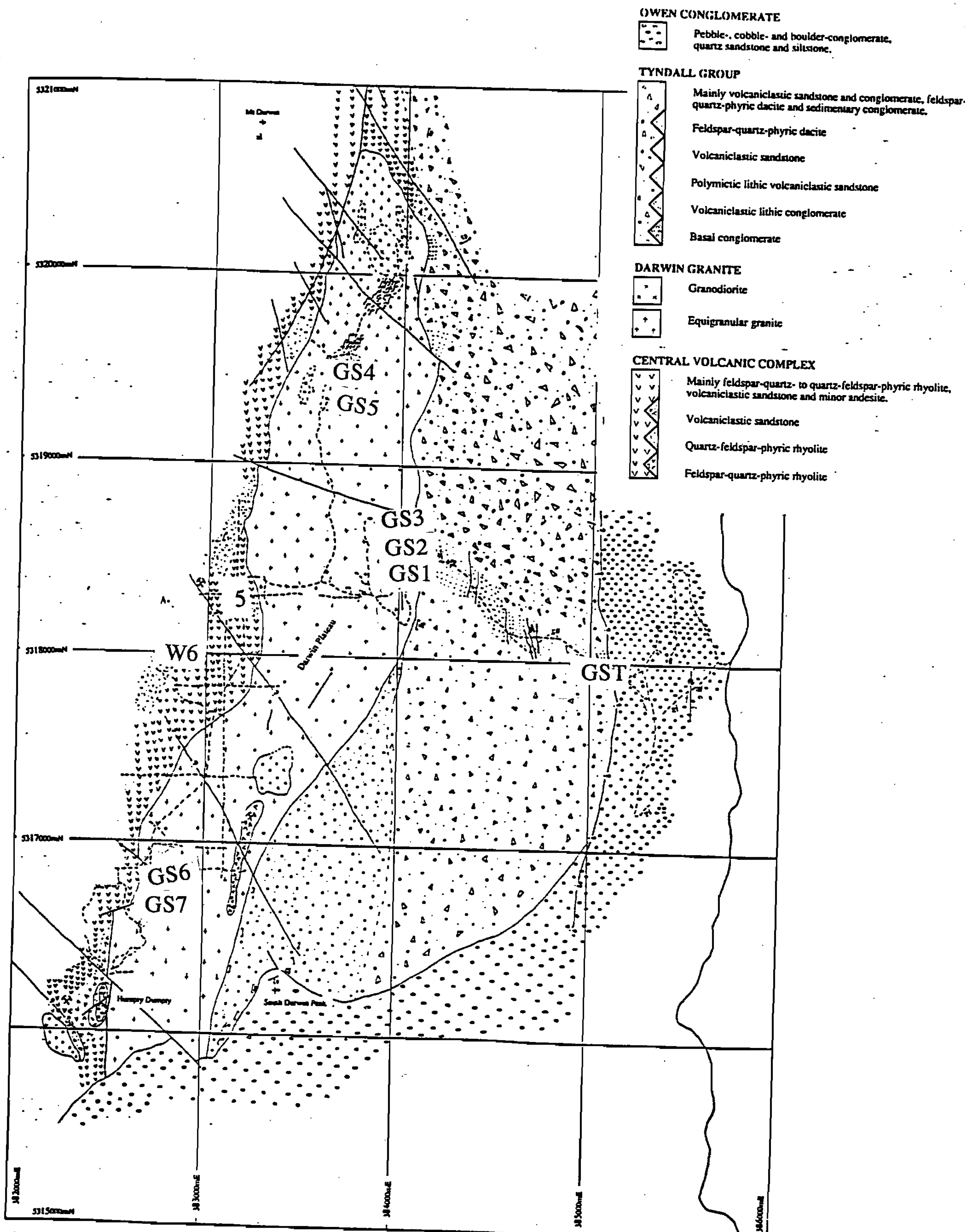


Fig: Geochemical Sample collection localities. GS1, GS2, GS3, GS6, GS7 (Equigranular Granite); GS4, GS5 (granodiorite); GST (Tyndall Group); W6, 5 (CVC).

Alteration Index calculated using the methods of Ishikawa *et al*. (1976).

