THE GEOLOGY OF THE BALCOOMA MASSIVE SULPHIDE DEPOSIT

NORTH-EAST QUEENSLAND

Dissertation submitted by:

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In partial fulfillment of the requirements for the Degree of Master of Science in the Faculty of Science of the James Cook University of North Queensland.

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K.J. Harvey
December 10, 1984.

FRONTISPIECE

Diamond drill core from the discovery hole at
Balcooma showing various copper ore types.

ABSTRACT

The Balcooma massive sulphide deposit is located at 18°46'S, 144°43'E and 230 km west-north-west of Townsville in north Queensland. The deposit, which has reserves of 3.5 million tonnes of 3.0% copper, was discovered by the author late in 1978 during a search for volcanogenic massive sulphide deposits in the lower Palaeozoic sequences surrounding Charters Towers.

The deposit is hosted by a sequence of metamorphosed sediments and acid volcanics referred to in this report as the "Balcooma Metamorphics". These rocks, prior to discovery of the deposit, were included in the Greenvale Subprovince and were believed to be of Precambrian age. These rocks are now interpreted to be of lower Palaeozoic age and the Greenvale Subprovince is considered to form part of the Ravenswood Lolworth Province.

The geology of the area is exceedingly complex due to at least two strong deformation events. The immediate hosts to the mineralization are a sequence of quartz muscovite biotite staurolite schists and quartz muscovite biotite schists which are interpreted to be metamorphosed fine-grained and coarse-grained sediments respectively. Quartz feldspar porphyry bodies intruded these rocks prior to deformation and metamorphism.

Both copper and lead-zinc-copper mineralization occur. Copper mineralization occurs within two south-south-west plunging shoots as chalcopyrite in massive pyrite, as massive chalcopyrite with pyrrhotite, and as chalcopyrite in chlorite schist. Chlorite alteration accompanies the copper mineralization.

Lead-zinc-copper mineralization occurs within folded tabular bodies of massive pyrite which are associated with gahnite bearing quartzite and quartz schists which are interpreted to be metamorphosed siliceous exhalites.

The deposit is considered to be a metamorphosed volcanogenic massive sulphide deposit.

CONTENTS

Page No.

CONTENTS (CONT.)

ILLUSTRATIONS

List of Figures

ILLUSTRATIONS (CONT.)

ILLUSTRATIONS (CONT.)

ILLUSTRATIONS (CONT.)

ILLUSTRATIONS (CONT.)

ILLUSTRATIONS (CONT.)

List of Tables

ACKNOWLEDGEMENTS

This dissertation is a summary of the results of exploration work carried out by Carpentaria Exploration Company Pty. Ltd. (CEC) in the Balcooma area since discovery of the gossans late in 1978. I gratefully acknowledge the assistance given by CEC during the completion of this dissertation and I thank the management of CEC for permission to submit the information arising from this work.

I have been closely involved with exploration of the Balcooma area since 1978 and the ideas and opinions expressed have been developed during that time. However, the exploration of any mineral deposit normally involves contributions from a number of people and this is the case at Balcooma. I wish to acknowledge the part played by other people in the area.

These include Mike Mulroney who has been working on the areas during the last few years, and Dave Morris and John Nenke who each have spent some time in the area. Dr. N. J. W. Croxford and Dr. D. Patterson have carried out thin section and polished section work on rocks from the area and have greatly improved the understanding of the geology of the area. I would also acknowledge the contribution made to exploration of the area by Jack Messenger who was with me at the discovery of the gossans, and who has provided support for exploration in the area since that time.

I specially thank my wife, Liz, and my boys, Ian, Andrew and Richard, for their support and encouragement during

ACKNOWLEDGEMENTS (CONT.)

preparation of this document and for their acceptance of the necessity for my absence during field work in the area.

I am very grateful to Mrs. Sally Fleming and to Mrs. Jackie Darr for typing the text.

1. INTRODUCTION

The Balcooma Deposit lies at 18°46'S 144°43'E near the centre of the Conjuboy (7860) 1:100 000 sheet which forms part of the Einasleigh (SE 55-9) 1:250 000 sheet. It is located on the eastern side of the Great Dividing Range about 40 km north-west of Greenvale and 230 km west-north-west of Townsville, north Queensland (Fig.1). The deposit lies on the boundary between the Balcooma and Herberton Mining Fields and in the Charters Towers Mining District.

Figure 2 shows the location of the Balcooma deposit in relation to important geographical features in the area and to features referred to in the text.

The prospect has an average elevation of 540 m. The surrounding country is undulating stunted open forest grazing country forming portion of Conjuboy South Holding. Stunted iron-bark, bloodwood, wattle and gum comprise the majority of the timber species in the area, and spear grass, spinifex and kangaroo grass are the most common grasses.

The deposit was discovered by the author late in 1978 during a search for volcanogenic massive sulphide deposits in the lower Palaeozoic sequences surrounding Charters Towers.

Reserves of mineralization for the Balcooma deposit are 3.5 million tonnes of 3% copper with a small amount of lead-zinc mineralization. Exploration by the Conjuboy Joint Venture in a neighbouring area approximately 2 km to the south-west of the Balcooma deposit has shown the existence of a small body of lead-zinc-copper mineralization similar to the Balcooma deposit and most probably belonging to the same mineralizing event. A further small body of lead-zinc-copper mineralization exists a further 1 km south of this deposit at Dry River South.

This study has been carried out in conjunction with exploration of the area conducted by staff of Carpentaria Exploration Company Pty.

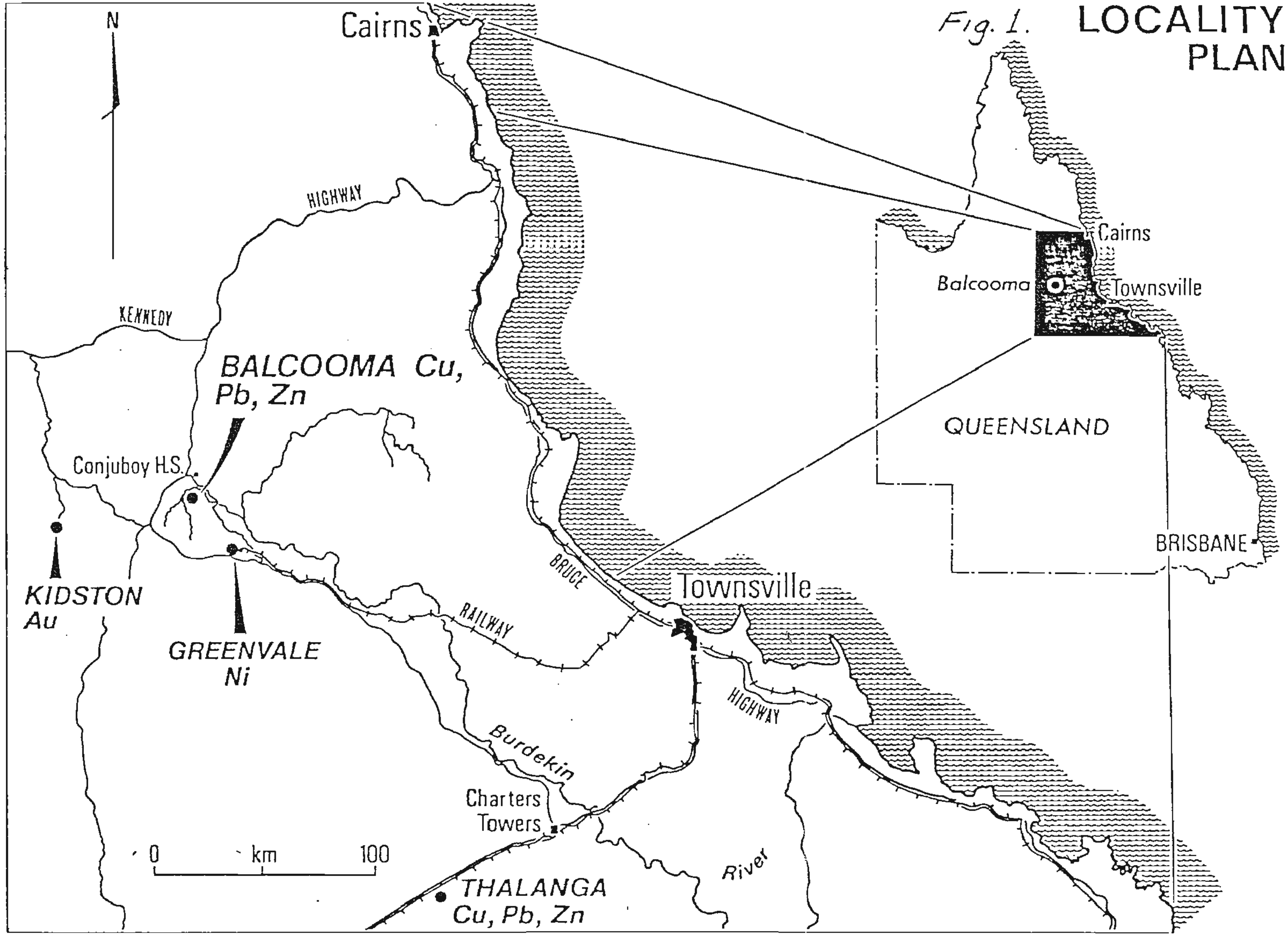


Fig. 1. LOCALITY PLAN
N
Cairns
HIGHWAY
KENNEDY
BALCOOMA Cu, Pb, Zn
Conjuboy H.S.
KIDSTON Au
GREENVALE Ni
BRUCE
RAILWAY
Townsville
HIGHWAY
Burdekin
River
Charters Towers
THALANGA Cu, Pb, Zn
0 km 100
Cairns
Balcooma
Townsville
QUEENSLAND
BRISBANE

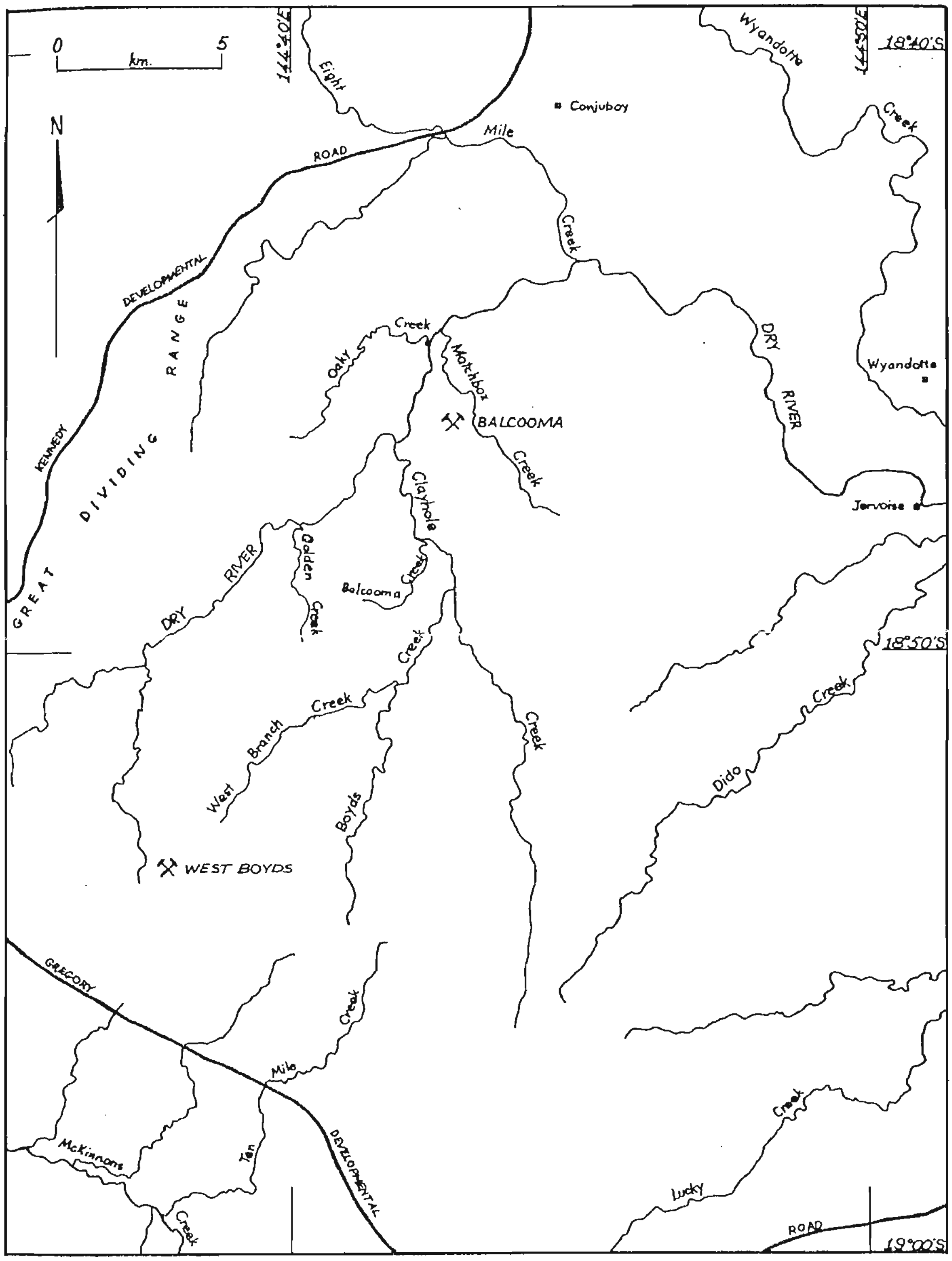


Fig.2 - Map of the Balcooma area showing important geographical features

Ltd. (CEC). Its purpose was to achieve a better understanding of the nature and distribution of the copper-lead-zinc mineralization and to eatablish the relationship of the mineralization to its geological setting.

During this work, it has been necessary to use informal names for some of the rock units in the area since the area has not previously been mapped in detail. Where this has occurred in this report, the names have been placed in quotes.

2. PREVIOUS INVESTIGATIONS

Up until the discovery of the Balcooma deposit, the Balcooma area had largely been neglected by previous investigators. The area lies to the east of the Georgetown area which at the time of discovery was being mapped in detail by a joint Bureau of Mineral Resources-Geological Survey of Queensland (BMR/GSQ) team at 1:100 000 scale (Bain et al., 1978; Withnall and Mackenzie, 1980) and it lies to the north-west of the Broken River-Greenvale area which had attracted some detailed attention (Arnold and Henderson, 1976; Arnold and Rubenach, 1976).

The area lies within the Einasleigh 1:250 000 sheet which was mapped by a joint BMR/GSQ party from 1956 to 1958. Results of this programme were published by White (1962, 1965) and the map was issued in 1963. This mapping was of a reconnaissance nature only. It showed the Balcooma area to contain ?Proterozoic Lucky Creek Formation overlain unconformably by late Palaeozoic acid volcanics. Areas of thin Tertiary laterite cover were also mapped.

During the Third Australian Geological Convention in Townsville in August 1978, a field excursion was conducted through the southern portion of the Balcooma area. The excursion handbook shows a broad mylonite zone running through the Balcooma area and the name

Balcooma Mylonite Zone was used for this feature (Rubenach, 1978).

Since the Balcooma discovery, mapping by a BMR/GSQ party, and in more recent years by a GSQ Party, has been carried out on the Conjuboy 1:100 000 sheet which contains the Balcooma deposit. Results for this work have yet to be published although some of this information is available on field sheets and in publications (Withnall, 1982).

Exploration conducted in the area up until CEC applied for Authority to Prospect 2036M "Balcooma" in 1978 was limited.

CEC held Authority to Prospect 789M "Clarke", Area 2 over the area during 1970 and 1971. A low density stream sediment sampling programme was carried out and anomalies located were followed up by soil sampling. No significant soil anomalies were located and the area was relinquished (Fletcher, 1971).

Esso Exploration and Production (Aust.) Inc. held Authority to Prospect 1653M over the area from August 1976 to February 1977. A search was carried out for uranium mineralization which involved a ground geological reconnaissance and a helicopter-borne radiometric survey. The area was found to be radioactively inactive and in the absence of favourable geological criteria, the area was relinquished (Billington, 1977).

Some minor gold mining has been carried out in the area to the south-west of the Balcooma deposit at Golden Creek and in the headwaters of West Branch Creek.

Very little information is available on this mining but gold was discovered in 1895 and the Balcooma Goldfield was proclaimed on January 27, 1897.

Occasional references to the area in the Queensland Government

Mining Journal and in Mining Warden's Reports suggest that shallow mining was carried out in the area until 1906 when a small battery on the field was shifted to the Lucky Creek area.

Brief references in the Queensland Government Mining Journal show that further minor mining activity occurred in the area during the period from 1932 to 1936.

Production from the field is unknown but is estimated at about 30 kg gold.

3. REGIONAL TECTONIC AND GEOLOGICAL FRAMEWORK

On the basis of the work carried out, as reported here, the rocks hosting the Balcooma deposit and rocks further to the east (Lucky Creek Formation) have been assigned a lower Palaeozoic age. The rocks are believed to have been laid down in an island arc environment and are considered to be approximate equivalents to the Cape River Beds including the Mount Windsor Volcanics in the Charters Towers area. Many of the features of the Balcooma area conform to the tectonic framework as described by Murray and Kirkegaard (1978) for the Thomson Orogen and, therefore, it is considered that the Balcooma rocks form a northerly extension of the Ravenswood Lolworth Province of the Thomson Orogenic Zone of the Tasman Fold Belt System.

This view contrasts with that of Murray and Kirkegaard (1978) who considered the northern boundary of the Thomson Orogen to be the Clarke River Fault. Inclusion of the Balcooma area in the Thomson Orogen requires the redefinition of the northern boundaries of this orogen.

The separation of the rocks in the Balcooma area from those of the Lolworth Ravensworth Province of the Thomson Orogenic Zone by the

Broken River Province requires that the Balcooma rocks be considered as a separate subprovince of the Ravenswood Lolworth Province (Fig.3).

The Balcooma area was previously considered to be within the Greenvale Subprovince forming part of the Precambrian Georgetown Province.

The term Greenvale Subprovince is retained in this report but it is redefined as a northerly extension of the Ravenswood Lolworth Province of the Thompson Orogenic Zone.

On the northern side, rocks belonging to the Greenvale Subprovince extend beneath the extensive sheet of basalt belonging to the McBride Basalt Province. The northern boundary of the subprovince can therefore not easily be determined. It is the author's favoured interpretation that areas of poorly outcropping metamorphics south of Mount Garnet are part of the lower Palaeozoic metamorphic suite and therefore the Thomson Orogenic Zone extends as far north as the extensive area of late Palaeozoic intrusives of the Herberton-Mount Garnet area.

On the western side, the subprovince is bounded by a major fault zone, here termed the "Oaky Creek Fault Zone" (Fig.4). Mapping by the GSQ (Withnall pers. comm.) has outlined another small area of probable lower Palaeozoic rocks west of the "Oaky Creek Fault Zone" but this outcrop is not sufficient to warrant the extension of the western boundary to include this area. Under this interpretation, the "Oaky Creek Fault Zone" assumes the same importance as the Palmerville Fault which forms the boundary between the Palaeozoic Hodgkinson Province and the Precambrian Yambo Province some 200 km further north.