SAMPLE	ALTERATION INDEX $100(MgO + K_2O) / (MgO + K_2O + CaO + Na_2O)$
Equigranular Granite	
GS1	85.04
GS2	97.15
GS3	87.71
GS6	75.79
GS7	73.2
Granodiorite	
GS4	34.78
GS5	44.7
CVC	
W6	97.41
5	96.92
Tyndall Group	
GST	37.18

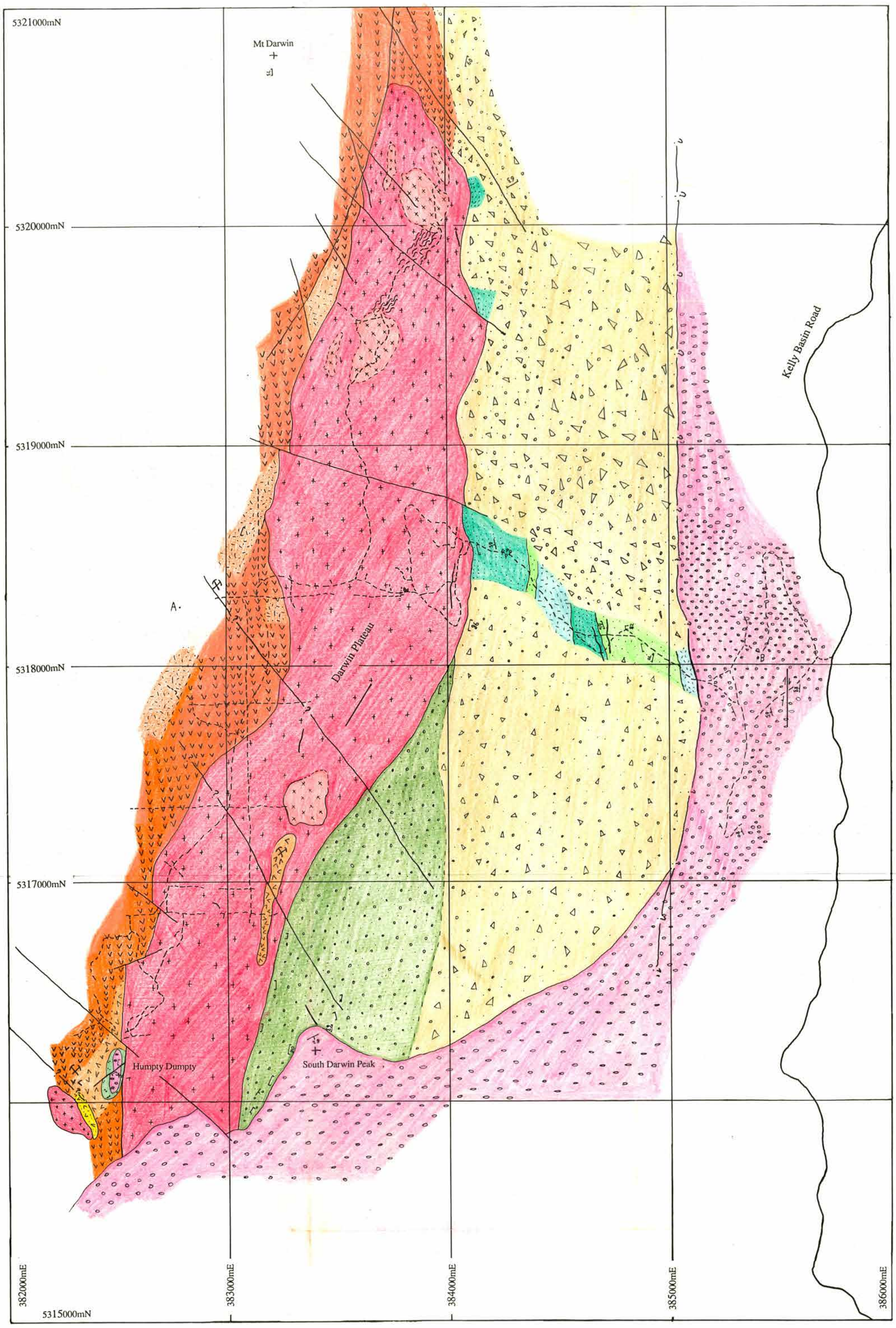
	Crawford et al., 1992		White, 1975					Stolz & Large, 1988								
								CVC from Mt Huxley and Jukes-Darwin area								
	JD13	T04137														
	840200	DH12311.5	Darwin Granite					Rhyolite	Alt. Rhyolite	Dacite	Rhyolite	Alt. Rhyolite	Alt. Rhyolite	Alt. Rhyolite	Alt. Rhyolite	Alt. Rhyolite
	Darwin Gr.	Murchison Gr.	41174	41372	41373	41374	41375	HX1/A	HX1/B	HX1/C	JD2001/A	JD2002/B	JD2001/D	JD2002/A	JD2002/B	JD2002/C
(Wt%)																
SiO2	75.4	69.1	73.92	76.8	77.63	77.62	71.9	71.75	72.71	69.01	75.99	70.49	74.68	72.23	72.24	74.46
TiO2	0.22	0.54	0.18	0.06	0.12	0.19	0.21	0.41	0.36	0.5	0.32	0.48	0.3	0.38	0.53	0.31
Al2O3	14.3	14.4	13.59	12.67	13.07	13.78	9.63	14.85	13.25	14.87	13.24	15.29	12.98	12.79	13.4	13.13
Fe2O3	1.71	4.25	1.62	0.74	0.68	0.6	13.35	4.07	6.17	5.49	2.64	3.69	3.34	8.13	5.21	4.21
MnO	0.02	0.24	0	0	0	0	0.24	0.06	0.29	0.12	0.07	0.23	0.08	0.34	0.34	0.11
MgO	0.37	1.96	0.34	0.08	0.26	0.09	1.26	1.2	1.58	2.28	0.45	0.76	0.38	0.4	1.36	0.47
CaO	0.28	3.53	0.17	0.17	0.08	0.55	0.15	0.43	0.81	1.38	1.33	3.58	0.06	0.44	2.33	0.05
Na2O	3.1	3.16	2.68	2.94	2.93	4.01	0.06	3.67	0.99	3.49	2.89	0.63	<0.2	0.23	<0.2	<0.2