On the south-eastern side the boundary of the Greenvale Subprovince is the Burdekin River Fault Zone. Ordovician rocks have been

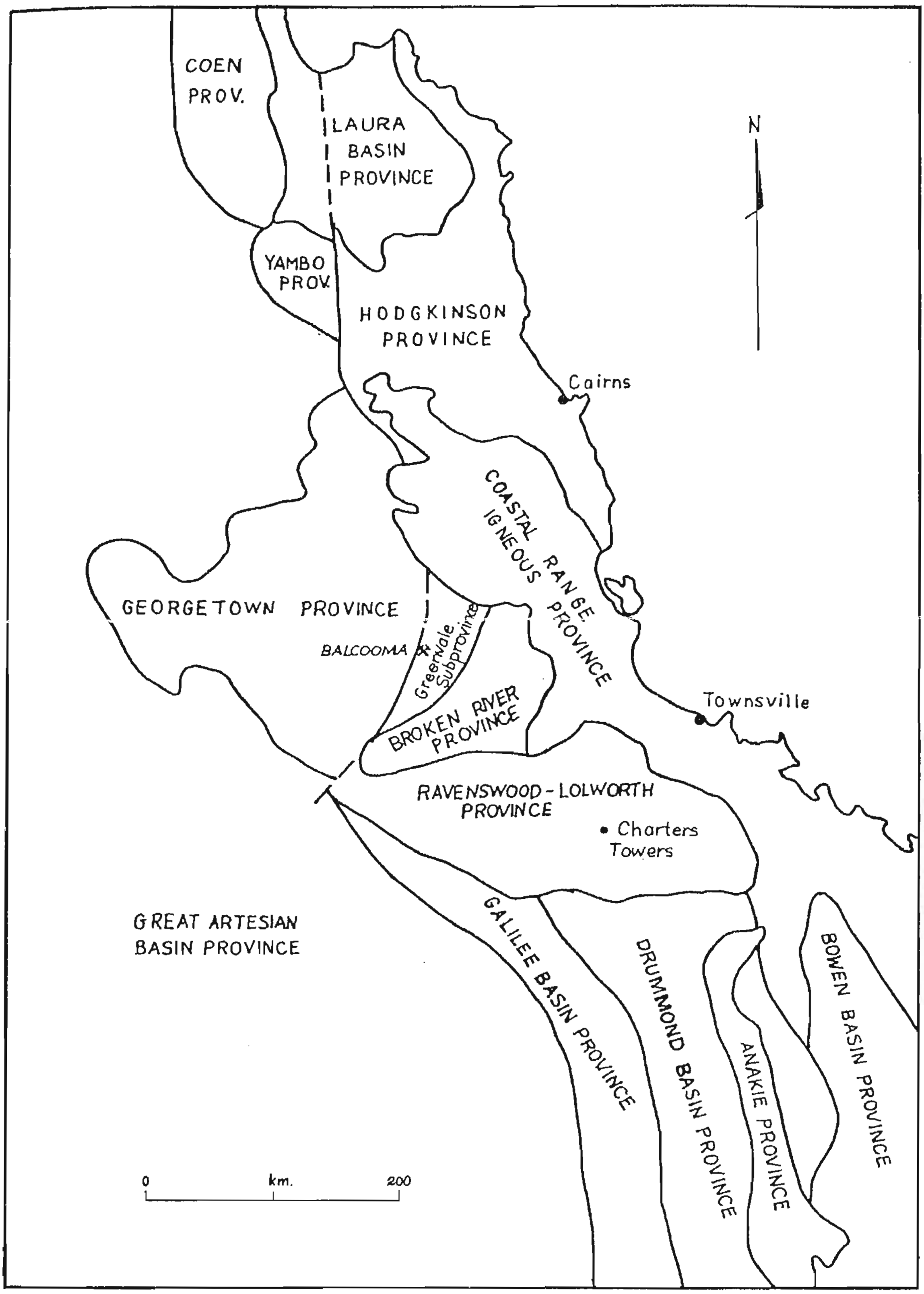


Fig.3 - Regional tectonic framework of north east Queensland showing geological provinces

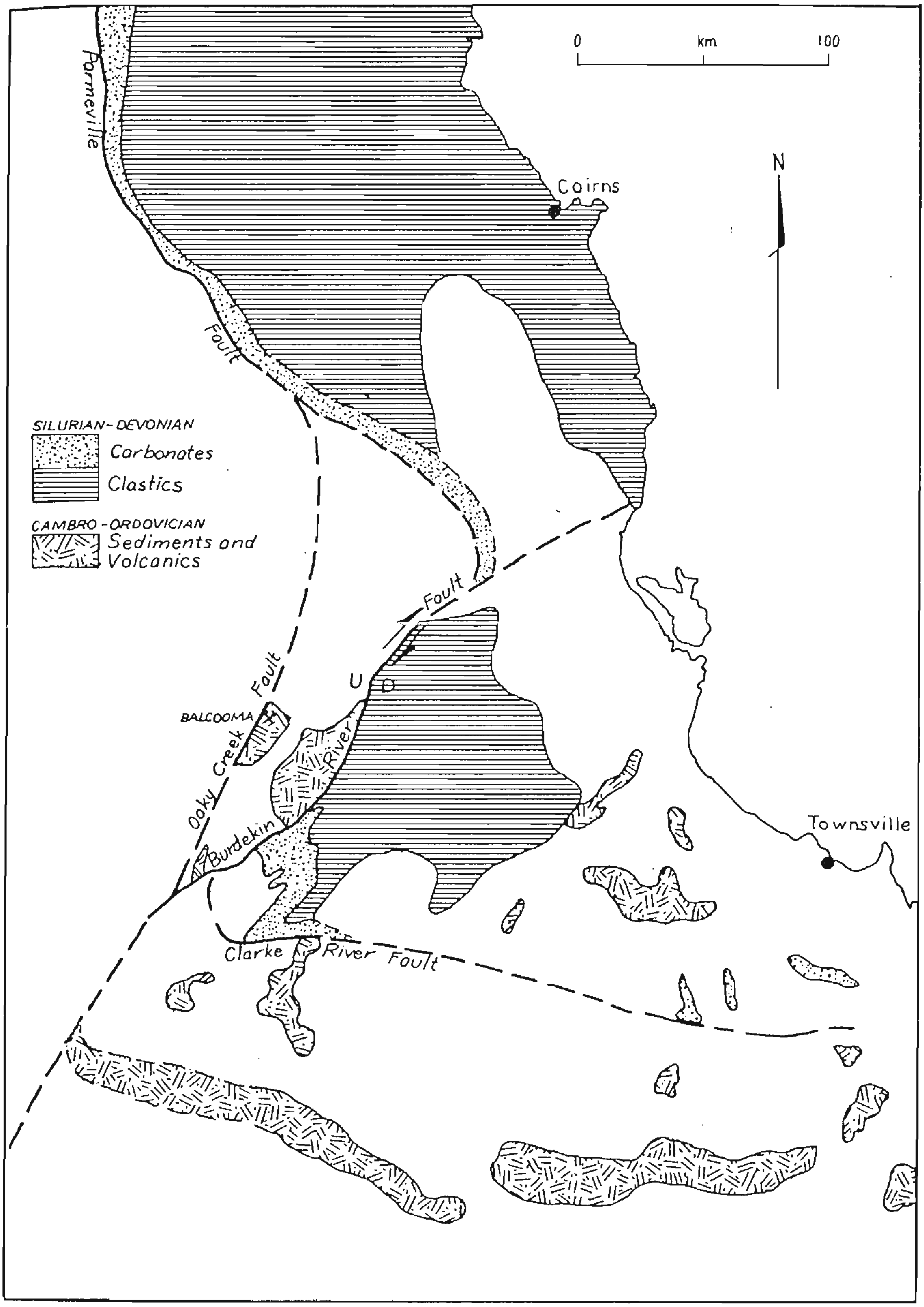


Fig.4 - Simplified geological map of the lower to middle Palaeozoic of north east Queensland showing the displacement on the Burdekin River Fault

mapped to the east of this Fault Zone (Arnold and Henderson, 1976; Withnall pers. comm.) but these are infolded and infaulted with middle Palaeozoic rocks that form part of the Broken River Province.

The Tasman Fold Belt developed in the late Precambrian to early Palaeozoic on the eastern margin of the Australian continent. Rocks of the Thomson Orogen, which are the earliest rocks of the Tasman Fold Belt System in north Queensland, appear to have been laid down during subduction of the ocean floor under the Precambrian craton from the east.

Much of the geological record is missing and nothing like a complete reconstruction is possible. However, the broad geological history appears approximately as follows.

Deposition on the western margin was probably onto thin Precambrian crustal rocks, while to the east it was probably onto oceanic crust (Murray & Kirkegaard, 1978). Early deposition on the western margin of the Thomson Orogen was probably largely clastic sedimentation. These sediments were probably followed by finer grained clastics with some carbonates.

As subduction progressed, an island arc type environment formed. Initially volcanism was of intermediate composition but as the island arc developed, volcanism largely became dacitic to rhyolitic in composition. As volcanism waned, deposition returned largely to clastic rocks.

During the existence of this island arc, the volcanics and sediments of the Balcooma area were laid down. The rocks of the Lucky Creek and Paddys Creek Formations are also considered to have formed at this time.

Deformation, intrusion and metamorphism of the volcanics and sediments of the Balcooma area occurred in the middle Ordovician. The deformation probably resulted from the continuing subduction from the east and consequent compression of the newly deposited volcanics and sediments against the Precambrian craton. Isoclinal folding resulted and metamorphism reached lower amphibolite facies in some areas particularly close to the granitic intrusives. A number of west dipping thrust faults developed early in the deformation including the "Oaky Creek Fault Zone". As deformation continued with compression from the east-south-east, these thrust faults steepened. A further result of this was to tilt the sequence such that the overall younging was to the west. This resulted in the youngest rocks (the "Balcooma Metamorphics") being exposed on the western side of the province and the oldest rocks, the Lucky Creek and Paddys Creek Formation, being exposed to the east. Further east, Precambrian basement (Halls Reward Metamorphics) and some of the ocean floor (Grays Creek Complex) is now exposed as a result of this tilting.

The Balcooma area was cratonised by the middle Ordovician orogen and following this it largely acted as a stable area providing material to the basins to the east during middle Palaeozoic times.

During the middle Palaeozoic these basinal areas adopted a more northerly trend reflecting a change in the relative direction of movement of the subducting plate. Accompanying this the Burdekin River Fault was activated as a transverse structure cutting across the structural grain in the lower Palaeozoic Thomson Orogen at an acute angle. The movement along this fault was east block south and down and the main movement seems to have been during the Devonian, although movement continued after this time.

The results of this faulting were that sediments in the southern portion of the Hodgkinson Province were displaced some 100 km to the south-west and now appear in the Broken River Province (Fig.4).

Widespread intrusion of granitic rocks occurred during the late Silurian or early Devonian. This was accompanied by an orogenic event. The granitic intrusives were largely restricted to the area west of the middle Palaeozoic basins in the cratonic source of the sediments to the basins. Folding and metamorphism accompanied this event in the craton but the effects were somewhat milder than those of the Ordovician event. Significant metamorphism was largely restricted to the areas adjacent to the granitic intrusives and folding was of a more open style with a generally northerly trend.

In the Balcooma area, the Dido Granodiorite was intruded at this stage and folding of this type has been recognized immediately west of the Balcooma deposit.

East of the active Burdekin River Fault Zone, folding of the pre-early Devonian rocks occurred but granitic intrusion was limited. In this area also, deposition recommenced after only a short time break when the limestones and associated sediments of the Broken River Formation were laid down. The Burdekin River Fault Zone was active as a strike slip fault and largely acted as a western edge to the basinal area. However, as evidenced by occasional areas of middle Devonian marine limestones and sediments in the Balcooma area, the seas transgressed this fault zone, at least for short periods of time but deposition was limited.

During the late Devonian, further folding occurred and the middle Palaeozoic basinal areas were essentially cratonised at this stage. The effects of folding at this stage are not obvious in the Balcooma area where no significant foliation developed. The "Oaky Creek Fault Zone" was reactivated at this stage and the middle Devonian strata was titled westward into the fault zone, possibly due to isostatic readjustment (i.e. east block upwards). Extensive faulting may have occurred at this stage. However, this is uncertain and it may have occurred later during the Carboniferous.

Deposition after this time was epicontinental but involved both terrestrial and marine sedimentation. The Burdekin River Fault Zone was probably active and acted as a western boundary to the Bundock Basin. Deposition occurred over a wide area during the late Devonian-early Carboniferous including that in the Gilberton, Bundock, Clarke River, Burdekin, Drummond and Hodgkinson Basins. This deposition was halted in Visean times when uplift and some folding of the eastern portion of the area took place. No evidence of the effects of this folding exists in the Balcooma area but some warping and faulting may have occurred. The Oweenee Granite was intruded at this time.

Following this period of deformation and intrusion, terrestrial volcanics and some related sediments were laid down. To the west of the present Coastal Range, deposition was largely restricted to a number of cauldron subsidence areas, including the Newcastle Range and the Featherbed Range Cauldron Subsidence Areas. In the Balcooma area a thin sequence of acid fragmentals with some basal sediments was laid down in a poorly formed subsidence area immediately east of the Balcooma deposit. Further to the north-east, in the area north-east of Wyandotte Homestead, a similar sequence of volcanics occurs.

Widespread intrusion of granitic rocks occurred in the late Carboniferous-early Permian, particularly along the Coastal Range area. No intrusives of this age have been recognized in the Balcooma area.

Following the widespread intrusive activity of the early Permian, downwarping of the continental crust took place and in the Bowen Basin, volcanics were followed by largely terrestrial deposition with some marine incursions. In the Galilee Basin, only terrestrial sediments accumulated. None of these rocks is represented in the Balcooma area.

Likewise, rocks belonging to the Great Artesian Basin of Mesozoic age are not represented in the Balcooma area.

Widespread lateritisation occurred during the Tertiary and remnants of the lateritic profile are scattered through the area.

During the Cainozoic, widespread extrusion of continental basalts occurred and basalt masks large parts of the area surrounding Balcooma. One of the interesting features of the basaltic volcanoes is that they are located in a north-easterly trending belt some 150 km wide centred on and parallel to the Burdekin River Fault Zone. This distribution suggests some relationship between the position of basaltic volcanoes and the Burdekin River Fault Zone.

4. REGIONAL GEOLOGY

The simplified geological picture of the area (Fig.5) is that of a sequence of Precambrian metamorphic rock (Einasleigh Metamorphics) on the western side, faulted against a sequence of lower Palaeozoic metamorphosed sediments and volcanics on the eastern side. In this report these lower Palaeozoic rocks are referred to as the "Balcooma Metamorphics" and the fault zone as the "Oaky Creek Fault Zone". Granitic rocks of probable Precambrian age intrude the Precambrian metamorphics while intrusives of probable Ordovician and Devonian (Dido Granodiorite) age intrude the lower Palaeozoic metamorphics. Small remnants of middle Devonian sediments lying unconformably on the lower Palaeozoic metamorphics exist in two areas. A thin veneer of late Palaeozoic acid volcanics occurs to the east of the Balcooma deposit. Numerous remnants of a Cainozoic laterite sheet, particularly in the northern and eastern portion of the area, exist. Cainozoic basalts of the McBride Basalt Province, which post-date the laterite, lap onto the Precambrian and

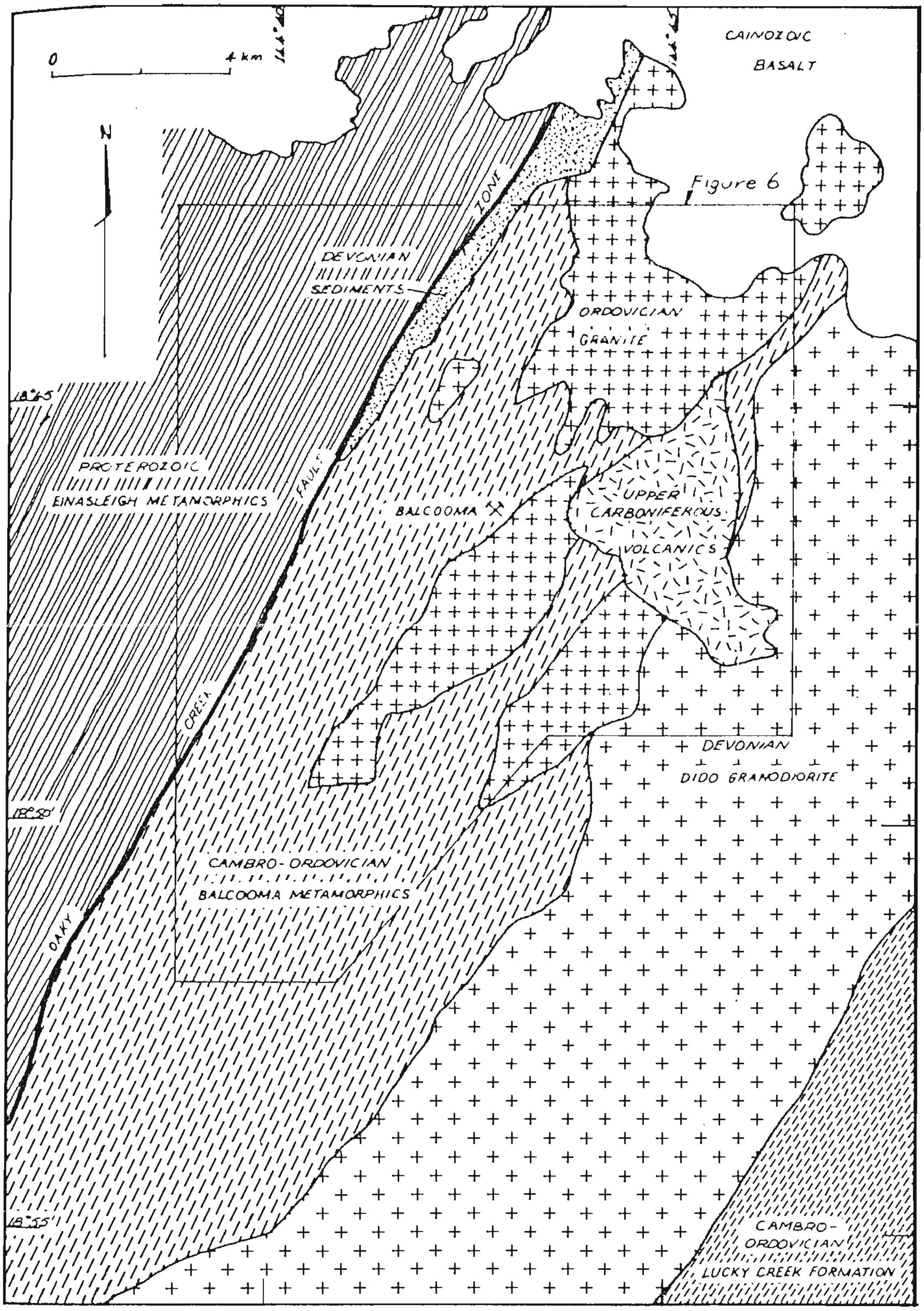


Fig.5 - Simplified regional geology of the Balcooma area showing the major rock units. Laterite is omitted.

Palaeozoic rocks in the northern portion of the area.

Alluvial deposits have developed on the major drainage systems in the area. A generally thin but extensive soil cover has developed on less resistant lithologies in the area.

4.1. Einasleigh Metamorphics

The oldest rocks in the Balcooma area are a sequence of metamorphic rocks belonging to the Einasleigh Metamorphics. Although subdivision of these rocks has been carried out in the Georgetown-Forsayth-Einasleigh area approximately 50 km to the west, by the BMR/GSQ, no subdivision has yet been attempted in the Balcooma area. Since these rocks do not host the Balcooma deposit, they have not been studied in detail.

They consist of a sequence of gneisses, schists and amphibolites of probable Proterozoic age (Withnall and Mackenzie, 1980). These show evidence of multiple deformation and although they now show a steeply dipping north-north-easterly trending foliation, the structure of the rocks is relatively unknown.

Black et al. (1978) report five periods of deformation for these rocks and they undoubtedly have undergone a number of periods of metamorphism. The geology of these rocks is exceedingly complex.

A number of coarse-grained biotite granodiorite bodies occur scattered through these rocks. These bodies show complex relationships with the metamorphics, are foliated and, in general, are intruded by basic dykes which have been metamorphosed to amphibolites. Because of these features, the granodiorite bodies are thought to be Precambrian rather than Palaeozoic in age. Palaeozoic intrusives, however, do occur within these rocks further west.

Pegmatite veins and small intrusions are common in the metamorphics. They are principally quartz feldspar muscovite pegmatites and no economic minerals are known in these bodies. They appear to have resulted through metamorphic processes rather than through intrusion of the granodiorite bodies, since they show no spatial relationship to these intrusives.

Metamorphism and deformation has almost completely destroyed the original textures in the Einasleigh Metamorphics and the precursors to the metamorphic rocks are not known. However, it is suspected that these rocks were originally sediments intruded by basic dykes.

4.2. "Balcooma Metamorphics"

A sequence of lower Palaeozoic rocks, the "Balcooma Metamorphics", is faulted against the "Einasleigh Metamorphics" on their eastern side. The name "Balcooma Metamorphics" has been used for all the metamorphic rocks lying between the Dido Granodiorite to the east and the Einasleigh Metamorphics to the west, as shown in Figure 5.

These lower Palaeozoic rocks consist of a sequence of metamorphosed volcanics and sediments of upper greenschist-lower amphibolite facies. They host the Balcooma massive sulphide deposit.

Acceptance of a lower Palaeozoic age for these rocks is based on broad correlation with the Mount Windsor Volcanics, which have been dated as lower Palaeozoic (Webb, A.W., 1974) from lead isotope data presented later in Figure 46, which shows the lead mineralization to be of lower Palaeozoic age, and from dating of zircons in volcanics within the sequence (Withnall et al. in prep.). Dating of the lead mineralization is considered to be significant since it is interpreted to be of an exhalative syngenetic type and therefore the enclosing sequence is interpreted to be of the same age.

The complex metamorphic and deformational history of the area has made detailed mapping of these metamorphics a difficult task. However, it has been possible to subdivide these rocks into six separate units. These are shown in Table 1. Because of the complex structure of the area and extensive faulting, the thicknesses of the various units comprising the Balcooma Metamorphics are very difficult to establish accurately. Those shown in Table 1 are included as a rough approximation only.

The lower Palaeozoic metavolcanics and metasediments occupy a south-south-westerly trending belt of country stretching from just south of Conjuboy homestead to McKinnons Creek. They occupy an area of about 150 km^2.

To the south and east, these rocks are intruded by the Siluro-Devonian Dido Granodiorite and to the north-east by granitic rocks, including the "Matchbox Creek Microgranite" of probable Ordovician age. These intrusives effectively limit the distribution of the "Balcooma Metamorphics" in these directions, although more recent mapping by the GSQ has shown the existence of metamorphics, which are thought to belong to the lower Palaeozoic further south in the McKinnons Creek area (Withnall pers. comm.).

The "Balcooma Metamorphics" are extensively faulted and folded. The rocks generally show a north-north-easterly trending foliation paralleling the "Oaky Creek Fault Zone".