K2O	4.59	2.57	5.36	5.2	2.59	1.08	2.04	3.47	3.75	2.75	3.02	4.76	8.13	5.01	4.49	7.22
P2O5	0.03	0.13	0.06	0.02	0	0	0.13	0.09	0.09	0.11	0.04	0.08	0.04	0.05	0.11	0.04
L.O.I.	1.56	1.68	1.17	0.91	1.46	1.68	2.2	1.97	3.77	3.43	2.71	5.6	1.64	2.38	5.6	1.9
Total	100.02	99.88	99.19	99.61	98.9	99.61	101.22	100	100	100	100	100	100	100	100	100
Trace Elements (ppm)																
Ni	1	3	1	2	0	0	0									
Cr	1	16	20	30	22	23	0									
V	21	104	27	26	17	24	156									
Sc	3	18	1	2	0	0	8									
Zr	132	218	138	65	90	156	46	302	279	199	279	261	267	265	235	276
Nb	14	13	12	20	17	19	16	13	12	12	15	15	13	14	11	13
Y	18	36	25	10	10	3	15	40	36	27	41	37	37	38	38	58
Sr	138	345	130	56	96	183	4	91	36	114	90	96	72	35	53	37
Rb	135	148	185	215	115	47	105	111	172	108	116	168	239	193	177	239
Ba	1385	604	896	234	748	100	468									
Th																
Pb			23	8	25	43	5	4	131	82	9	19	7	55	10	6
Ti/Zr	10	14.6	7.8	5.5	8	7.3	27.4	8.1	7.7	15.1	6.9	11	6.7	8.6	13.5	20.9
Zr/TiO2	0.06	0.04	0.08	0.11	0.08	0.08	0.02	0.07	0.08	0.04	0.09	0.05	0.09	0.07	0.04	0.09
Nb/Y	0.78	0.36	0.48	2	1.7	6.3	1.07	0.33	0.3	0.44	0.37	0.41	0.35	0.37	0.29	0.22
Rare Earth Elements (ppm)																
La	44.7	32.8	103	43	37	33	48									
Ce	89.5	73.7	0	0	0	0	130									
Pr	8.21	8.31														
Nd	26.5	32														
Sm	4.15	5.51														
Eu	1.23	0.83														
Gd	2.68	4.87														
Tb																
Dy	2.68	5.36														
Ho																
Er	1.85	3.73														
Yb	1.85	3.48														