Although folding is obvious in a number of areas, the dominant attitude of the "Balcooma Metamorphics" is steeply dipping with a westerly facing. The detailed structure within these rocks is generally unknown except in the area of the prospect where detailed drilling has been carried out.

More detailed mapping in the deposit area has indicated that two major periods of deformation have occurred. The structure of the area is the subject of a Ph.D. Thesis currently being completed by

TABLE 1

Stratigraphy of the "Balcooma Metamorphics".

Name	Approx. Thick. (m)	Lithologies	Original Rocks	Comments
"Golden Creek Volcanics"	+800	Actinolite albite schist, quartz mica schist.	Andesite to basaltic lapilli tuffs, tuffs, flows and breccias, minor intercalated sediments.	Faulted against other lower Palaeozoic lithologies.
"Highway Beds"	600 - 800	Quartz mica schist, quartz mica albite schist, minor amphibolite.	Sediments, acid tuffs, minor basic volcanics.	Grades into the "Oaky Creek Fault Zone" on western side and boundary is therefore subjective.
"Lochlea Volcanics"	500 - 800	Meta rhyolite, meta dacite minor metasediments.	Rhyolite to dacite flows and tuffs, minor sediments.	Prominent outcropping horizon with coincident airborne magnetic anomaly.
"West Branch Creek Beds"	500 - 800	Quartz mica schists, quartz mica albite schist.	Sandstones, siltstones, acid tuffs.	Host to stratiform barytes-carbonate-sulphide horizon at West Boyds Creek prospect.
"Dry River Volcanics"	+1500	Quartz mica albite schist.	Rhyolites, rhyodacites, dacites.	
"Clayhole Creek Beds"	+1500	Quartz mica schist, quartz mica staurolite schist, quartz mica albite schist.	Sandstones, siltstones, shales, acid tuffs.	Host to Balcooma Deposit. Base not exposed.

Mr. F. van der Hor and it is not the intention to discuss this in detail in this report, other than where it is relevant to the disposition of the sulphide bodies.

Faulting within the "Balcooma Metamorphics" is extensive. A number of faults occur which are parallel or near parallel to the major north-north-easterly trending "Oaky Creek Fault Zone". As this faulting direction is parallel to the major lithological strike in the area, this faulting is almost certain to be more extensive than mapped.

A more obvious faulting direction is that trending north-easterly. Numerous faults with this strike direction have been mapped in the area. The dominant displacement on these faults is north block easterly (i.e. right lateral separation). These north-easterly faults post-date the major deformation events as evidenced by the tendency for foliation to be curved into the faults. A north-easterly fault also determines the northern boundary of the late Palaeozoic volcanics, suggesting that this faulting may have been activated in the late Carboniferous period, during or after this volcanic activity. This faulting also offsets the middle Devonian sediments.

4.2-1. "Clayhole Creek Beds"

The "Clayhole Creek Beds" are a sequence of schists of upper greenschist to lower amphibolite facies which are interpreted as the basal unit of the "Balcooma Metamorphics" (Fig.6). They host the Balcooma massive sulphide deposit. They lie to the east of the main acid volcanic unit ("Dry River Volcanics") and between this acid volcanic unit and the intrusive bodies to the east (Fig.6). The boundary of this unit with the overlying "Dry River volcanics" is taken to be the point at which the dominantly metasedimentary sequence becomes a dominantly metavolcanic sequence. This boundary in all cases is quite sharp and is easily mapped where exposed.

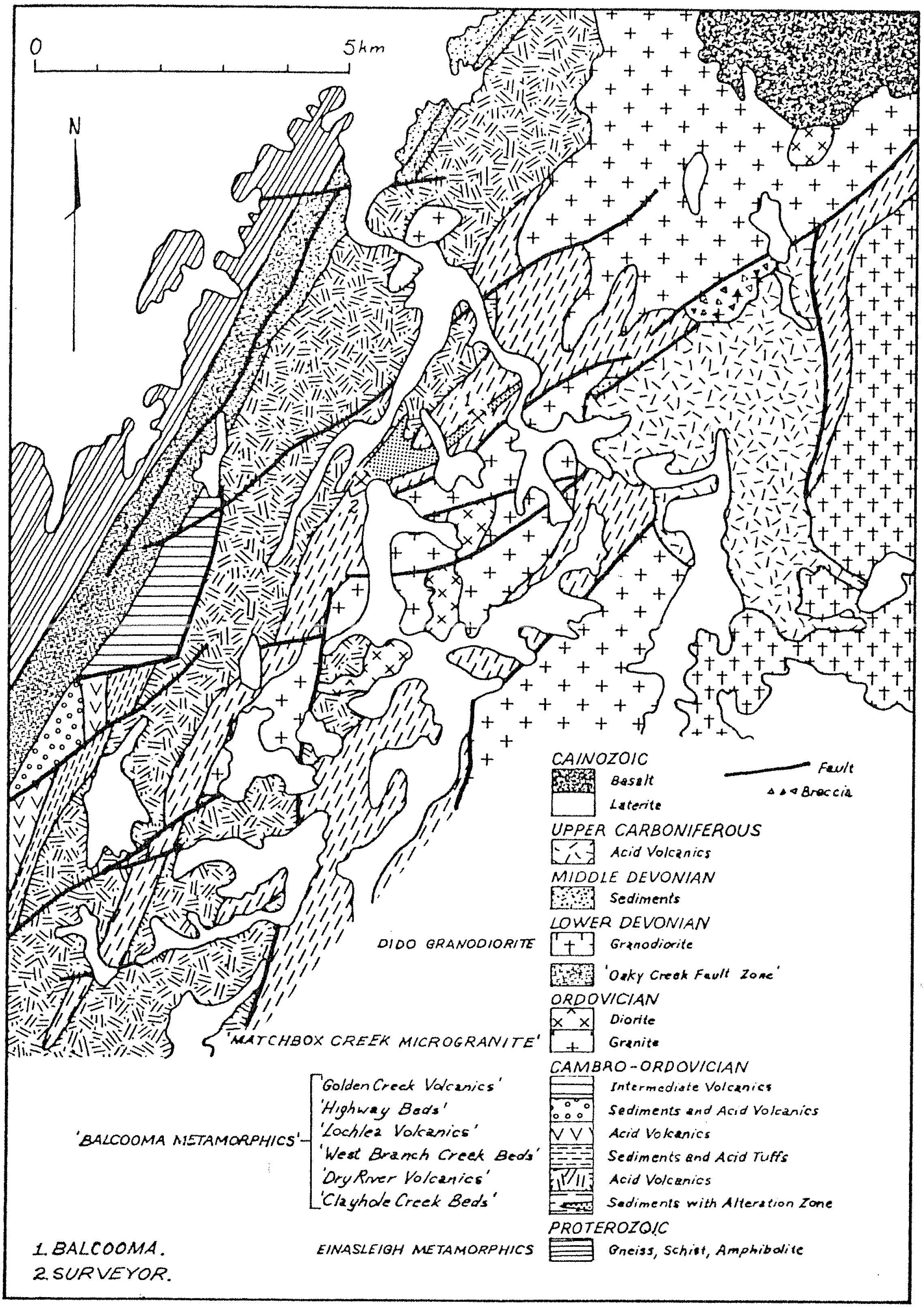


Fig.6 - Detailed regional geology of the area surrounding the Balcooma deposit

They outcrop over an area of 50 km^2 in a north-north-easterly trending zone from the Gregory Developmental Road to the area east of the Oaky Creek-Dry River junction.

Although the soil cover is usually thin on these rocks, outcrop is generally poor. Good outcrops, however, do occur in some of the streams draining the area. Information on the "Clayhole Creek Beds" has been collected from these outcrops and from diamond drill core from the Balcooma prospect area.

The rocks are comprised of a series of quartz-mica schists containing, in addition to quartz, biotite and muscovite, varying proportions of staurolite, plagioclase (low Ca), andalusite and cordierite. K-feldspar, garnet and kyanite report in a few of the thin sections but these are very minor phases only. Accessories include magnetite, apatite and zircon. Chlorite and garnet, which are prevalent in the host rock to the massive sulphide mineralization, are considered as part of an alteration envelope and are therefore discussed separately.

The most common schist types in the "Clayhole Creek Beds" are quartz muscovite biotite schist and quartz muscovite biotite staurolite schist. The quartz muscovite biotite schist is distributed throughout the area but is predominant in the southern portion of the area. Quartz muscovite biotite staurolite schist is present in the central and northern portion of the area forming about 50% of the rocks of the "Clayhole Creek Beds" in the vicinity of the Balcooma deposit. This distribution is considered to be related to the lithologies from which the metamorphics were derived, rather than to differences in metamorphic facies.

Almost all of the petrology of these rocks has been carried out on rocks collected from the northern portion of the area where all important lithologies are represented. Selected petrographic reports of rocks from Balcooma are included in Appendix 1.

Two main varieties of staurolite-bearing schists are recognized. The dominant type consists of a rock with large pale pink staurolite and large black biotite porphyroblasts, together often comprising 50% or more of the rock, with quartz and muscovite in a finer-grained matrix (Fig.7); while the second type consists of a rock usually with fewer, but still large, staurolite porphyroblasts in a finer grained quartz muscovite biotite matrix (Fig.8). These two types are likely to reflect slight differences in the chemical composition of the lithologies prior to metamorphism.

Staurolite porphyroblasts range from anhedral to euhedral in shape and are commonly twinned. They range in size up to 30 mm but average about 7 to 10 mm in length. In thin section they are shown to be strongly sieved by quartz which may comprise up to 40% of the porphyroblasts. Parallel layering of quartz seen in some of the staurolites may reflect primary bedding in the sediments which were precursors to the schists (Fig.9). Staurolite may appear to comprise up to 50% of some schists in hand specimen but because of the large amount of quartz inclusions, the content is less than it appears to be.

Biotite porphyroblasts tend to be equidimensional in character and range in size up to 10 mm but are, on average, about 5 mm in diameter. Biotite generally may comprise up to about 20 to 30% of the rock. Biotite porphyroblasts also tend to be sieved with quartz (Fig.10). They also contain inclusions of zircon which have radiation haloes. Both the quartz and the zircon inclusions define a layering which is probably an inherited sedimentary effect. Where biotite and staurolite prophyroblasts comprise a majority of the rock, these tend to destroy the fissility within the schist, since muscovite and quartz wrap around the porphyroblasts rather than becoming strongly oriented.

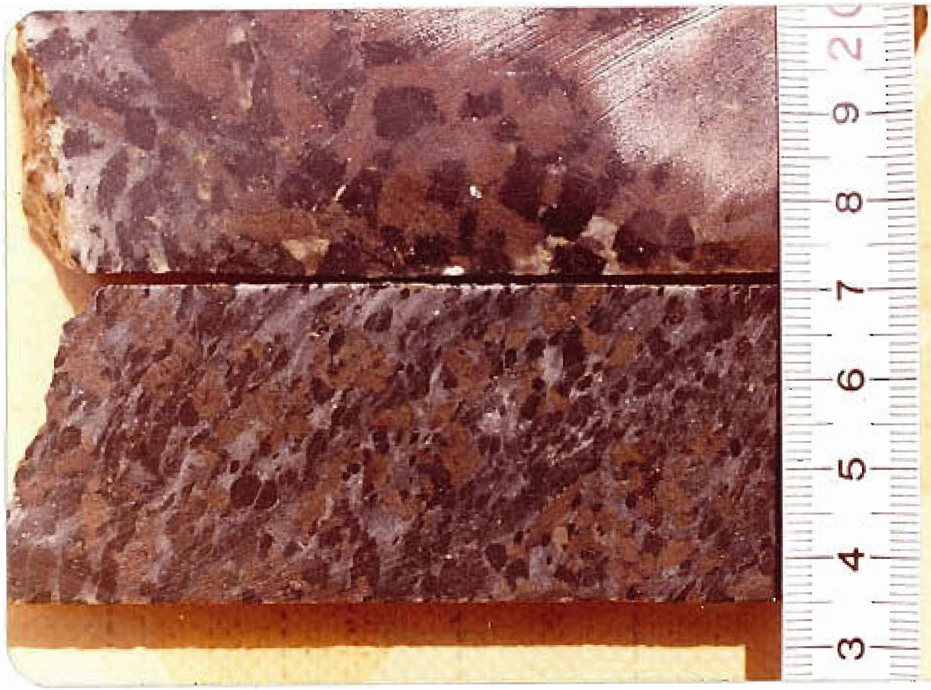
Plagioclase (albite or occasionally oligoclase) may sometimes occur in staurolite-bearing schist but it is more common in finer grained

Fig.7. BQ drill core of staurolite (pink), biotite (black), quartz muscovite schist of the "Clayhole Creek Beds".

Loc. Balcooma DDH 1

Fig.8 Weathered surface of staurolite quartz biotite muscovite schist of the "Clayhole Creek Beds" showing large euhedral staurolite porphyroblasts.

Loc. Balcooma 9900N 2000E


3
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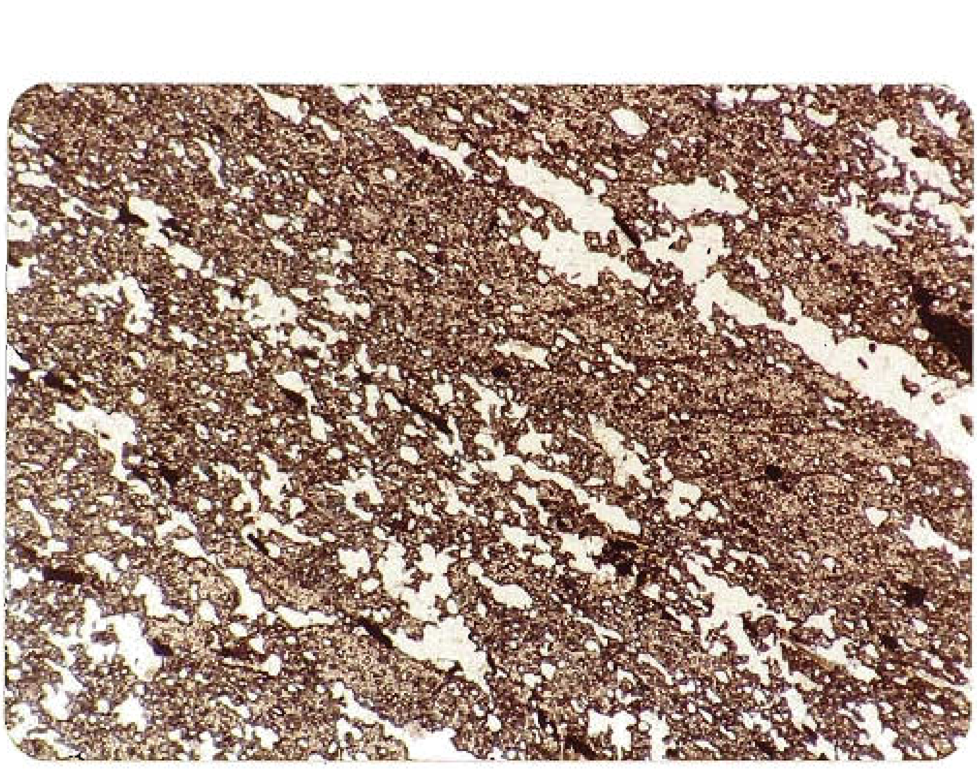
YASHICA

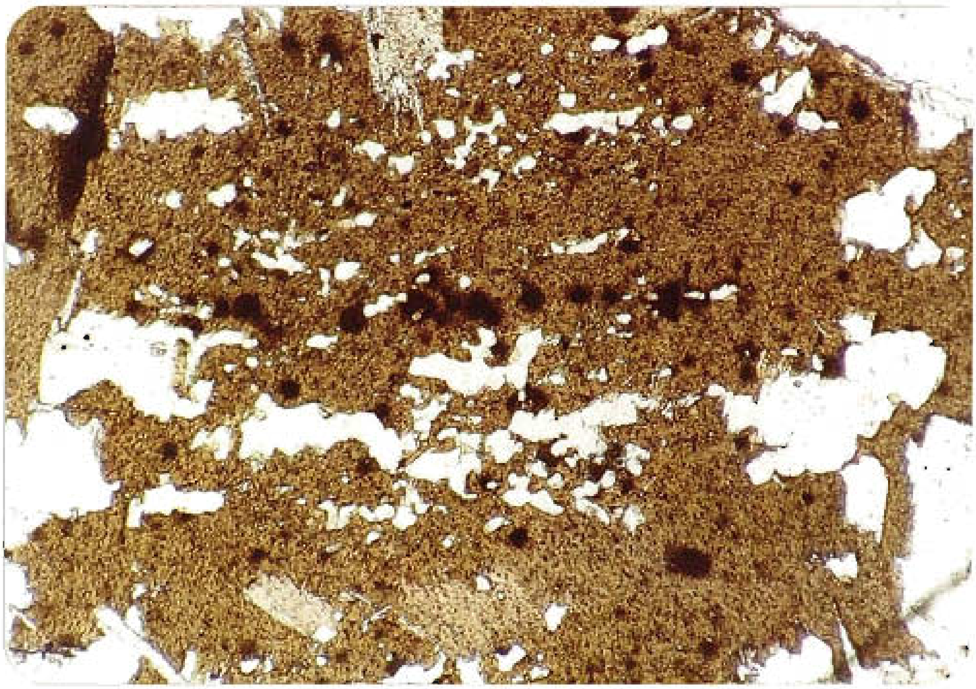
Fig.9. Photomicrograph of a staurolite porphyroblast in staurolite quartz biotite muscovite schist. Note layering of the quartz inclusions. PPL, x25.

Loc. Balcooma DDH1

Fig.10. Photomicrograph of a biotite porphyroblast in staurolite quartz biotite muscovite schist showing quartz sieving and radiation haloes around included zircons. PPL, x25.

Loc. Balcooma DDH1





schist or in schists with a lower staurolite content.

Analyses of staurolite biotite muscovite quartz schists for major elements are shown in Table 2. These are compared with data from Pettijohn (1957) for an average shale. The results show that the staurolite-bearing schists contain similar major element compositions to an average shale, except that Fe_2O_3 and MgO are slightly higher and CaO and Na_2O are anomalously low. The low CaO probably reflects the absence of any calcite in the Balcooma rocks, while the average shale might be expected to contain some data for calcareous shales. The low Na_2O probably reflects the loss of this during metamorphism. As will be seen in Section 5.1, Na_2O enrichment has occurred in feldspathic rocks such as tuffs and granites where Na_2O has probably been fixed in albite. Since albite did not form to any degree in the metamorphosed fine grained sediments, Na_2O has apparently been lost during metamorphism.

Further evidence that the staurolite bearing schists are metamorphosed shales comes from both drill core and outcrops of interbedded metasandstones and staurolite schists. Good outcrops of these occur in Matchbox Creek 2 km north of the deposit (Fig.11). Here the staurolite-bearing schist can be seen to be the metamorphosed fine grained shaly tops to graded beds (Fig.12). Good examples also occur within diamond drill core from the Balcooma prospect (Fig.13).

Where these interbedded metamorphosed sandstones and shales occur, the effects on the rocks of both deformation and metamorphism become clear. Coarse grained sediments, such as quartzo-feldspathic sandstones, have not responded to these processes to the same degree as the fine grained sediments (shales). They have developed a weak foliation due to alignment of the micas formed during metamorphism, and grain sizes have increased due to recrystallization, but in general, sandstone beds are easily recognizable as such. In the fine grained sediments metamorphism

TABLE 2

Analyses of staurolite biotite muscovite quartz schists of the "Clayhole Creek Beds", Balcooma, compared with average shale. Major elements in wt %

	1	2	3	4	5	6
SiO_2	57.2	65.1	60.4	66.7	62.35	58.1
TiO_2	0.78	0.71	0.84	0.75	0.77	0.65
Al_2O_3	14.8	17.9	15.7	16.3	16.17	15.4
Fe_2O_3	10.0	7.95	7.10	8.5	8.38	6.74
MnO	0.21	0.08	0.08	0.08	0.11	-
MgO	5.20	3.80	3.65	3.30	3.98	2.44
CaO	0.51	0.21	0.47	0.26	0.36	3.11
Na_2O	0.37	0.33	0.32	0.22	0.31	1.30
K_2O	3.55	3.75	4.10	2.98	3.59	3.24
P_2O	n.d.	n.d.	n.d.	0.15	-	0.17
SO_3	n.d.	n.d.	n.d.	0.20	-	0.64
CO_2	1.0	0.05	0.25	n.d.	-	2.63
H_2O	n.d.	n.d.	n.d.	n.d.	-	5.0
LOI	n.d.	n.d.	n.d.	0.99	-	-

1. DDH 5 , 118.0 m
2. DDH 5 , 120.0 m
3. DDH 5 , 126.7 m
4. DDH16A, 182.0 m
5. Average of Samples 1 to 4
6. Average composition of shale (Pettijohn, 1957)

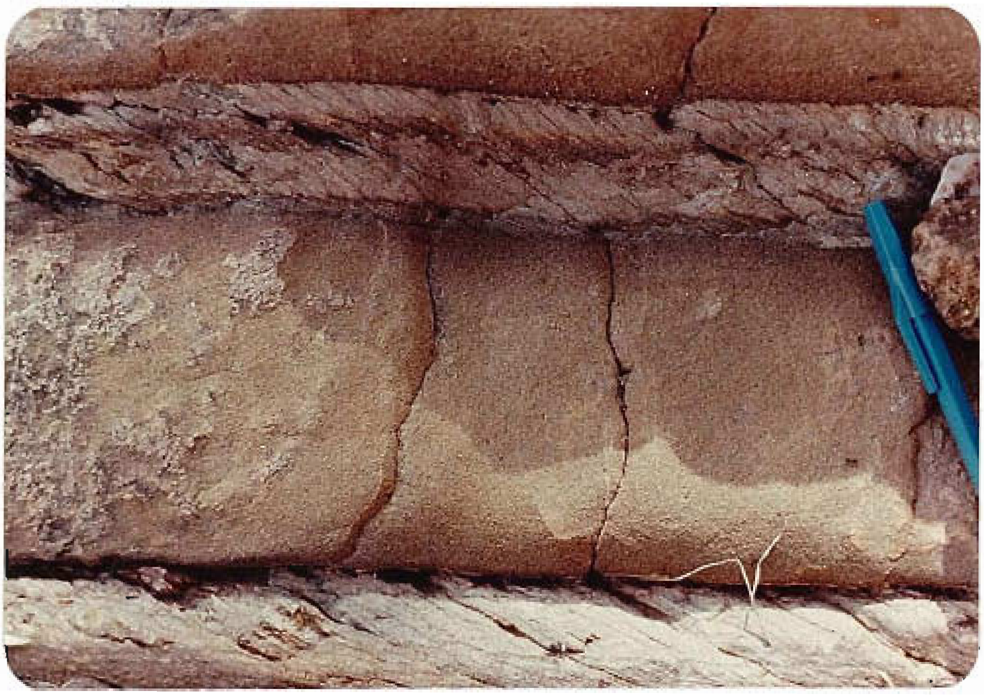
n.d. = not determined

Fig.11. Outcrop of interbedded metasandstones and staurolite bearing schists showing easily recognizable sandstone beds with interbedded coarse grained schists after fine grained sediments.

Loc. 2 km north Balcooma deposit

Fig.12. Close-up photograph of beds in Figure 11 showing the development of a relatively strong foliation in the metamorphosed shaly tops to graded beds. Facing is indicated both by the sharp bases to the metasandstone beds compared to the gradational contact between the metasandstone and schist within an original graded unit.

Loc. 2 km north Balcooma deposit



has completely recrystallized and changed their character. They are reflected by the formation of schists containing coarse grained staurolite and biotite, particularly towards the tops of the graded beds and they show a well defined foliation which is not so well developed in adjacent metasandstones (Figs 12, 13).

Staurolite is absent from the base of the graded beds and only appears higher in the beds when the argillaceous content increases and therefore the alumina content increases. It becomes the predominant mineral species at the extreme top of some of the graded beds. Biotite is present throughout the beds but is fine grained and a minor component at the base of the beds. Muscovite has a similar distribution. Plagioclase (albite or low calcium type) is more common in the basal portions of the beds. It probably partly represents albitised detrital feldspar in the original sediment. Quartz occurs throughout but decreases from bottom to top as the proportion of staurolite increases.

The detailed information arising from this study of the mineralogy of graded beds has been applied in understanding the metamorphosed sediments throughout the area. This has allowed an interpretation of the premetamorphic geology of the area and therefore an increased understanding of the original setting of the mineralization.

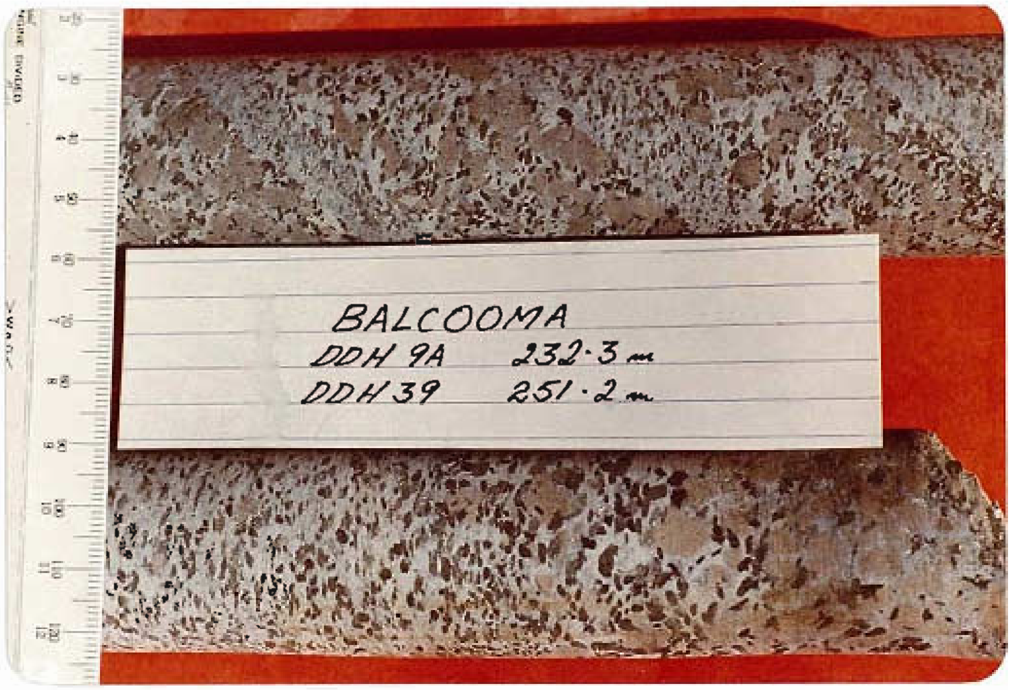
Acid tuffs occur within the metasediments of the "Clayhole Creek Beds" (Fig.14). Although these rocks have a schistosity and consist of metamorphic assemblages, they retain their volcanic appearance and are relatively easy to identify since they commonly contain quartz (sometimes plagioclase) phenocrysts. They are generally represented by weakly foliated quartz albite biotite muscovite schists, with quartz and plagioclase (albite) phenocrysts up to 4 mm, set in a fine grained groundmass of quartz, albite, biotite and muscovite. In the area 2 km north of the Balcooma prospect these tuffaceous units are more prevalent in the sequence,

Fig.13. BQ drill core from the Balcooma deposit showing the coarsening of staurolite (pink) porphyroblasts towards the metamorphosed fine grained tops of originally graded beds. Note the absence of staurolite in the sandy bases to the beds. Facing is to the right.

Loc. as indicated

Fig.14. Outcrop of strongly crenulated quartz muscovite biotite schist of the "Clayhole Creek Beds" showing an interbedded acid tuff.

Loc. Balcooma 10 000N 1700E


BALCOOMA
DDH 9A 232·3 m
DDH 39 251·2 m

and individual units are up to about 20 m in thickness. At the Balcooma prospect, quartz feldspar porphyry bodies closely associated with the copper bearing massive sulphides, appear to be sills and/or dykes although they are very similar to some of the volcanics. Graded fragmental volcanic units within the "Clayhole Creek Beds" have also been intersected in drill holes which have been drilled well into the footwall of the mineralization (Fig.15). These generally contain fragments of lapilli size (up to 20 mm) at the base and grade up into ash tuffs at the top. These in turn are overlain by either sediments or, in some cases, by further pyroclastic units. Grading within these units has been important in establishing facing in the prospect area.

The structure within the "Clayhole Creek Beds" has only been deciphered in the vicinity of the Balcooma deposit. Facing evidence from graded bedding in metasediments and tuffs, along with bedding to cleavage relationships and lithological correlations in this area, have shown the existence of at least two periods of strong deformation.

Evidence of these two deformation events is well recorded in the schists of the "Clayhole Creek Beds". These rocks show a well developed prominent early slaty cleavage which is axial plane to an isoclinal folding event and a crenulation cleavage which is axial plane to a later folding event (Fig.16).

In the vicinity of the Balcooma deposit, the strike and dip of the early cleavage is variable since it has been deformed by the later event. It is also usually strongly refracted as it passes from metasandstones to metashales, making it difficult to establish meaningfully since it can be highly variable in one outcrop. On the other hand, the crenulation cleavage is remarkably consistent throughout the area surrounding the Balcooma prospect. It shows a dip of around 85° to the east-south-east and a strike of about

Fig.15. BQ diamond drill core from the Balcooma deposit showing graded acid lapilli tuffs.

Loc. as indicated

Fig.16. Staurolite quartz biotite muscovite schist showing an early slaty cleavage (now crenulated) and a later prominent crenulation cleavage at a high angle to the early cleavage.

Loc. Balcooma 9200N 1700E


BALCOOMA
DDH U840 646.4 m
DDH 23 213.3 m

220°. A prominent crenulation lineation (Fig.17) is developed at the intersection of the two cleavages. This plunges at about 20° to 210°.

Examples of isoclinal folds within the "Clayhole Creek Beds" are rare. However, the evidence from detailed drilling is that they are common. They are apparently difficult to detect in outcrop because of the fact that they are very tight and because of the lack of good continuous exposure. The type of folding at Balcooma is believed to be similar to that which occurs within the Burnie Quartzite and Slate on the northern coast of Tasmania. Here similar rocks to those of the "Clayhole Creek Beds", although relatively less metamorphosed, can be seen to be isoclinally folded in good exposures on the beach and in large road cuttings (Fig.18). Elsewhere the folding is very difficult to detect.

Faulting is extensive in the area but is often difficult to recognize. Within the "Clayhole Creek Beds" this is particularly the case, and it should be appreciated that more faulting exists than is indicated on the geological plans. Faulting is usually only recognized where two different rock units are juxtaposed.

Faulting and folding make it difficult to establish the thickness of the "Clayhole Creek Beds". The bottom of the sequence is not exposed and the thickness is probably in excess of 1500 m.

4.2-2. "Dry River Volcanics"

The contact between the "Dry River Volcanics" and the "Clayhole Creek Beds" has been defined at that position where a dominantly metasedimentary sequence changes to a dominantly metavolcanic sequence.

The contact between these units is normally sharp and well defined and it appears that volcanism that had previously been infrequent,

Fig.17. Outcrop of quartz muscovite schist showing a slaty cleavage surface on which a prominent crenulation lineation has developed.

Loc. Balcooma 8500N 2150E

Fig.18. Road cutting exposure of isoclinally folded Burnie Quartzite and Slate on the north coast of Tasmania. These beds are similar to the "Clayhole Creek Beds", although relatively less metamorphosed, and the style of folding is believed to be similar.

Loc. Burnie to Devonport road approximately 5 km east of Burnie

and probably distant from the area, suddenly changed its location. Faulting may explain the sharpness of this contact in some areas. The "Dry River Volcanics" overlie the "Clayhole Creek Beds" as evidenced by good graded bedding information in the sediments immediately underlying the contact (Figs 11 and 12). However, as might be expected, some interfingering of the "Clayhole Creek Beds" and the "Dry River Volcanics" occurs and the sediments can be seen interfingering with the volcanics in the south-west of Figure 6.

The volcanics appear to overlie the sediments conformably and no break in time is envisaged. Rare sedimentary interbeds in the volcanics west and north-west of the Balcooma prospect indicate that the volcanics were deposited in a sub-aqueous environment, at least in this area. However, much of the volcanics may have been deposited subaerially.

The volcanics occur as schistose rocks reflecting the deformation and metamorphic history of the area. The most common schist type is quartz albite biotite muscovite schist. Although these rocks show a well defined foliation, some of the igneous textures are still preserved. This is particularly the case with phenocrysts where quartz and, less often, plagioclase phenocrysts occur in the rock. In a few areas, the original fragmental nature of the volcanics is obvious. Coarse acid fragmentals occur to the north-east of the prospect area (Fig.19). These are the most obvious fragmentals in the Balcooma area although deformation and metamorphism may have destroyed the fragmental texture in other areas.

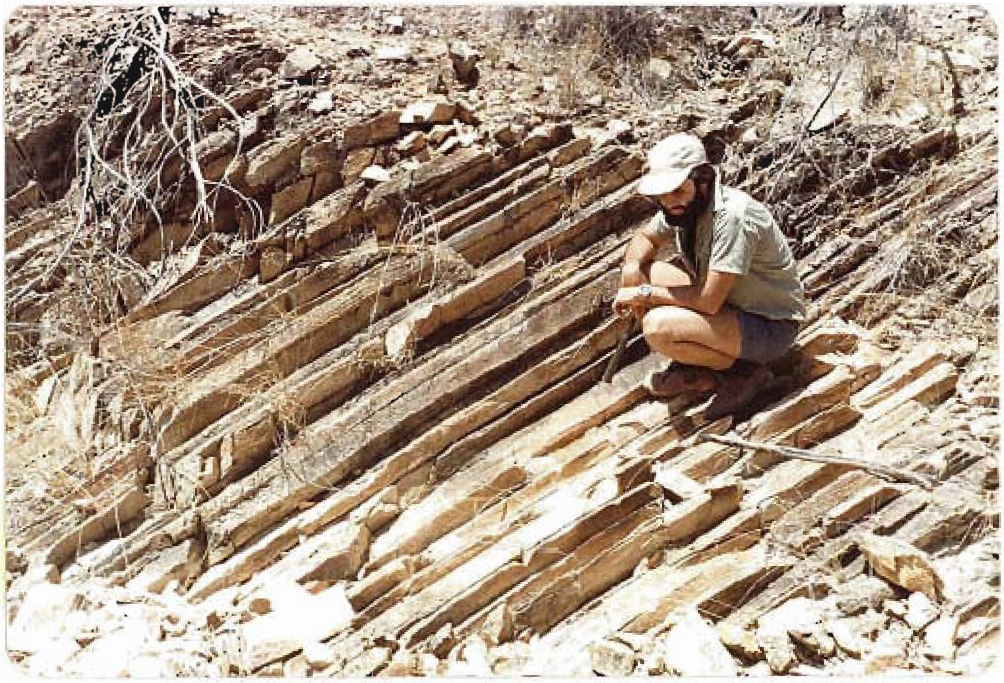
In the West Branch Creek area, the "Dry River Volcanics" show a more massive appearance and appear not to have developed such a strong foliation in response to metamorphism and deformation. In a few places, columnar jointing occurs (Fig.20). These rocks are thought to represent welded tuffs. If this is the case, it indicates that the volcanics were deposited subaerially in this

Fig.19. Acid agglomerate of the "Dry River Volcanics".

Loc. 2.5 km north-north-west of the Balcooma deposit

Fig.20. Massive acid pyroclastics of the "Dry River Volcanics" showing columnar jointing. These rocks are interpreted as welded tuffs and are thought to have been deposited subaerially.

Loc. 10 km south-south-west of the Balcooma deposit



area. The volcanics were, therefore, probably laid down in both subaerial and subaqueous environments.

The similarity of the "Dry River Volcanics" to the Mount Windsor Volcanics, noted during original mapping in the area prior to the discovery of the Balcooma deposit, strongly suggested that these two formations were of the same age. This similarity also highlighted the potential of the Balcooma area for volcanogenic massive sulphide deposits, since deposits of this type (Thalanga, Liontown) were known in the Mount Windsor Volcanics.

Both these formations contain appreciable amounts of quartz crystal tuff or, as commonly known, quartz eye tuffs (Fig.21). These tuffs are characterised by the smoky blue quartz eyes which are often characteristic of acid volcanic sequences hosting volcanogenic massive sulphide deposits.

The only significant difference between the "Dry River Volcanics" and the Mount Windsor Volcanics is that the grade of metamorphism is higher and the intensity of deformation is greater in the Balcooma area.

The absence of an understanding of the structure within the "Dry River Volcanics" does not allow an accurate estimate of the thickness of this unit. However, the thickness is at least 1500 m and probably substantially more than this.

4.2-3. "West Branch Creek Beds"

A sequence of interbedded metamorphosed tuffs and sediments overlies the "Dry River Volcanics" in the south-west portion of Figure 6. These tuffs and sediments extend from this area to the south-south-west, and are important, as they contain lead-zinc mineralization at the West Boyds Creek prospect located just outside of the area mapped in detail.

The boundary between the "Dry River Volcanics" and the "West Branch Creek Beds" as mapped is at the point where the first major metasedimentary bed occurs above the massive volcanic unit.

The beds apparently represent periods of intermittent subaqueous acid volcanism with periods of clastic sedimentation in between the volcanic events. Most of the sediments were originally sands and silts with a high volcanic component. However, a graphitic slate unit is evidence of finer-grained sedimentation at one period of time.

The lead-zinc mineralization at the West Boyds Creek prospect occurs within a barytes-carbonate horizon which lenses into thin banded cherts away from the mineralization. Extensive silicification and sericitisation occurs in parts of the footwall to the mineralized horizon. No economic grade mineralization is known in the area.

4.2-4. Lochlea Volcanics"

A massive volcanic unit overlies the "West Branch Creek Beds". This horizon outcrops along a prominent ridge which extends from the south-western portion of Figure 6 in a south-south-west direction to McKinnons Creek. This unit has a distinctive airphoto expression as well as an associated airborne magnetic anomaly and it therefore has been mapped out as a separate unit.

The unit is largely comprised of a massive hard flinty dacite but some rhyodacite occurs. The nature of the dacite suggests that it may have been a flow rather than a tuff. Some of the material, however, shows a fragmental texture and, therefore, at least some of this material is of tuffaceous origin.

4.2-5. "Highway Beds"

A sequence of interbedded meta tuffs and sediments overlies the "Lochlea Volcanics" and is cut by the "Oaky Creek Fault Zone" on its western side. Outcrop of these rocks is poor and they are generally outside the area of detailed mapping.

4.2-6. "Golden Creek Volcanics"

A small area of metamorphosed intermediate volcanics occurs to the north of the junction of the Dry River and Golden Creek. These volcanics form a wedge which is faulted against the "Dry River Volcanics" on their eastern side and are bounded by the "Oaky Creek Fault Zone" on the west. Hence, the stratigraphic position of this unit is uncertain.

Volcanics of similar appearance occur to the east in the Lucky Creek Formation.

The "Golden Creek Volcanics" are represented by actinolite albite quartz K-feldspar schists after andesitic volcanics, and quartz mica schist after clastic sediments. The andesites consist of tuffs and flows. Lapilli tuff is a common rock type.

A prominent "chert" ridge on the western side of these rocks was initially considered to be a zone of silicification associated with the eastern margin of the "Oaky Creek Fault Zone". However, recent detailed mapping and petrology of samples from this area show that the "chert" is accompanied by a suite of minerals, including andalusite, diaspore, topaz, pyrophyllite, scorzalite, goyazite, apatite and barite, and the area is now considered to be a metamorphosed alumina/silica deposit resulting originally from intense acid sulphate alteration of volcanics and sediments. Similar deposits occur in the Carolina slate belt (Sykes, M.L. and Moody, J.B., 1978).

4.3. Ordovician? Intrusives

4.3-1. "Matchbox Creek Microgranite"

Outcropping to the east of the Balcooma deposits and extending from just south of Conjuboy homestead to the Balcooma Creek area, is a pink microgranite intrusive which is thought to be of Ordovician age.

The reason for this is that this intrusive is very similar in appearance to some of the quartz eye tuffs of the "Dry River Volcanics", and they are thought, therefore, to be comagmatic. This microgranite also shows evidence of having undergone the two major deformation events that affect the "Balcooma Metamorphics". This suggests that the microgranite is of a similar age to the metamorphics which have been assigned to the Cambro-Ordovician.

The microgranite generally consists of elongated rounded quartz phenocrysts in a fine-grained groundmass of quartz, K-feldspar and albite. In some areas the quartz phenocrysts reach 10 mm in length and phenocrysts of both K-feldspar and albite occur in a fine grained groundmass (Fig.22).

A smaller area of microgranite occurs west of the junction of Oaky Creek and the Dry River. This microgranite intrudes the "Dry River Volcanics" in this area.

4.3-2. Other Intrusives

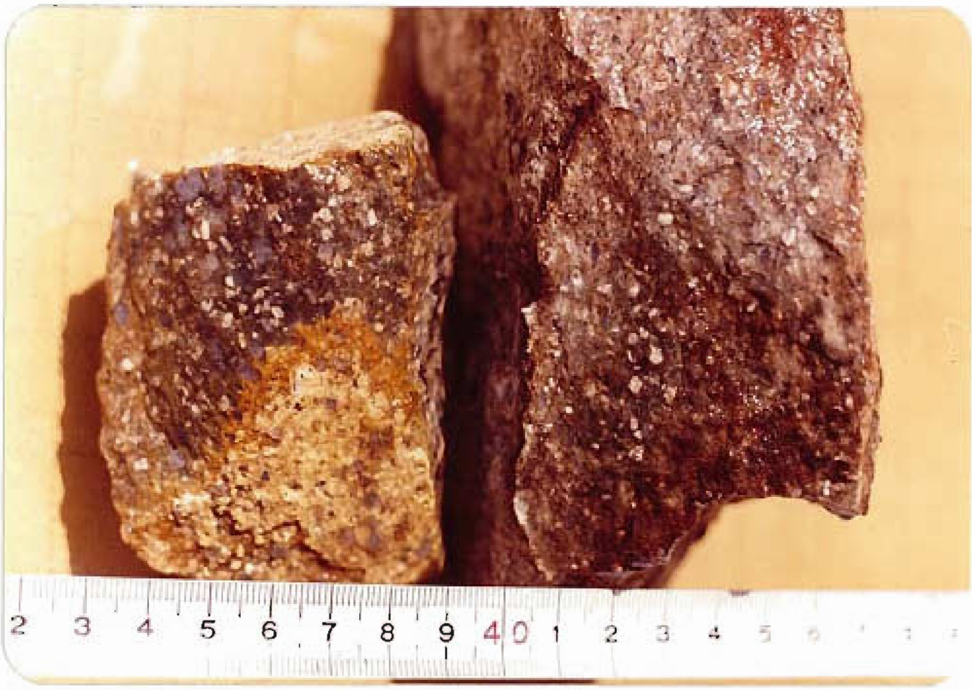
In the Conjuboy homestead area, to the north of the "Matchbox Creek Microgranite", a poorly outcropping body of muscovite-biotite leucogranite exists as a separate phase to the microgranite in the Balcooma area. It would appear also to be of Ordovician age because it has also undergone the two major deformation events

Fig.21. Quartz crystal tuff (quartz eyetuff) of the "Dry River Volcanics" (right) compared to quartz crystal tuff of the Mount Windsor Volcanics (left).