Geology of the Mt Darwin - South Darwin Peak area

A.T. Jones

SCALE 1 : 10 000

0 .2 .4 .6 .8 1km



OWEN CONGLOMERATE

Pebble-, cobble- and boulder-conglomerate, quartz sandstone and siltstone.

MOUNT READ VOLCANICS

TYNDALL GROUP

Mainly volcaniclastic sandstone and conglomerate, feldspar-quartz-phyric dacite and sedimentary conglomerate.

Feldspar-quartz-phyric dacite

Volcaniclastic sandstone

Polymictic lithic volcaniclastic sandstone

Volcaniclastic lithic conglomerate

Basal conglomerate

DARWIN GRANITE

Granodiorite

Equigranular granite

CENTRAL VOLCANIC COMPLEX

Mainly feldspar-quartz- to quartz-feldspar-phyric rhyolite, volcaniclastic sandstone and minor andesite.

Volcaniclastic sandstone

Quartz-feldspar-phyric rhyolite

Feldspar-quartz-phyric rhyolite

Geological boundary

Geological boundary - inferred or concealed

Fault

?—? Fault - inferred or concealed

Strike and dip of bedding

Strike and dip of cleavage

Road

Minor road and 4-wheel drive track

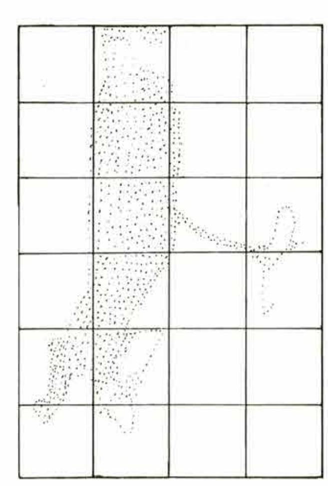
Prospect or abandoned mine

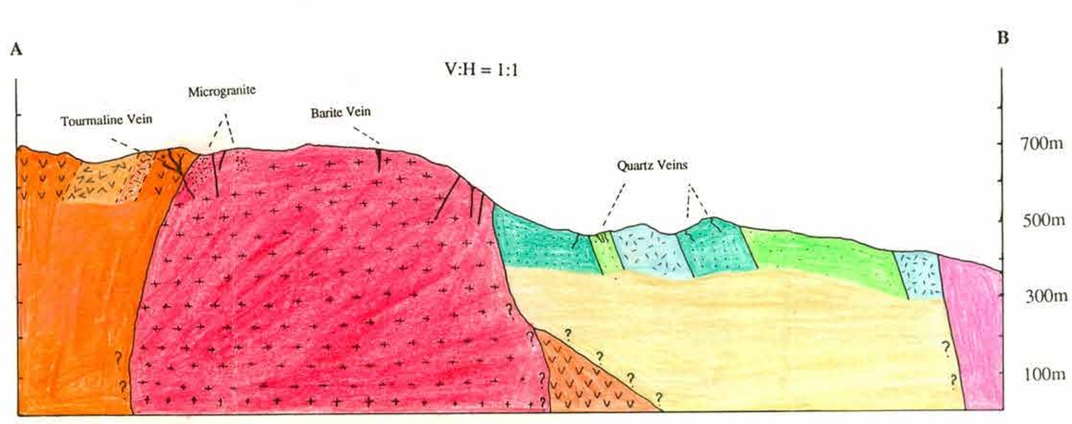
Mylonite zone

Pyrite within the Tyndall Group

Barite vein

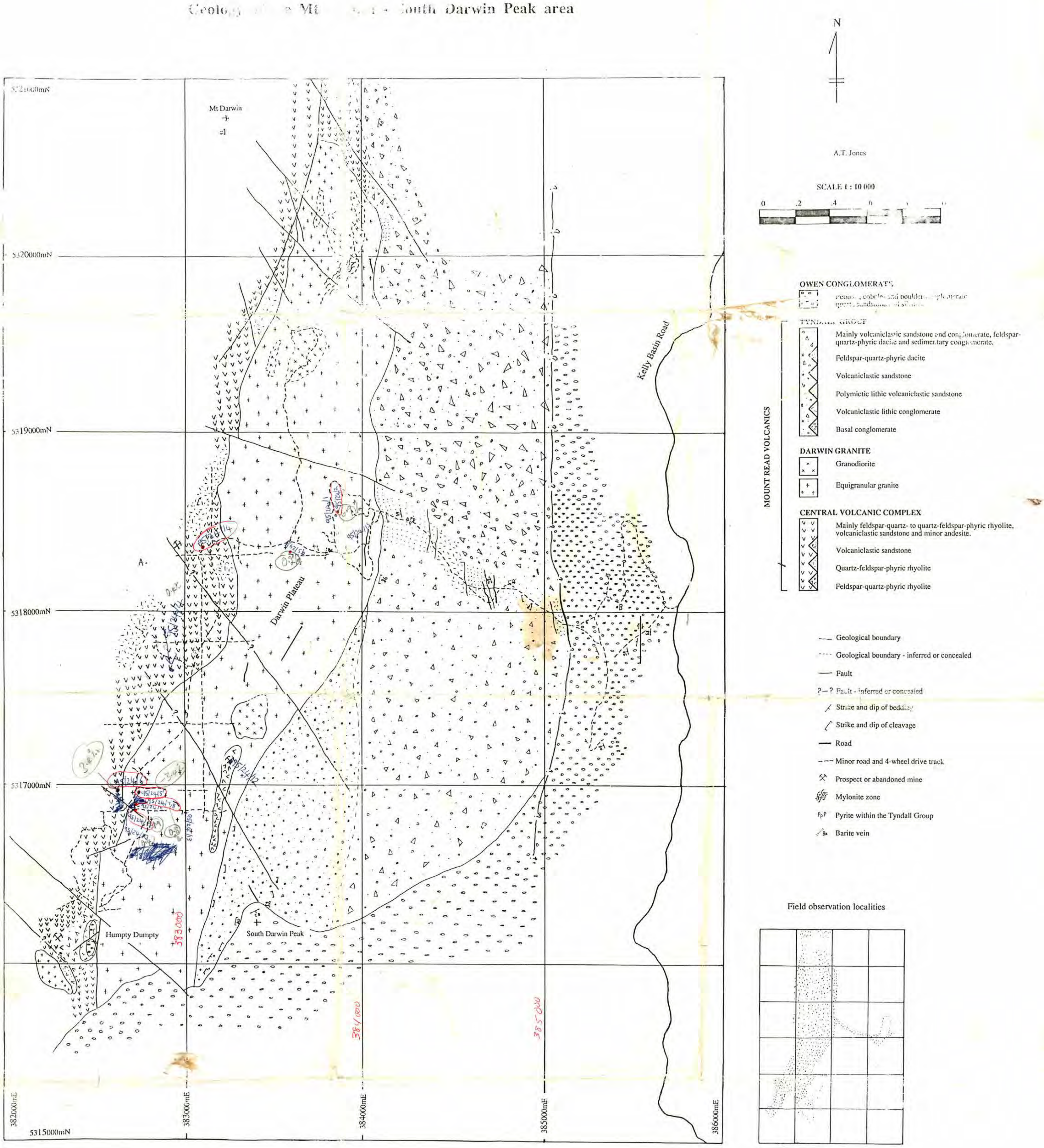
Field observation localities

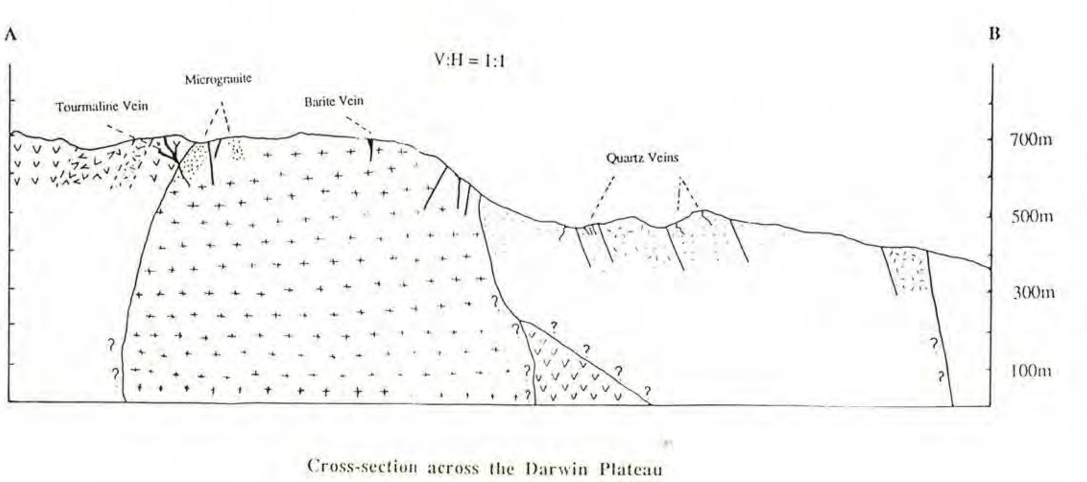




Cross-section across the Darwin Plateau

Geology ... Mt ... - South Darwin Peak area





Cross-section across the Darwin Plateau