Loc. 1.3 km west of the Balcooma deposit and 20 km north-west of the Thalanga deposit respectively

Fig.22. "Matchbox Creek Microgranite" showing the fine grained (right) and coarser grained (left) phases. Note the rounded elongate quartz phenocrysts and the foliation particularly evident in the fine grained phase.

Loc. 1 km east of the Balcooma deposit



evident in the "Matchbox Creek Microgranite".

A number of bodies of hornblende quartz diorite are scattered through the "Matchbox Creek Microgranite". While these more basic intrusives do not show the strong deformation evident in the "Matchbox Creek Microgranite", they are thought to be of the same age because of the spatial relationship between the two igneous rock types. However, it is possible that these quartz diorite bodies are of a later age and they may be equivalent to the Dido Granodiorite.

4.4. "Oaky Creek Fault Zone"

This fault zone which separates the Precambrian Einasleigh Metamorphics from the Palaeozoic "Balcooma Metamorphics" is a major structure which has had a profound influence on the rocks that it displaces.

The central portion of the fault zone which has a width of a few hundred metres has been mylonitised while a pronounced shearing exists in the rocks on either side of this central area. The whole of this zone, which is up to 1 km in width, has been mapped out and the name "Oaky Creek Fault Zone" has been used, since Oaky Creek runs along the fault to the west of the Balcooma deposit.

The term "Balcooma Mylonite Zone", used by various authors (Rubenach, 1978; Withnall et al., 1980) has not been used in this report, to prevent confusion. This latter term was initially used to include all of the metamorphic rocks shown in this report as the "Balcooma Metamorphics" and the view expressed by Rubenach (1978) that the rhyolites mapped by White (1965) are mylonitised granite is rejected.

As the "Oaky Creek Fault Zone" is approached from the east, the acid volcanic rocks of the "Dry River Volcanics" become progressively more schistose, and fragments within tuffaceous rocks become more flattened. In the central portion of the fault zone, where extreme flattening occurs, the rock develops a parallel parting not unlike that of a siltstone. In fact, the outcrops from a distance have the appearance of a siltstone. The rock also often shows a crude mineralogical layering of feldspar and quartz because of extreme flattening of domains of varying composition (Fig.23). The term "mylonite" is used for these rocks which have undergone extreme deformation and the author believes it should be restricted to rocks of this nature only.

Most of the rocks within the central mylonite zone are very similar in appearance. This is probably because they are mostly derived from quartz feldspar rocks originally, whether these were acid gneiss or granitic rocks of the Einasleigh Metamorphics, or acid volcanics of the "Balcooma Metamorphics".

The foliation and layering within the "Oaky Creek Fault Zone" indicate that it now has a near vertical dip. However, it is overlain by undeformed middle Devonian sediments which show a dip of about 30° to the west and the original mylonite zone therefore probably dipped about 60° west.

Faulting of the middle Devonian sediments on their western side indicates that some reactivation of faulting along this zone has occurred since the middle Devonian.

4.5. Dido Granodiorite

A large body of biotite granodiorite intrudes the "Balcooma Metamorphics" to the east. This body is some 10 to 15 km in width and trends in a north-north-easterly direction. It separates the "Balcooma Metamorphics" from the Lucky Creek Formation. Hornblende from the Dido Granodiorite has been dated at 410 million years and biotite has been dated by K-Ar at 385 million years (Richards et al. 1966; Black, 1973). This indicates that the granodiorite is either late Silurian or lower Devonian in age. However, considerable speculation has occurred in recent years about whether many of the dates of this age obtained for granitic rocks in the Georgetown area are valid or whether they represent resetting due to metamorphism (Richards, 1980).

The Dido Granodiorite has thermally metamorphosed the contact zone of the "Balcooma Metamorphics" and the Lucky Creek Formation, and the effects can be seen for up to about 1 km from the contact zones. Where the granodiorite has intruded sediments, it has caused granitisation of some of the sediment bands and converted some of the others to gneiss. Injection of some of the granitised sediments has occurred and dykes of pale grey granite intrude generally along the foliation in the metamorphics near the granodiorite body.

It appears likely that the second major deformation and metamorphic event evident in the Balcooma rocks occurred during the emplacement of the Dido Granodiorite.

4.6. Middle Devonian Sediments

An area of middle Devonian sandstones and shales outcrops about 4 km north-west of the Balcooma prospect. The sandstones forming the base of the sequence are coarse-grained and are largely composed of detritus derived from both the "Balcooma Metamorphics" and the Einasleigh Metamorphics. Some areas near the base of the sandstones contain rounded pebbles of quartz, and occasionally thin beds of conglomerate occur locally.

The shales are soft and calcareous and outcrop poorly. However, they are of interest as they contain an abundant coral fauna of middle Devonian age (Henderson pers. comm.).

This area of middle Devonian sediments is of further interest since it unconformably lies on top of strongly foliated rocks comprising part of the "Oaky Creek Fault Zone". These beds dip to the west at about 30° and are truncated on their western side by a fault which is apparently a reactivation of the "Oaky Creek Fault Zone".

The sediments are partly obscured by laterite but appear to be thickening to the north-north-east. It is possible that larger areas of these rocks occur to the north-east under the basalts of the McBride Basalt Province.

A small outcrop of similar sediments occurs 2 km east-north-east of the Balcooma deposit and this outcrop also has an abundant middle Devonian coral fauna.

4.7. Upper Carboniferous Volcanics

An area of flat-lying to gently dipping acid volcanics forms a triangular shaped area lying 2 km east of the Balcooma deposit. These volcanics are almost totally pyroclastic rocks and they vary from ash tuffs to coarse agglomerate with fragments up to 40 cm across. They are rhyolitic in composition.

The volcanics unconformably overlie the "Balcooma Metamorphics", "Matchbox Creek Microgranite" and the Dido Granodiorite. Thesevolcanics have a thickness up to about 100 m.

They are similar to those that occur in the Spring Creek area 10 km north-east of Wyandotte and it seems likely that they are contemporaneous. Their age is not known, but it is highly likely that they are of upper Carboniferous age, and were deposited during the widespread volcanic activity which occurred throughout north Queensland at that time (Branch, 1966).

On the northern boundary of these volcanics an area of bleached brecciated microgranite, containing some flow banded rhyolitic fragments and flow banded rhyolitic dykes, occurs (Fig.24). The bleaching of the microgranite has been caused by albitisation, apparently by hydrothermal solutions associated with the upper Carboniferous volcanic activity. The brecciation has apparently been caused by explosive activity associated with the nearby volcanic activity. Evidence for this is that the microgranite varies from fractured material through partially disoriented fractured material to totally chaotic breccia. This, along with the fact that the fragments are totally microgranite, apart from the small amount of volcanic material mentioned, suggests that brecciation has largely occurred in situ. Explosive activity would appear to be the most reasonable explanation for these features.

4.8. Cainozoic Laterite and Basalt

Remnants of an apparently once extensive laterite sheet exist throughout the area. The more obvious laterite forms flat-lying mesas up to 50 m thick on all rock types. It is now known from exposures in creek banks and from drill holes that laterite occurs beneath some soil covered areas and under many of the alluvial flats associated with the major drainages in the area. Many of these obscured lateritic areas are developed on alluvial deposits associated with a pre-laterite drainage system. In places this approximately coincides with the present day drainage but there are some areas where major differences occur. For example, the laterite that occurs in the Dry River to the west of the Balcooma Deposit marks out the ancestral course of this river. This stream apparently flowed down the current course of the Dry River until the present day junction with Oaky Creek, and then it flowed north-westerly and northerly to cross Eight Mile Creek just below the main road crossing. North of this point the old channel is covered by basalt.

These laterite filled channels may appear to be of academic

Fig.23. Mylonite from the "Oaky Creek Fault Zone" showing the parallel parting and mineralogical layering characteristic of this rock.

Loc. 4 km west-south-west of the Balcooma deposit

Fig.24. Bleached brecciated microgranite near the northern boundary of the upper Carboniferous acid volcanics. The bleaching is due to alteration and the brecciation is believed to be caused by explosive activity related to the deposition of the acid volcanics.

Loc. 6 km north-east of the Balcooma deposit

interest only but they are of importance in the interpretation of geochemical and geophysical data where, for example, in the latter instance, their low resistivity results in airborne "Input" electromagnetic anomalies.

An extensive area of olivine basalt belonging to the McBride Basalt Province occurs to the north of the mapped area. This basalt did not extend much further south than its current boundary and therefore its main influence on the geology of the area surrounding the Balcooma deposit was to cause the development of thick alluvial deposits in northward flowing streams by damming of their channels.

5. GEOLOGY OF THE BALCOOMA DEPOSIT

5.1. Geology

The Balcooma deposit occurs within a sequence of metasedimentary and minor metavolcanic rocks of the "Clayhole Creek Beds". In the vicinity of the deposit these beds are faulted against the "Matchbox Creek Microgranite" on their eastern side and are in contact with metavolcanics of the "Dry River Volcanics" to the west (Fig.25). Poor exposure does not allow the nature of the contact with the "Dry River Volcanics" to be definitely determined.

However, the contact is quite sharp and straight and it may therefore be faulted. It is shown as a fault in Figure 25.

The "Dry River Volcanics" in the area north-west of the deposit contain a large proportion of acid agglomerate along with lapilli, crystal and ash tuffs (Fig.19). Whether the position of the mineralization and this agglomerate are related is a matter of speculation. However, it is suggested by their spatial relationship. The association of massive sulphide deposits with coarse pyroclastics (mill rock) is well documented (Sangster,

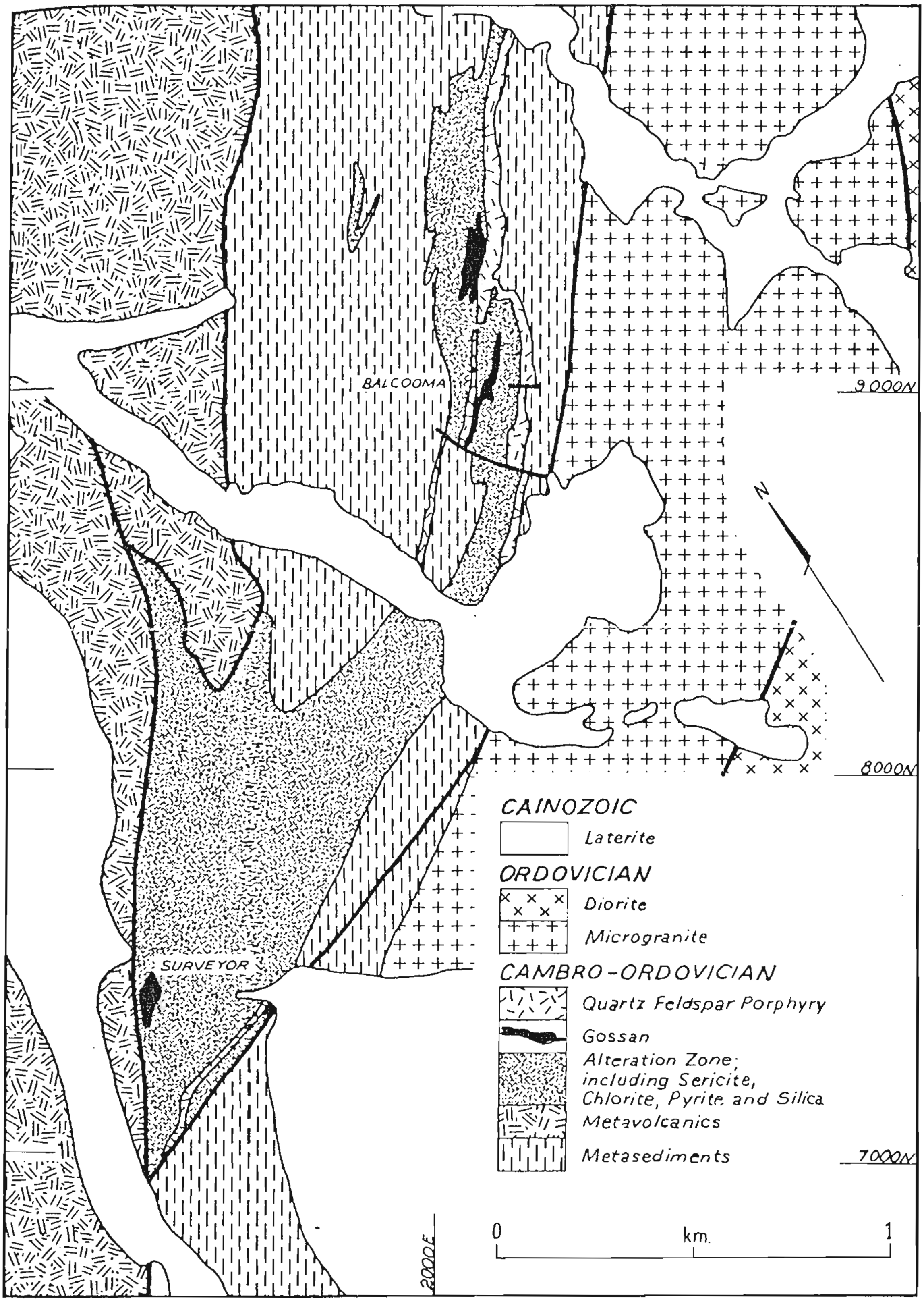


Fig.25 - Geology of the area surrounding the Balcooma and Surveyor deposits

1972).

Another feature of this agglomerate is that it allows an appreciation of the amount of deformation which the rocks in the area have undergone. All fragments in the agglomerate show a pronounced elongation which allows the conclusion that these rocks, and presumably most of the other rocks in the area, have been stretched in one direction of the order of twice their original dimensions. This stretching direction is uniform in the deposit area, being almost always at a plunge of about 20° to the south-south-west. The bodies of mineralization at Balcooma also plunge in this direction as outlined below.

The "Matchbox Creek Microgranite" to the immediate east of the Balcooma deposit, consists of a pink foliated microgranite similar to that which occurs elsewhere and which has been described previously. A number of the more easterly drill holes have intersected it and in core it can be seen to be a fractured rock, apparently because of its rather brittle behaviour during deformation. This fracturing is apparently responsible for the reasonable flows of groundwater obtained in some of the rotary percussion holes drilled into the microgranite. Areas within the microgranite in some of the drill core are similar in appearance both to quartz feldspar porphyry bodies associated with the mineralization, and to some of the volcanics of the "Dry River Volcanics". This suggests the possibility that the microgranite as mapped may include some volcanic material. It also tends to confirm the conclusion that the microgranite is comagmatic with the volcanics.

The "Clayhole Creek Beds" in the vicinity of the mineralization, as previously reported, consist largely of quartz biotite muscovite schist and staurolite quartz biotite muscovite schist. These have been interpreted to be a sequence of metamorphosed feldspathic sandstones and shales.

Situated within the "Clayhole Creek Beds", and directly associated with the mineralization at both Balcooma and Surveyor, is a large zone of alteration. This zone, shown in Figure 25, contains alteration of various types. Close to the Balcooma prospect, this zone includes variably chloritised schist, which is associated with the massive pyrite chalcopyrite mineralization, and siliceous rocks, which are associated with the massive pyrite sphalerite galena mineralization. These alteration types are discussed further below.

In the area immediately to the south-west of the Balcooma prospect and extending to the Surveyor prospect, a broad zone of quartz muscovite schist containing disseminated pyrite to 10% and some chlorite rich areas has been included in this alteration zone (Fig.26). The chlorite rich areas on the surface show a characteristic purplish-brown staining due to the release of iron on weathering. These chloritic areas also contain magnetite and garnet and, in places, significant copper values. They strongly resemble the alteration associated with the massive pyrite chalcopyrite at Balcooma.

This broad zone of quartz muscovite alteration is considered to be a metamorphosed sericite quartz (chlorite, pyrite) alteration zone. Such alteration zones are often found in the stratigraphic footwall of volcanogenic massive sulphide deposits (Franklin et al., 1980).

The zone contains both altered sediments from the "Clayhole Creek Beds" and altered acid fragmentals (Fig.27) which appear to be from the "Dry River Volcanics". One of the problems with this alteration zone is that if the altered volcanics do belong to the "Clayhole Creek Beds", then this zone is actually, at least in part, in the hanging wall to the mineralization. While there is no reason why this could not be the case, it seems unlikely and it suggests that either the volcanics within the alteration zone are

Fig.26. Altered sediments from the broad alteration zone at Balcooma and shown in Figure 25. Altered sediments include quartz muscovite schist (bottom) and chlorite quartz muscovite schist (top). Note the iron oxides after pyrite in the sample on the bottom and the red brown colour due to oxidation of chlorite in the sample on the top.

Loc. Balcooma 7900N 1600E

Fig.27. Silicified acid lapilli tuff from the alteration zone shown in Figure 25.

Loc. Balcooma 8100N 1400E

actually some of those within the "Clayhole Creek Beds" or the "Dry River Volcanics" actually underlie the "Clayhole Creek Beds".

Of these alternatives, the first is preferred since there is enough good evidence, as outlined previously, from graded bedding to indicate that the "Dry River Volcanics" overlie the "Clayhole Creek Beds". The altered volcanics, therefore, apparently just happen to be faulted against the "Dry River Volcanics" at this point. Further evidence for this is that the contact is very sharp. Under this interpretation, this fault is folded as shown in Figure 25.

Laterite is scattered through the prospect area and occurs both as cappings on higher ground where it forms mesas, and as fillings in old stream channels, where it often goes undetected because of soil or alluvium cover.

Detailed mapping and extensive drilling in the immediate vicinity of the Balcooma deposit, carried out by CEC staff during the period since discovery, show that, in detail, the geology is exceedingly complicated (Fig.28).

It is now known that much of this complexity has been caused by an early intense isoclinal folding event which has been followed by at least one other important folding event. These events are evidenced in the rocks by an early dominant slaty cleavage and a superimposed prominent crenulation cleavage, as was previously illustrated in Figure 16.

In view of the complex nature of the geology and the generally poor nature of the outcrop in the deposit area, it has only been possible to determine the structure, and therefore the geology, with any degree of certainty where detailed drilling has been carried out. Outside of the drilled area the detailed structure remains somewhat of a mystery.

During detailed mapping and core logging, the schists of the "Clayhole Creek Beds" were subdivided into numerous varieties based on slight differences in mineralogical composition and texture. While these subdivisions were locally useful for predicting the position of targets during drilling, based on detailed correlations between holes, they serve little purpose in understanding the geology of the deposit. The most meaningful subdivision of the schists is based on whether they carry significant quantities of staurolite or not. This is related to whether the sediments were originally fine-grained aluminous rocks (shales) or coarser-grained sandy rocks (feldspathic sandstones). This subdivision has been employed in Figures 28 and 29. In reality, a complete separation of these two rock types is not possible since the metamorphosed sandstones contain some staurolite schist after thin interbedded shale bands, and the staurolite schists contain some non-staurolite bearing metasandstones.

The staurolite bearing schists are the immediate hosts to the copper mineralization. They outcrop both east and west of the two main gossan outcrops, and large intersections occur in most drill holes in the footwall of the copper mineralization (Fig.29).

In drill core, where the staurolite schists contain thin interbedded metasandstone beds, it is often possible to determine both facing and bedding direction relative to the drill core (Fig.13). Facing usually varies in direction in most holes, that is, both up and down the holes, while the bedding to core angles are highly variable. Both these features support the conclusion that the sequence is highly folded but, unfortunately, there is insufficient bedding and facing data to fully determine the folding pattern in these rocks.

Andalusite and cordierite porphyroblasts occur within the staurolite schists but, in general, are a minor component only. In the southern portion of Figure 28 at 8580N, 1950E and within the staurolite schist, outcrops of a metasandstone show large nodules up to 10 cm across which protrude from the weathered surface. In thin section these nodules are composed of quartz (80%), andalusite (15%) and biotite (5%). The andalusite in thin section is optically continuous and the nodules are due to the porphyroblastic development of the andalusite in the schists. However, like many of the other schist types in the area, this unit does not extend for any distance.

An interesting feature of the staurolite porphyroblasts in the deposit area is that they contain significant quantities of zinc. Microprobe analyses indicate contents of up to 4% zinc. Microprobe analyses of staurolite porphyroblasts and other minerals within the alteration zone to the copper mineralization are included in Appendix 2. Zinc bearing staurolite porphyroblasts in metamorphic rocks that host massive sulphide deposits have been reported from other areas including Broken Hill (Corbett & Phillips, 1981).

The second schist type (Fig.30), carrying only minor amounts of staurolite (less than 5%), occurs well to the west of the gossans (Fig.28) and also in drill holes that penetrate well into the western side of the prospect (Fig.29). These schists are located in the footwall to the lead-zinc mineralization in this area and occur above a sequence of interbedded tuffs and metasediments lying within the "Clayhole Creek Beds". Because these schists are grey in colour, have a distinctly sandy appearance, and are believed to have been feldspathic sandstones originally, they are locally referred to as the "Greywacke Sequence". These schists often contain porphyroblasts of andalusite and cordierite which are usually less than 10 mm in size.

Within the underlying tuff sediment sequence of the "Clayhole Creek Beds", the individual tuff units vary from about 0.5 m to 3 m in thickness. Most of the tuffs display grading from lapilli sized fragments to ash tuffs at the top (Fig.15). This grading generally indicates an easterly facing, suggesting that they stratigraphically underlie the "Greywacke Sequence". They outcrop north of 9500N 1800E (Fig.28).

These tuffs may be those that occur within the alteration zone to the south-west of the Balcooma deposit and which were discussed previously. For these to occur in outcrop in the alteration zone it would require a cross-cutting fault underlying the laterite at about 8500N, shown in the centre of Figure 25, with the southern block of the fault uplifted. Other evidence for this fault is that quartz feldspar porphyry bodies do not appear on the southern side of the laterite and the chlorite alteration is much more intense on the southern side of the laterite.

This fault could also be used to explain the relationship of the Surveyor mineralization to the Balcooma mineralization. The Balcooma mineralization would have been upthrown south of the laterite and largely eroded away. However, because of its southerly plunge it would again intersect the ground surface further to the south, that is, at Surveyor.

Within the "Clayhole Creek Beds" and surrounding the Balcooma gossans, the presence of a chlorite alteration zone is indicated by the reddish-brown staining of the schists due to the release of iron from the weathering of the chlorite. Where massive chlorite has been weathered the resulting iron oxide product can be mistaken for gossan. The red-brown colour anomaly, as seen on coloured air photographs of Balcooma (Fig.31), is partly due to gossan and partly due to the weathering of chlorite. This chlorite alteration has been mapped out and is shown in Figure 28. It is discussed in greater detail in Section 5.3.

A number of lensoidal outcrops of quartzite and quartz rich schist occur to the west of the gossans (Fig.28). The lensoidal nature of the outcrops is believed to result from deformation and the

Fig.30. Outcrop of schist with low staurolite content. These rocks are metamorphosed feldspathic sandstones and are locally termed "Greywacke Sequence".

Loc. Balcooma 8450N 1650E

Fig.31. Photograph of portion of a 1:25 000 scale colour air photograph of the Balcooma deposit. The red brown colour anomaly is partly due to iron oxides after sulphides and partly due to iron oxides after chlorite. The distance from top to bottom is approximately 1.6 km.

quartzite and quartz schist were probably originally one continuous unit.

The origin of this siliceous unit can be deduced from the fact that, in places, it carries appreciable contents of the zinc rich spinel, gahnite, that it often carries iron oxides after sulphide bands, and that, in one area, it can be seen to grade into massive sulphide gossan (Fig.32). In drill holes these rocks also normally occur both adjacent to, and within, massive pyrite intersections containing sphalerite galena and chalcopyrite (Fig.33). The rocks are therefore interpreted as metamorphosed cherts or cherty sediments, deposited on the sea floor from siliceous exhalations associated with the mineralizing event.

Gahnite may be disseminated through the quartzite or occur in bands which are thought to represent the original bedding in these rocks. Where present, it imparts a distinctly greenish appearance to the normally white quartzites (Fig.34). It occurs as octahedra usually about 1 to 2 mm across, but rarely it is up to 10 mm across (Fig.35).

Gahnite quartzite is reported from Broken Hill where a similar origin has been proposed (Barnes, 1983).

Quartz feldspar porphyry (QFP) is a common lithology in proximity to the copper mineralization. It also occurs in other areas away from mineralization, however.

The QFP, although metamorphosed, retains its porphyritic nature with quartz and lesser feldspar (albite) eyes up to 5 mm set in a fine-grained mesh of albite and quartz (Figs 36 and 37). The colour varies from pink to grey.

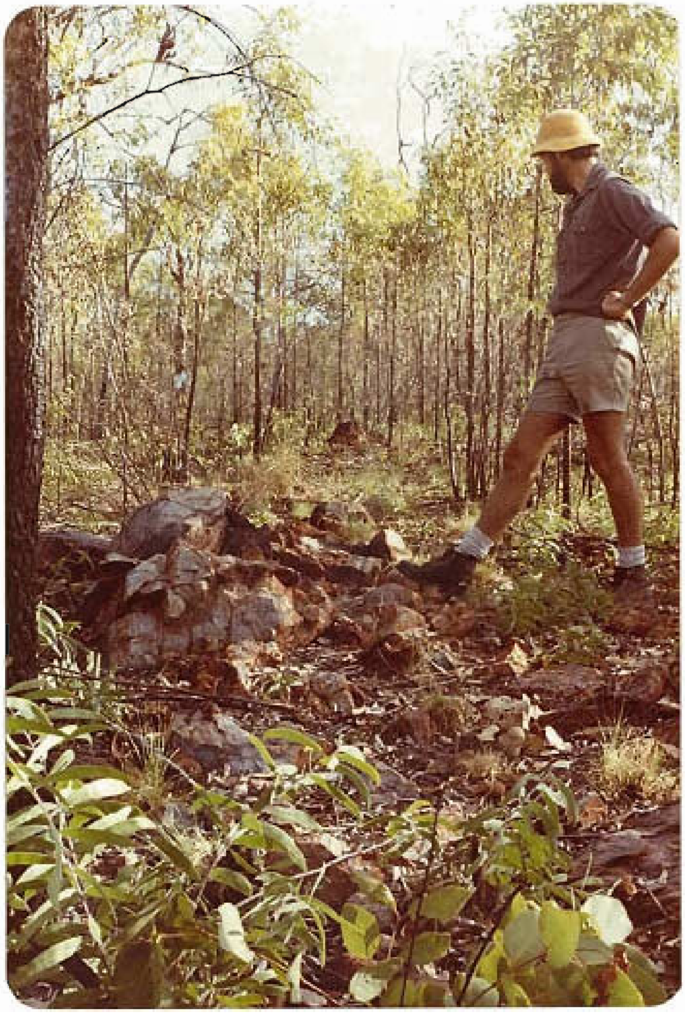
The QFP bodies are interpreted as sills and dykes which intruded the sediment prior to metamorphism. Evidence for an intrusive

Fig.32. Gahnite quartzite (foreground) grading into gossan after massive sulphides (dark outcrop in background).

Loc. Balcooma 9500N 2075E

Fig.33. BQ diamond drill core of massive pyrite, sphalerite (galena, chalcopyrite)(top) associated with gahnite quartzite (bottom).

Loc. Balcooma DDH 3



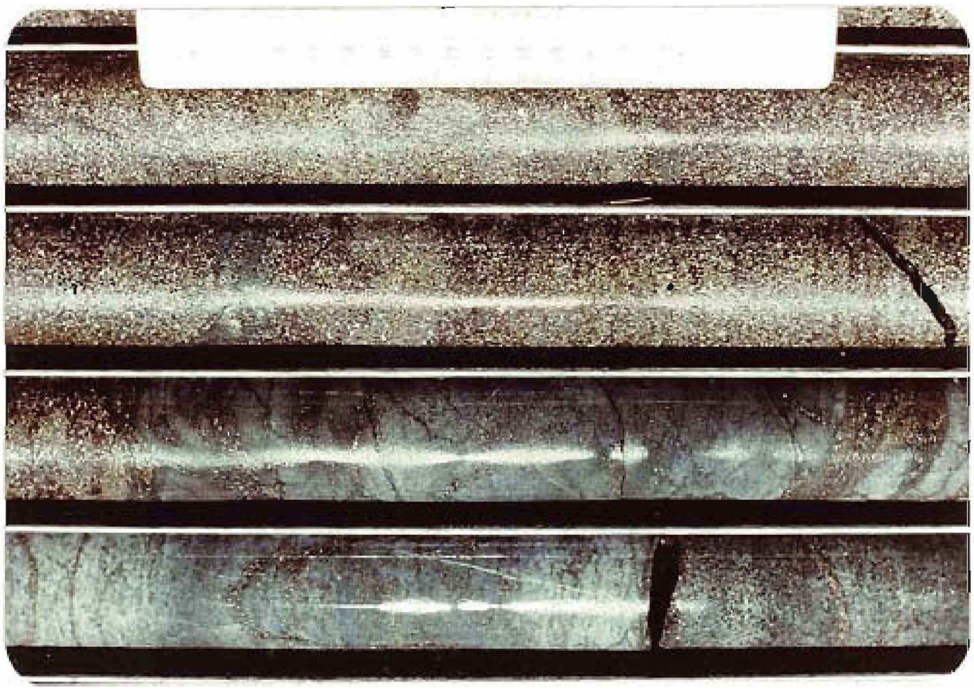


Fig.34. Gahnite quartzite showing the green colouration due to gahnite.

Loc. Balcooma 9400N 2000E

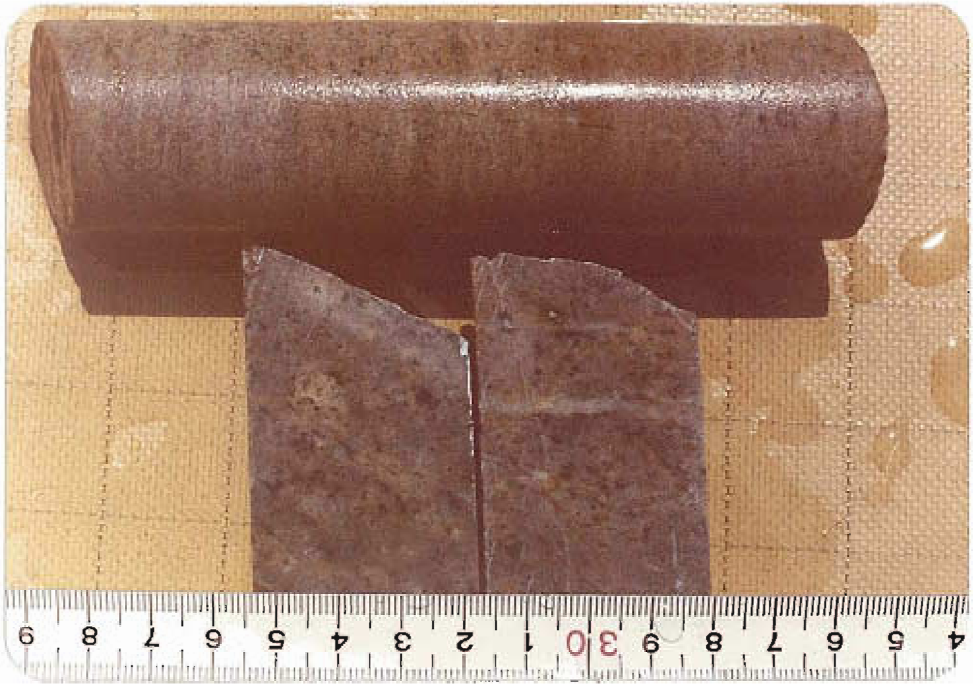
Fig.35. Close-up photograph of gahnite bearing quartz schist with octahedral gahnite porphyroblasts on weathered surface.

Loc. 9400N 2050E

Fig.36. Quartz feldspar porphyry with quartz phenocrysts in a glassy quartz albite matrix.

Loc. Balcooma DDH 1

Fig.37. Photomicrograph of quartz feldspar porphyry showing quartz and feldspar phenocrysts in a fine grained matrix of quartz and feldspar. XN, x25.



origin includes the uniform nature of the groundmass and the fact that the QFP has not been altered, even when it is in contact with intensely chloritised schist. It therefore, apparently, post-dates the mineralizing event and QFP actually cuts through the main shoot of copper mineralization.

The QFP has been important in that it can readily be mapped out at the surface, and that it occurs in numerous drill holes, allowing it to be used as a marker to determine the complex structure in the prospect area (Fig.29).

The QFP shows evidence of having undergone the deformation and metamorphic events that have affected the surrounding rocks and it is thought that it was intruded at a very early stage, possibly even before the surrounding sediments were properly lithified. The most likely situation is that it was intruded during the volcanic activity associated with the "Dry River Volcanics".

Whole rock analyses of the QFP are compared with data from the Woodlawn Volcanics in Table 3.

These data show that the QFP is similar in most major elements to the Woodlawn Volcanics but that it has a much higher Na_2O content and a much lower K_2O content.

The high Na_2O and low K_2O of the QFP and traces of K-feldspar inclusions within some of the albite is consistent with albitisation of both K-feldspar (and plagioclase) during metamorphism. A similar albitisation of K-feldspar and plagioclase has occurred in the "Matchbox Creek Microgranite". The low Na_2O content of the metasediments of the "Clayhole Creek Beds" suggests that Na_2O has been transferred from these sediments to the feldspathic rocks during metamorphism. K_2O released from the feldspathic rocks may have been taken up during muscovite and biotite development in the surrounding schists and CaO has apparently been lost to the system.

TABLE 3

Average major element data for Balcooma and Woodlawn Volcanics (Gulson 1977)

	BALCOOMA QFP		WOODLAWN VOLCANICS #	
Element	Av (29 samples)	Range	Av (5 samples)	Range
SiO_2	73.30	68.80 - 78.30	73.30	70.60 - 75.40
Al_2O_3	13.16	10.30 - 15.70	13.00	11.40 - 13.90
Fe_2O_3	2.93	1.15 - 5.95	2.07	0.60 - 3.35
MgO	0.73	0.20 - 1.85	0.63	0.16 - 1.16
CaO	0.53	0.08 - 1.50	0.49	0.16 - 0.95
Na_2O	5.86*	3.60 - 7.90	3.74	2.59 - 6.23
K_2O	0.75	0.07 - 2.85	4.30	2.40 - 6.23
TiO_2	0.24	0.04 - 0.66	0.19	0.09 - 0.36

data from Gulson and Rankin, 1977.

* Na_2O average of 16 samples only

5.2. Mineralization

Two types of mineralization occur at Balcooma. Copper mineralization dominates, while zinc-lead-copper mineralization is subordinate.

Average grades based on in-ground resource estimates for both the copper and zinc-lead-copper mineralization are :

Copper Ore	-	3.8%	Cu
		18 g/t	Ag
		0.4 g/t	Au
Zinc-Lead-Copper Ore	-	3.3%	Pb
		7.4%	Zn
		1.1%	Cu
		51 g/t	Ag
		0.5 g/t	Au

The copper mineralization occurs within two south-south-west plunging shoots (Fig.38) which are expressed on the surface as the two gossan outcrops.

The northern gossan, centred at about 9350N, 2075E, is the surface expression of the main shoot which has been extensively drilled and which contains the larger part of the reserves in the area. This body of mineralization plunges at an average of about 20° to 210° magnetic until about 8800N, where it is cut by a crosscutting fault. On the southern side of the fault, it is poorly developed but appears to be replaced by another body of copper mineralization occurring about 100 m to the west. This body continues to plunge to the south-south-west until about 8500N.

The main shoot outcrops to the west of the main QFP body, but as it plunges to the south-south-west, it is progressively transgressed by the QFP, until at 9000N, the QFP is to the west of this body of mineralization (Fig.29).

Minor amounts of lead-zinc-copper mineralization occur immediately to the west of the shallower portions of this body of copper mineralization and these are represented on the surface by the gahnite quartzite and gossan shown in Figure 32.

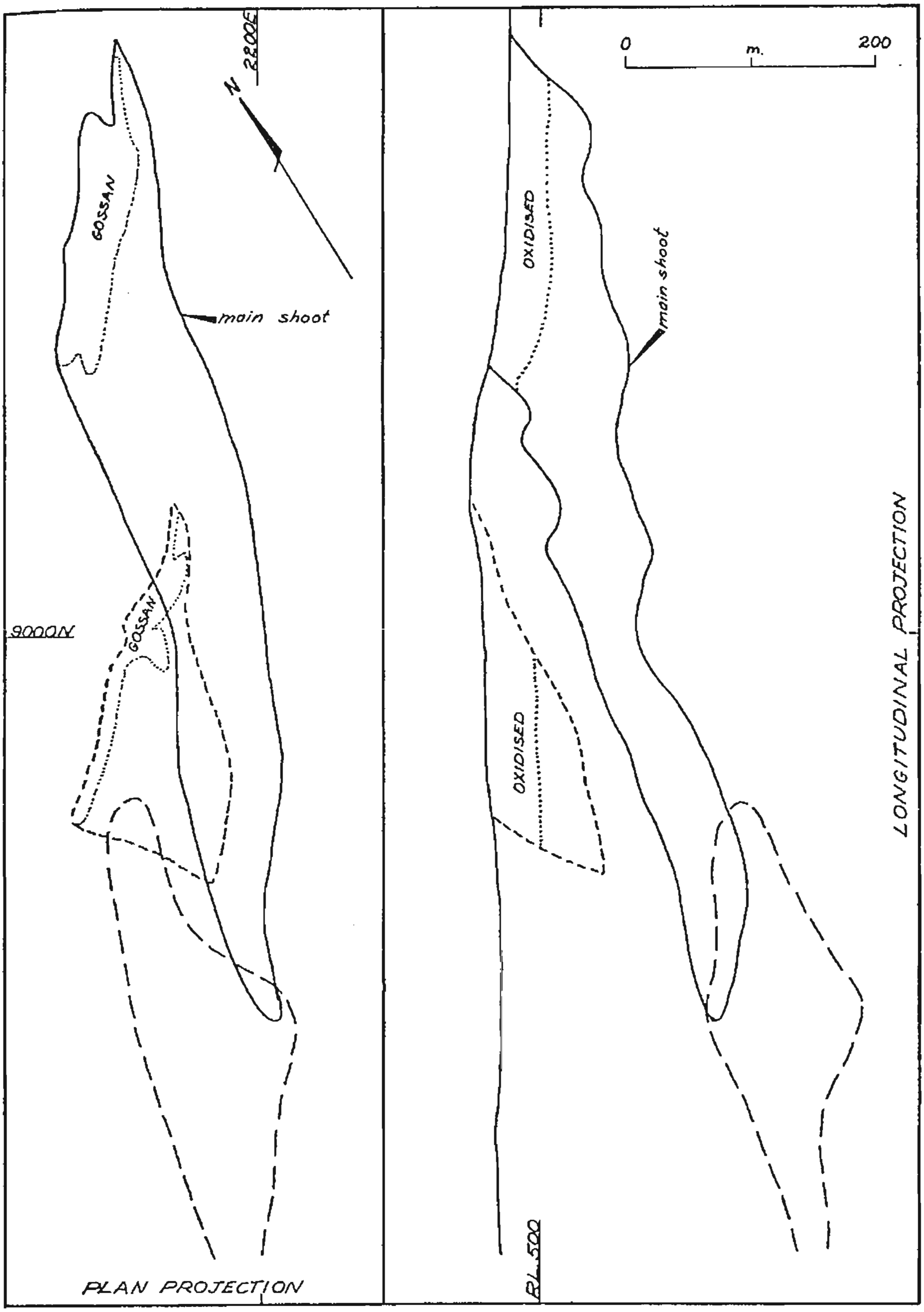


Fig.38 - A composite plan projection and longitudinal projection of the shoots of copper mineralization at Balcooma showing the south-south-westerly plunge of the mineralization

At the northern end, the main shoot is essentially oblong in shape in cross section with the long axis dipping from about 20 to 50° (Fig.29). At the southern end, the shoot can more easily be interpreted as an intensely folded originally tabular body (Fig.29).

Correlation between widely spaced drill holes and between drill holes and the surface, on sections, is difficult. The reason for this is that the deformation and consequent south-plunging rodding means that units intersected in drill holes outcrop progressively further north with greater depth in the holes. The lensing caused by deformation also makes direct correlation with the surface difficult. An example of this is that the sequence of acid tuffs occurring below the "Greywacke Sequence" and intersected in some of the deeper drill holes, occurs to the north of the area drilled at 9500N, 1800E.

At the northern end of the deposit, copper grades tend to be higher towards the bottom, or down dip, parts of the shoot (Fig.39). This grade distribution strongly suggests that chalcopyrite has been preferentially remobilised during deformation and consequently enriched in the down dip portions of the shoot.

The main shoot of copper mineralization was probably originally a tabular lens of mineralization which was largely stratigraphically controlled. However, during folding and deformation it has apparently been stretched in a south-south-west plunging direction and folded into a sausage-shaped body. Remobilisation of sulphides has apparently also occurred, such that the relationship of the mineralization to the original stratigraphy is difficult to establish.

The copper mineralization is thought to have originally been deposited beneath, but close to, the seawater sediment interface, by hot spring activity that deposited lead-zinc-copper

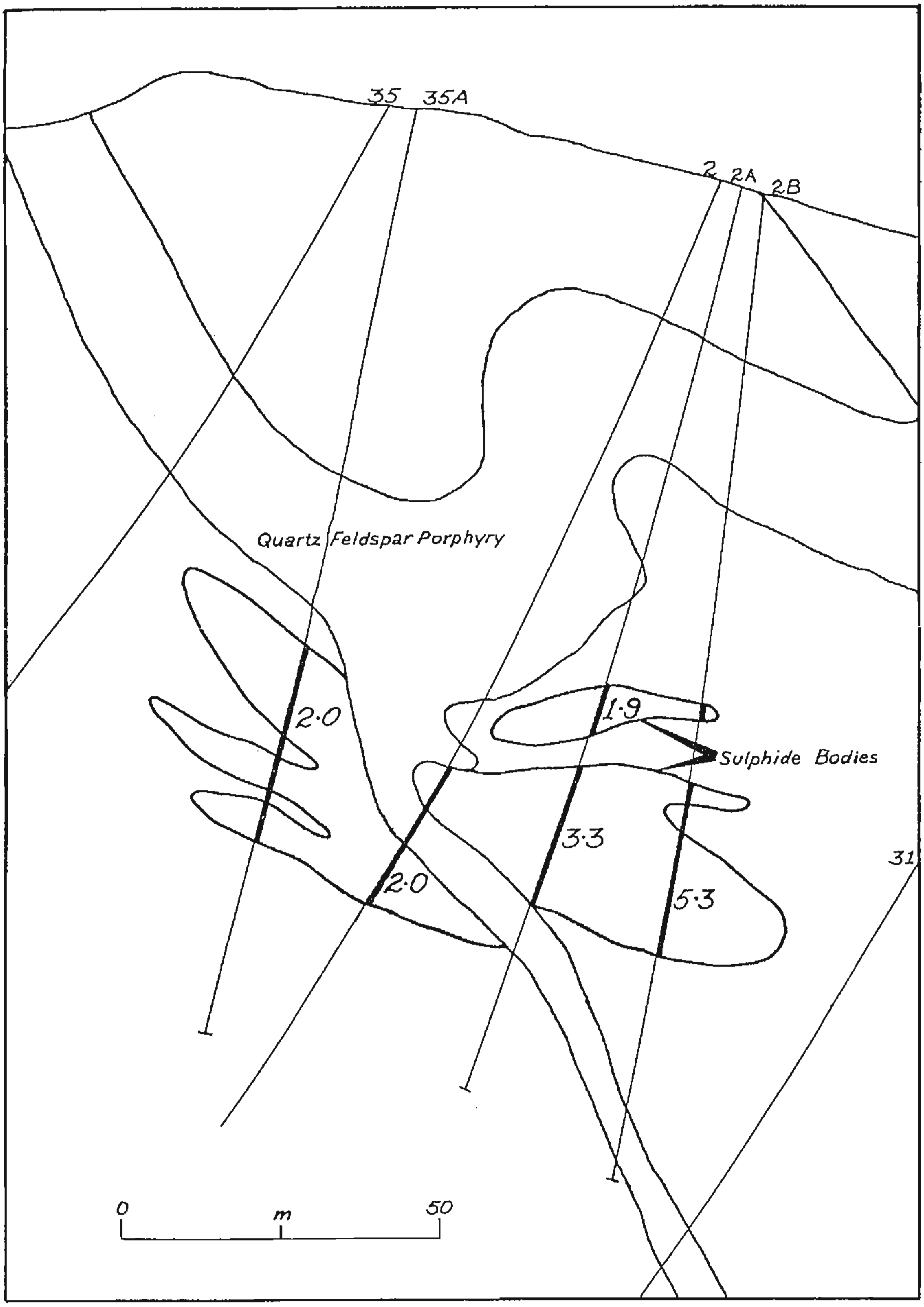


Fig.39 - Section through the main copper shoot at 9080N showing the increase in copper grades towards the down dip portion of the shoot

mineralization on the sea floor.

In the primary zone of the main shoot, copper occurs only as chalcopyrite. Ore types include chalcopyrite in massive pyrite (Fig.40), massive chalcopyrite with pyrrhotite and pyrite (Fig.41) and chalcopyrite with pyrite and pyrrhotite in chlorite schist (Fig.42). Significant amounts of chalcocite occur within the supergene enriched zone (Fig.43). Other secondary minerals, including malachite, azurite, tenorite and native copper, occur in a few drill holes although these appear to be only of a minor nature.

Massive pyrite with chalcopyrite is the most common ore type. Chalcopyrite occurs as interstitial material between euhedral pyrite crystals which vary in grain size from about 1 mm to 10 mm. Minor pyrrhotite occurs in some areas within the massive pyrite and dark-brown sphalerite is sometimes present in very minor amounts. Massive pyrite ore is normally structureless but some areas show a crude layering which could possibly be interpreted as bedding. However, it is more likely that this crude layering was produced by deformation.

Massive chalcopyrite is a subordinate copper ore type. However, it is, nonetheless, very important because of the grade of copper it contains. It usually consists of massive chalcopyrite enclosing wispy lenses of pyrrhotite averaging 5 to 10 cm in length and about 5 mm in width. It occurs both within and adjacent to the massive pyrite ore and may grade into it.

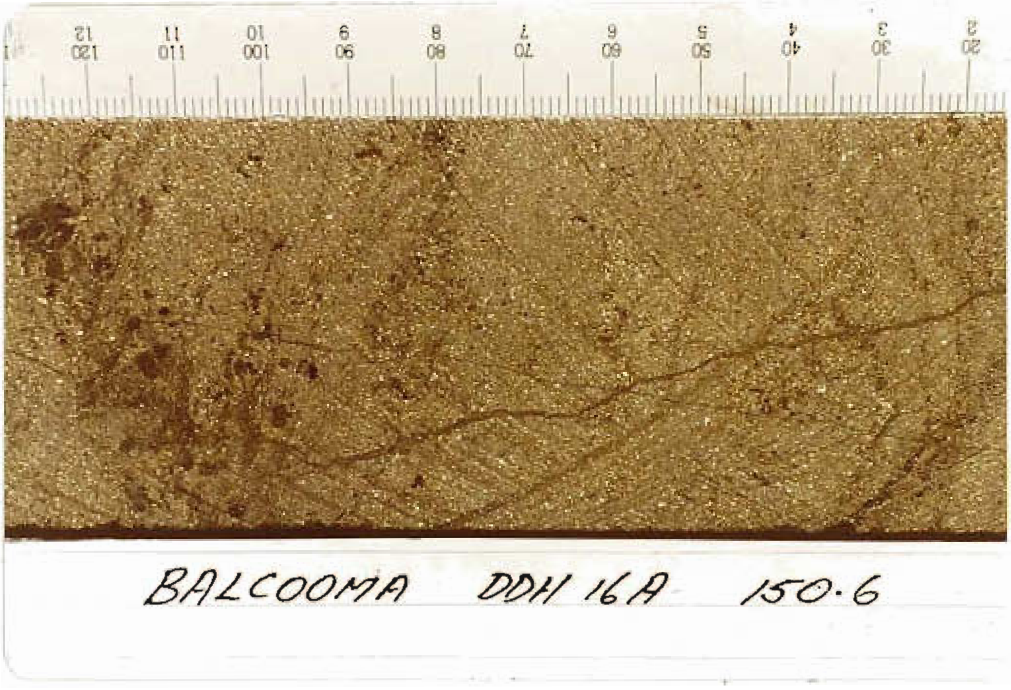
Chlorite schist ore consists of massive chlorite containing garnet, cordierite and magnetite enclosing wispy lenses of chalcopyrite, pyrite and pyrrhotite. This material is found on the edges of the massive sulphide bodies and the sulphide content decreases with increasing distance from the massive sulphides.

Fig.40. Massive pyrite type copper ore with chalcopyrite occurring in the interstices between recrystallised pyrite euhedra. This is the most common ore type.

Loc. as indicated

Fig.41. Massive chalcopyrite type copper ore showing the thin wispy bands of pyrrhotite in massive chalcopyrite.

Loc. as indicated


BALCOOMA DDH 16A 150·6


BALCOOMA DDH 16A 124·0

Fig.42. Chlorite schist type copper ore with chalcopyrite, pyrrhotite and pyrite in massive chlorite.

Loc. as indicated

Fig.43. Supergene copper ore with chalcocite replacing chalcopyrite and pyrite.

Loc. as indicated


BALCOOMA DDH 16A 158·8


BALCOOMA DDH 14 54·0

Molybdenite, native bismuth and bismuthinite form minor phases in the copper ores along with arsenopyrite, marcasite, galena and ilmenite.

Much of the massive chalcopyrite ore and chlorite schist ore are believed to represent ores that have largely, if not totally, remobilised into their current positions. The chalcopyrite is believed to have originally come from the massive pyrite type ore and the enrichment of chalcopyrite has apparently been caused by the greater mobility of chalcopyrite with respect to pyrite. The association of pyrrhotite with these apparently remobilised ores suggests further that its formation is linked in some way to the process of remobilisation.

Intersections of massive magnetite up to about 10 m in thickness have been obtained in some drill holes associated with massive sulphides. The origin of this material is obscure. It is not banded and cannot be interpreted as banded iron formation. On the other hand, it would seem unlikely that it could be remobilised from magnetite in the chlorite schist alteration zone. It has apparently been deposited as areas of massive magnetite (or haematite/limonite) adjacent to the massive sulphide areas. Massive magnetite generally contains only sub-economic copper values.

The second copper shoot is expressed at the surface by the gossan at 9000N, 2100E and it also plunges at about 20° to the south-south-west. Unlike the main shoot, however, this shoot is capped by a narrow (1 to 2 m) layer of lead-zinc-copper mineralization which is responsible for the lead gossan on the surface. South of 8800N this shoot is not significant and it apparently lenses out south of 8650N. The copper mineralization is identical to that within the main body and the thin layer of lead-zinc-copper mineralization which lies on the upper surface of this body is identical to the other areas of lead-zinc-copper mineralization described below.

Unfolding of the QFP shows that this body of mineralization occurs at the same stratigraphic position as the main copper shoot. Similarly the lead-zinc-copper mineralization which caps this body is equivalent to the minor amounts of lead-zinc-copper mineralization which occur to the west of the shallow portions of the main shoot.

Lead-zinc-copper mineralization is widespread throughout the Balcooma prospect area extending from 8500N to 9400N. However, grades within this mineralization are variable and areas of economic grade material are restricted to small areas with dimensions of 100 to 200 m.

Because the lead-zinc-copper mineralization is not as significant as the copper mineralization, it lacks the detailed drilling that has been carried out on the copper mineralization and therefore much of the detailed structure of the lead-zinc mineralization is unknown. However, it also occurs within south-south-west plunging shoots, and patches of economic grade material are restricted to narrow areas.

The mineralization itself consists generally of massive pyrite with variable quantities of sphalerite, galena and chalcopyrite (Fig.44). These generally have a sugary texture and grain size is from 1 to 3 mm. Sphalerite, which is the dominant sulphide after pyrite, is dark-brown in colour and commonly occurs as bands in the massive pyrite (Fig.45). Galena occurs with the sphalerite while chalcopyrite, normally comprising less than 3%, is distributed more generally through the massive pyrite.

In most drill hole intersections, gahnite bearing quartzite and quartz rich schist occur with the lead-zinc-copper mineralization. These also are the main expression of mineralization at the

Fig.44. Massive pyrite sphalerite galena chalcopyrite ore showing the coarse (recrystallised) grain size of the sulphides.

Loc. as indicated

Fig.45. Massive pyrite sphalerite galena chalcopyrite ore showing the layering of the sphalerite (brown) which is interpreted as bedding in a syngenetic ore. BQ core.

Loc. Balcooma DDH 12


BALCOOMA DDH 24 153·6

surface. Gossan after lead-zinc bearing massive sulphides occurs only in two places.

Within the gahnite bearing quartzites, banding due to sulphide layering is common. This banding and the banding of the sphalerite in the massive sulphides is interpreted as original sedimentary banding and these lead-zinc-copper ores are considered to be syngenetic ores associated with exhalative cherts and cherty sediments.

Lead isotope analyses of various Balcooma ores were carried out by Dr. Matti Vaasjoki of the CSIRO as part of the AMIRA project "Lead isotopic characterization of gossans and soils". Data from this study show similar isotopic values for both the copper and lead-zinc ores (Vaasjoki, 1981). However, the copper ores are slightly more radiogenic, reflecting their low lead content. Average lead isotope ratios for Balcooma ores are shown in Table 4 compared with values for Palaeozoic deposits in New South Wales.

The zinc-lead ores at Balcooma are considered to be syngenetic and such ores typically give lead isotope ratios that plot on or near the growth curves and from which an approximate age can be obtained (Stanton and Russell, 1959; Gulson and Mizon, 1979). A plot of Balcooma lead isotope ratios on the model 111 growth curve of Cumming and Richards (1975) indicates an age of lower to middle Palaeozoic (430 million years) (Fig.46). This age is consistent with the age interpreted on geological grounds.

The remarkable similarity of the lead isotopes at Balcooma with those from the Silurian deposits of Woodlawn, Cobar and Captains Flat (Table 4) also confirms that Balcooma is a Palaeozoic massive sulphide deposit. However, it also suggests that the age may be slightly younger than Cambro-Ordovician, the age interpreted on geological grounds. An age as young as Silurian, however, is difficult to accept as other Silurian sequences in north Queensland

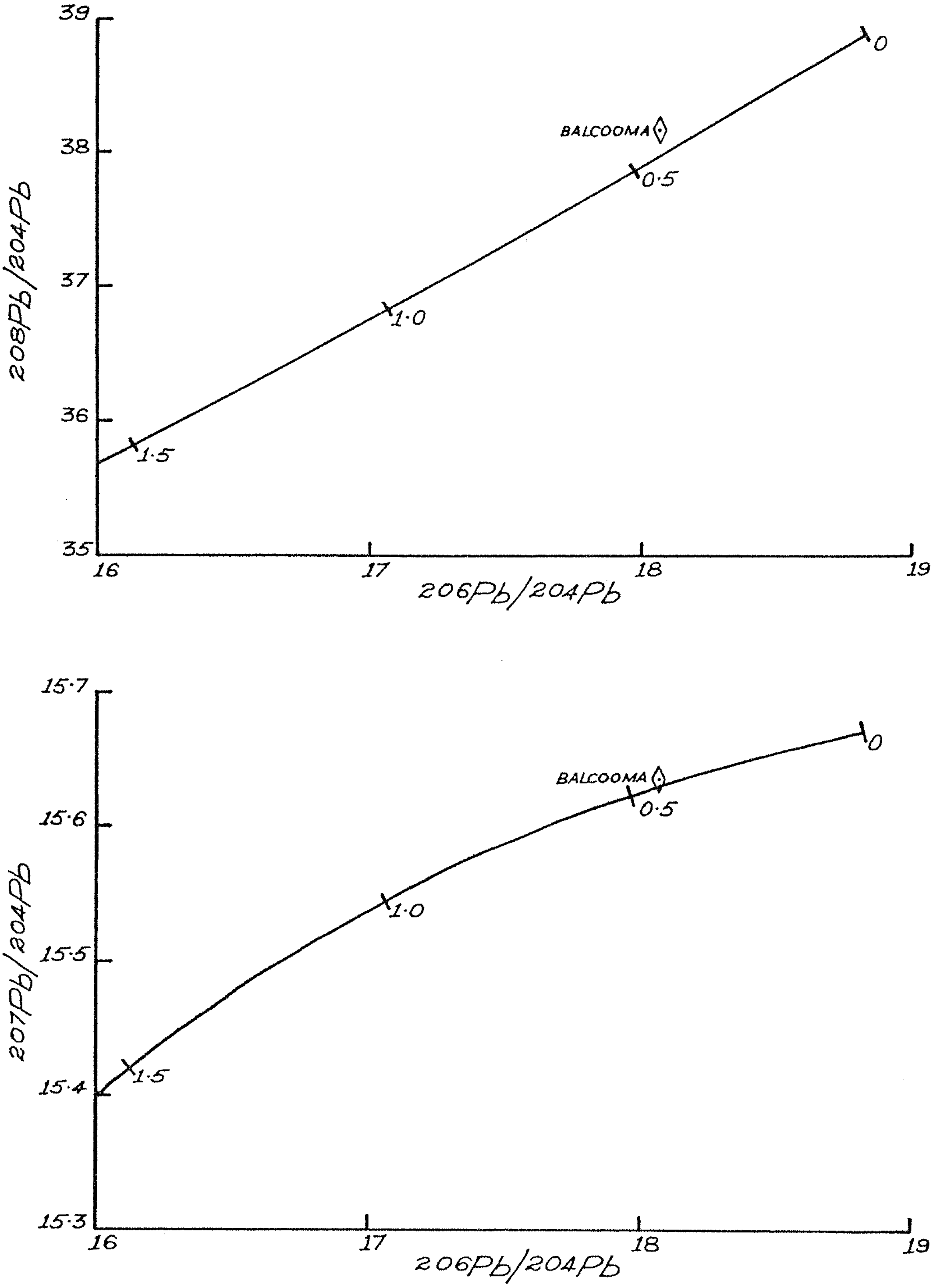


Fig.46 - Lead isotopic ratios for the Balcooma zinc lead mineralization plotted on the Model 111 growth curve of Cumming and Richards (1975)

do not contain significant amounts of acid volcanic material. In addition, the Balcooma lead isotope ratios are almost identical to those from the Thalanga volcanogenic massive sulphide deposit (Gulson pers. comm.). The age of the Mount Windsor Volcanics which host the Thalanga deposit (Gregory and Hartley, 1982) has been determined on both isotope data (Webb, 1974) and on fossil evidence (Dear, 1974; McClung, 1975; Henderson, 1982) as Cambro-Ordovician. This gives further support to a Cambro-Ordovician age for the Balcooma deposit and the "Balcooma Metamorphics" which host the deposit.

TABLE 4

Lead isotopic ratios from Palaeozoic base metal occurrences

Location	Age	208Pb/ 206Pb	207Pb/ 206Pb	206Pb/ 204Pb
Balcooma Zn Pb Cu	Cambro-Ordovician	2.1115	0.8650	18.075
Balcooma Cu	Cambro-Ordovician	2.1078	0.8637	18.100
Balcooma Average	Cambro-Ordovician	2.1111	0.8652	18.07
Captains Flat	Silurian	2.1122	0.8643	18.07
Woodlawn	Silurian	2.1094	0.8633	18.11
Cobar	Silurian	2.1078	0.8631	18.11

Source of Data :	Balcooma	Vaasjoki, 1981
	Cobar and Captains Flat	Ostic et al., 1967
	Woodlawn	Gulson, 1979

5.3. Alteration

A substantial chlorite alteration zone is associated with the shoots of copper mineralization at Balcooma (Figs 28, 29). This chlorite occurs both above and below the mineralization, except in the quartz feldspar porphyry, and also laterally to the mineralization, such that it forms an envelope to the massive pyrite chalcopyrite (pyrrhotite) mineralization. This alteration zone has been metamorphosed and, consequently, its mineralogy is determined by both its original chemistry and by the metamorphic grade to which it was subjected.

A series of four samples beneath the ore intersection in DDH 16A were selected to study the chemical and mineralogical nature of this alteration zone. The samples were selected from DDH 16A since this hole showed very little variation in texture and mineralogical composition of the rocks immediately below the alteration zone. This suggested that any variation detected might be more related to alteration than to compositional variations in the original sediments. The samples included normal country rock with no visible chlorite alteration (182.0 m), very slightly altered rock (175.0 m), moderately altered rock (174.0 m), and strongly altered rock (173.2 m) which was immediately adjacent to ore grade copper mineralization. The four samples are shown in Figure 47 and a close-up photograph of the strongly altered rock is shown in Figure 48.

Mineralogy varies considerably through the alteration series (Table 5) and reflects the chemistry of the alteration process although the mineralogy is essentially a metamorphic assemblage.

In thin section biotite relicts within some of the chlorite, and the presence of titanium oxide inclusions within chlorite show that at least some of the chlorite formed at the expense of biotite. This has apparently occurred during retrograde metamorphism. The presence of staurolite rimmed by cordierite in these areas further suggests that the formation of chlorite from biotite is accompanied by the formation of cordierite from staurolite.

This can be represented generally by the following equation :

Fig.47. Samples of drill core through the chlorite alteration zone beneath the copper mineralization in DDH 16A. The unaltered schist on the right grades through slightly chloritised and moderately chloritised schist to massive chlorite schist on the left.

Loc. as indicated

Fig.48. A close-up photograph of the massive chlorite schist in Figure 47. Note the pale pink garnets, black magnetite and grey cordierite often rimming staurolite, e.g. lower right centre.

Loc. as indicated


BALCOOMA
DDH 16A


BALCOOMA DDH 16 A 173.2

$$\underset{\text{(Staurolite)}}{(Mg,Fe)Al_4Si_2O_{10}(OH)_2} + \underset{\text{(Biotite)}}{2K(Mg,Fe)_3AlSi_3O_{10}(OH)_2} + 2H^+$$

$$\rightleftharpoons$$

$$\underset{\text{(Chlorite)}}{(Mg,Fe)_5Al(AlSi_3)O_{10}(OH)_8} + \underset{\text{(Cordierite)}}{(Mg,Fe)_2Al_3(AlSi_5)O_{18}} + 2K^+$$

TABLE 5

Mineralogy of samples from the alteration zone at Balcooma

Approximate percentage compositions shown in brackets

Unaltered		Slightly Altered		Moderately Altered		Strongly Altered	
Staurolite	(35)	Quartz	(34)	Quartz	(36)	Chlorite	(70)
Biotite	(30)	Biotite	(30)	Chlorite	(30)	Cordierite	(8)
Quartz	(25)	Staurolite	(20)	Cordierite	(23)	Garnet	(6)
Muscovite	(10)	Chlorite	(10)	Staurolite	(4)	Quartz	(5)
Pyrite	(tr)	Muscovite	(4)	Magnetite	(3)	Magnetite	(5)
		Garnet	(1)	Biotite	(2)	Staurolite	(4)
		Magnetite	(1)	Garnet	(2)	Pyrite	(2)
		Pyrite	(tr)	Pyrite	(tr)	Chalcopyrite	(tr)

Results for whole rock analyses of the four samples are shown in Table 6. For comparison purposes, the analyses were recalculated on the basis that aluminium remained constant during alteration (Carmichael, 1968). The validity of doing this was indicated by the TiO_2 analyses which show little variation in the recalculated values. The recalculated values are shown in Figure 49.

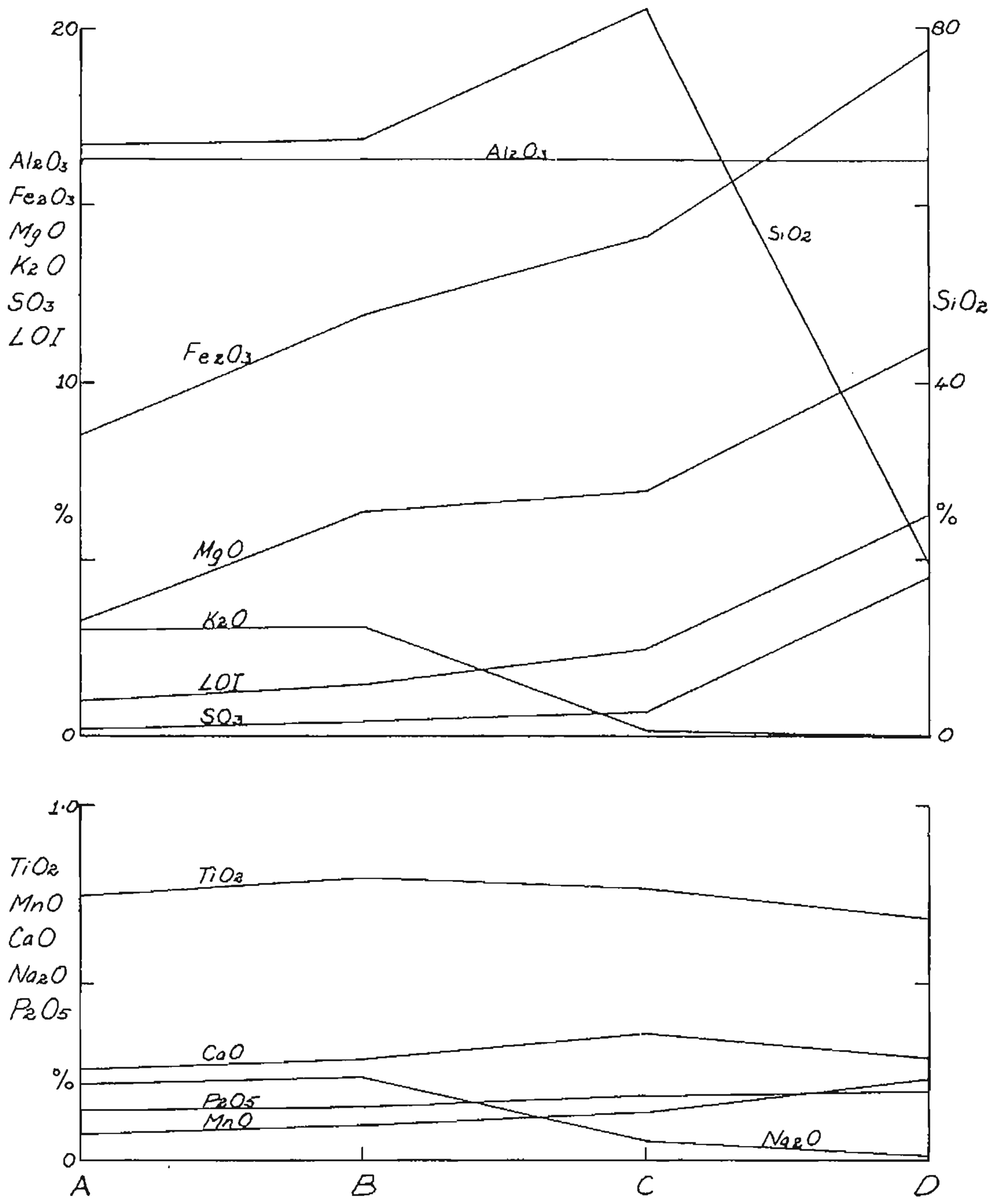


Figure 49. Variations in major element compositions through the chlorite alteration zone at Balcooma recalculated on the basis of Al_2O_3 remaining constant. A - unaltered; B - slightly altered; C - moderately altered; D - strongly altered. LOI - Loss on ignition. The locations of the samples are given in the text.

TABLE 6

Whole rock analyses of a series of samples through the alteration zone to the copper mineralization at Balcooma

Sample No.	QH 19048	QH 19049	QH 19050	QH 19051
Alteration	Unaltered	Slight	Moderate	Strong
SiO_2	66.7	62.5	65.9	26.4
TiO_2	0.75	0.74	0.62	0.92
Al_2O_3	16.3	15.1	13.1	21.7
Fe_2O_3	8.5	11.0	11.3	25.8
MnO	0.08	0.10	0.11	0.30
MgO	3.30	5.90	5.60	14.70
CaO	0.26	0.27	0.29	0.38
Na_2O	0.22	0.22	0.05	0.03
K_2O	2.98	2.80	0.08	0.01
P_2O_5	0.15	0.15	0.15	0.27
SO_3	0.20	0.33	0.50	6.00
LOI	0.99	1.35	1.97	8.35

These results indicate that significant quantities of iron and magnesium were introduced with the sulphide bearing hydrothermal fluids. Potassium and sodium on the other hand have been depleted. Chlorite, cordierite, garnet and magnetite which occur adjacent to the mineralization reflect the increase in iron and magnesium while the absence of biotite and muscovite reflects the absence of potassium. Silica is depleted adjacent to the ore in the massive chlorite schist but is enriched in the adjacent zone. The slight increase in manganese towards the ore is reflected by manganese in the almandine garnets in the alteration zone.

The evidence from the alteration zone is that it is a dynamic system responsive to changes in metamorphic grade. At higher grades of metamorphism, the biotite-chlorite isograd shifts towards the sulphide bodies and towards the area of higher iron and magnesium contents. During retrograde metamorphism this isograd shifts away from the sulphide bodies toward the area of lower iron and magnesium. Obviously, such a shift has to be accompanied by the addition and loss of potassium respectively.

Chlorite is rare in the area away from the sulphide bodies. This may partly reflect the lack of sufficient iron or magnesium contents in the normal metasediments and metavolcanics away from the mineralized areas. However, since chlorite does not usually occur, even in small amounts, away from the mineralized area, it is clear that its formation is facilitated by some factor near the sulphide bodies. It is suggested that the presence of a high sulphur fugacity acts as a catalyst for the formation of chlorite from biotite during retrograde metamorphism.

It is further suggested that chlorite existed immediately adjacent to the sulphide bodies even at the highest grades of metamorphism reached, and that this is possible because the stability range of chlorite is increased by the presence of sulphides and also by the existence of excess iron and magnesium in these areas. On the other hand, cordierite, which is normally regarded as a high temperature metamorphic mineral, appears to have formed at lower grades of metamorphism in the vicinity of the sulphide bodies.

These notions are in contradiction to the general idea of metamorphic facies which attempts to limit particular metamorphic minerals to particular ranges of temperature and pressure. Clearly, this can only be done where the chemistry of metamorphic rocks is relatively constant and the presence of volatile elements, such as sulphur, which may extend stability ranges for minerals, is negligible.

5.4. Gossan

Two main areas of gossan have been mapped out at Balcooma (Fig.28). These areas are not gossans in the strict sense of the word but rather are the surface expression of the mineralization. The largest part of these areas is composed of siliceous and iron stained breccias (Figs 50, 51). True gossan forms only part of these areas.

Although gossan is considered to be the normal surface expression of sulphide mineralization, the Balcooma example is consistent with the notion that massive sulphides in the deeply weathered terrains of Australia are more likely to be expressed as iron stained and siliceous breccias.

The origin of these breccias involves the dissolution of oxidised sulphide minerals by groundwater at or about the water table to form cavities. These cavities have been intersected by a number of drill holes entering the near surface zone of the mineralization and have dimensions up to 5 m across. As weathering proceeds, these cavities are progressively filled by insoluble gangue material remaining from the massive sulphides and from collapse of both the walls and roof of the original massive sulphide lens. At Balcooma this involves both chlorite and other schists and quartz feldspar porphyry. Iron released from the oxidation of sulphides permeates both the country rock and these breccia bodies to impart a liberal coating of iron oxides. Silica, which is available in groundwaters, is fixed by the acid conditions due to the oxidising sulphides, and extensive surface silicification of rocks near the oxidising sulphide bodies occur. The result of these processes is that massive sulphides are represented on the surface by siliceous and iron stained breccias.

True gossans only form where the sulphide content is low enough such that the gangue is present in sufficient quantities to

Fig.50. Iron stained collapse breccia after massive sulphides. The white breccia fragments are remnants of quartz chlorite schist and quartz feldspar porphyry.

Loc. 9000N 2100E

Fig.51. Silicified collapse breccia after massive sulphides.

Loc. 9000N 2100E

preserve boxworks after sulphides. True gossan at Balcooma, therefore, tends to occur marginally to the collapse breccia zones and also as fragments within the breccias.

Other effects related to oxidation of the sulphide bodies include the kaolinisation and silicification of the country rock to the oxidising massive sulphides. All these effects are restricted to the supergene zone and are therefore not part of the original mineralizing event.

The QFP adjacent to the oxidising sulphides has been leached by the acid solutions which result. This causes extensive kaolinisation of the feldspars. The volume change which accompanies this process results in cracking of the leached QFP. The cracks formed often become filled with kaolinite which is later silicified to a hard white material. Silicification of the whole rock mass of the QFP alco occurs and iron oxides stain the rock. The results of these processes is that the QFP near the oxidised sulphide bodies is very difficult to identify. It occurs as outcrops of iron stained, silicified kaolinitic rocks often cut by a network of white siliceous veins and bears little resemblance to QFP away from the mineralization. The only clue to the original rock type is the occasional quartz eye which is preserved in these rocks.

Silicification of the oxidised chlorite alteration zone occurs adjacent to the massive sulphide bodies. This material forms the top of the hill at Balcooma and interpretation of the origin of this material before drilling was difficult. Because of the fact that some of the material was after massive chlorite schist, it resembled the siliceous (chalcedonic) surface cappings often found on serpentinite bodies in the area.

Oxidation of the sulphides in the smaller copper shoot at Balcooma has resulted in the formation of a high grade lead gossan (Figs 52, 53) because of the existence of a thin zinc-lead layer on the upper

Fig.52. Outcrop of anglesite and cerussite of the lead gossan. This material has a grade of about 60% Pb and 700 g/t Ag.

Loc. 9050N 2120E

Fig.53. Costean exposure of the lead gossan. The white material in the left foreground is anglesite and cerussite which occurs as a sugary white powder. Grade is 40% lead.

Loc. 9000N 2120E

surface of this body. This lead gossan consists of both anglesite and cerussite in about equal proportions. Lead values range up to 60 percent and silver values are about 10 g/t per one percent lead. On the other hand, zinc is virtually depleted in this gossan and values over 100 ppm are rare. This indicates the intensity of leaching which has occurred in the area associated with the development of the laterite profile. Rare cassiterite grains within the lead gossan reflect the slightly anomalous tin values associated with the Balcooma ores.

5.5. Origin

The Balcooma massive sulphide deposit contains both stratiform zinc-lead-copper mineralization and adjacent cross-cutting copper mineralization. The mineralization is hosted by metamorphosed fine-grained metasediments which are part of an acid volcano-sedimentary sequence. The mineralization is associated with an extensive area of alteration containing sericite (now muscovite), chlorite, pyrite and quartz. As such, the deposit is similar to a number of other deposits such as Woodlawn and Thalanga which are volcanogenic massive sulphide deposits. Because of these features it is concluded that the deposit at Balcooma is of the volcanogenic massive sulphide type.

The deposit and its host rocks have undergone at least two periods of strong deformation and the deposit is metamorphosed to upper greenschist-lower amphibolite facies. The deposit shows features which are associated with other deformed and metamorphosed stratiform massive sulphide deposits such as remobilised ores, zinc in staurolite porphyroblasts in the enclosing schists, and gahnite bearing quartzites formed by metamorphism of siliceous exhalites.

The deposit occurs within a sequence of rocks which, on the bulk of evidence, are lower Palaeozoic in age and it is therefore considered that the Balcooma deposit formed during the Cambro-

Ordovician when the Thalanga and Liontown deposits in the Charters Towers area formed. All these deposits are believed to have formed in an island arc setting which formed at the beginning of the development of the Tasman Fold Belt System in the eastern margin of the Precambrian Australian Craton.

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APPENDIX 1

BALCOOMA

PETROLOGY

QH19001

Location: Grid - 7610N 1800E

Hand Specimen: Schist of the "Clayhole Creek Beds" with large ?cordierite porphyroblasts.

The bulk of this rock consists of interlocking anhedral quartz (20-50 um) separating discontinuous foliae of subparallel pale brown biotite (now somewhat oxidized). Cordierite occurs in coarse (1 cm - 3+ cm) sieve textured poikiloblasts containing abundant inclusions of quartz and pale biotite (both finer-grained than in the bulk of the rock), and locally rather coarse flakes of muscovite. Cordierite is extensively altered to a low birefrigent product with mottled extinction - probably still crystalographically similar to cordierite - and to fine grained sericite, particularly along grain boundaries and around inclusions. Andalusite also occurs as skeletal porphyroblasts, 1 - 3+ mm in diameter, within and outside cordierite porphyroblasts. Opaques partly altered to limonite. A porphyroblastic quartz biotite schist.

QH19002

Location : Grid - 7960N 1555E

Hand Specimen: . Ferruginous schist from footwall alteration zone.

This specimen consists chiefly of interlocking polyhedral quartz (100 - 200 µm), with about 10% staurolite in subhedral poikiloblasts (200 - 1000+ µm) and 10% ferroan chlorite in anastomosing foliae of subparallel flakes, strongly stained by hematite. Magnetite occurs in sporadic 2 - 5 mm euhedra (partly altered to hematite), and sporadic cavities probably after euhedral pyrite filled by hematite and koalinite. Chlorite shows no evidence of the former presence of biotite, and staurolite is quite fresh although somewhat iron-stained. The rock is a quartz-chlorite-staurolite schist probably originally very weakly pyritic.

<u>QH19003</u>

Location: Grid - 7900N 1555E

Hand Specimen: Ferruginuous schist from footwall alteration zone.

This is a quartz rich schist generally similar to QH19002, consisting mainly of sutured polyhedral quartz with about 10% each of poikiloblastic staurolite, poikiloblastic hematite (after magnetite) and sinuous foliae of strongly oxidized phyllosilicates. The latter are much more strongly oxidised than in QH19002 and are extensively replaced by clay, but contain relict oxidized biotite and appear to have been mainly biotite rather than chlorite, plus traces of muscovite. The rock is an oxidized quartz-biotite-staurolite-magnetite schist.

<u>QH19004</u>

Location: Grid - 5600N 2100E

Hand Specimen: "Matchbox Creek Microgranite"

This is a microporphyritic microgranite, with about

10% each of 150 - 300 μm microphenocrysts of subhedral to anhedral quartz and sodic plagioclase in a granophyric matrix of quartz, albite, K-feldspar and subordinate biotite and subhedral muscovite. Plagioclase phenocrysts include minor secondary muscovite, epidote and calcite. Accessory minerals include zircon, allanite, apatite and anhedral opaques. Most quartz grain boudaries are sutured and it is likely that the rock has undergone some dynamothermal metamorphism after emplacement.

QH19005

Location : Grid - 7730N 330E

Hand specimen : "Dry River Volcanics"

This sample consists principally of fine-grained (100 - 200 μm) anhedral quartz and subordinate albite with about 5% of green-brown biotite and minor muscovite in 20 - 200 um flakes, generally weakly parallel and with the coarser flakes in discontinuos foliae. Coarse (500 um - 1 mm+) generally ovoid and generally polycrystalline patches of quartz and occasionally of albite make up 1 - 2% of the rock and may perhaps be strongly flattened and somewhat recrystallized phenocrysts, although none have definitely igneous microtextures. Zircon, highly poikiloblastic garnet and limonite moulds (after pyrite?) occur rarely. The rock is a quartz-albite-biotite schist, possibly an acid tuff although the traces of accessory zircon are rounded rather than euhedral.

QH19007

Location: Grid - 8945N 420E

Hand specimen: "Dry River Volcanics"

This is a quartz-muscovite-biotite schist, containing about 2% each of somewhat poikilitic green biotite (200 - 500 μm) and ovoid quartz or polycrystalline quartz (200 - 800 μm) in a matrix of fine-grained polyhedral and subordinate muscovite, the latter as intergranular flakes or anastomosing muscovite-rich foliae. Accessory minerals include zircon (generally euhedral) and traces of rutile. Quartz patches contain sporadic inclusions of sericite and partly sericitized albite occasionally in patterns resembling phenocryst embayments, but generally lack convincing igneous microtextures.

QH19008

Location: Grid - 9030N 510E

Hand Specimen: Acid agglomerate of "Dry River Volcanics"

This sample consists chiefly of a mosaic of irregularly intergrown, anhedral to polyhedral quartz and generally finer-grained albite, with about 10% muscovite predominantly in sinuous foliae, and 2 - 3% disseminated green biotite. Albite also occurs in sporadic ½ - 1 mm porphyroblasts and quartz plus minor albite form highly irregular discontinuous veins and patches, which together with grainsize variations in the groundmass suggest a relict fragmental texture. Accessory minerals include cloudy rutile and generally euhedral zircon and sporadic limonite-rimmed cavities probably after original pyrite. The rock is a quartz-albite-muscovite-biotite schist, possibly originally an acid fragmental.

QH19009

Location: Grid - 10925N 700E

Hand Specimen: Metasandstone of the "Clayhole Creek Beds".

This is a quartz-albite-muscovite-biotite schist, consisting predominately of 50 - 200 µm grainsize polyhedral quartz with about 10% each of weakly sericitized anhedral albite, brown biotite and muscovite the latter two minerals showing a high degree of parallelism and forming semi-continuous foliae with muscovite included in or mantling biotite. Accessory minerals include apatite and zircon (both generally rounded), fine-grained anhedral opaques and rare 1 - 2+ mm staurolite poikiloblasts. The sample shows a weak gradation in quartz grainsize, which however appears not to be depositional but a metamorphic feature related to abundance or phyllosilicates and cannot be used as evidence for facing.

QH19010

Location: Grid - 10440N 1560E

Hand Specimen: Staurolite quartz biotite muscovite schist of the "Clayhole Creek Bed"

This is a porphyritic quartz-muscovite-biotite schist, consisting principally of polyhedral quartz (100 - 200 μm), with about 10% muscovite as 100 - 200 um flakes generally in semi-continuous foliae, about 10% brown biotite generally in equant 100 - 200 μm poikilitic grains and grain aggregates disseminated throughout. Biotite generally is only weakly parallel to the cleavage defined by muscovite orientations and includes and apparently postdates muscovite formation. Staurolite and minor ?kyanite occur as sporadic 0.1 - 2+ mm poikiloblasts. Accessory minerals include magnetite (extensively altered to hematite), apatite, zircon and traces of allanite, and sporadic limonite-rimmed cavitites after pyrite.

<u>QH19011</u>

Location: Grid - 11080N 2665E

Hand Specimen: - Acid volcanic (tuff or dyke) within the "Clayhole Creek Beds"

The bulk of this sample consists of approximately equal amounts of polyhedral quartz and albite (50 - 200 μm grainsize), with 1 - 2% each of subparallel flakes of brown biotite and randomly oriented poikilitic muscovite, and subhedral to lenticular bodies of strained, generally polycrystalline quartz, which nevertheless contain scattered embayments and inclusions of albite and appear to represent strongly flattened quartz phenocrysts. Albite is disseminated evenly throughout the groundmass, but also occurs in acute lenticular schlieren of polyhedral grains which may represent flattened and recrystallized albite phenocrysts. Accessory minerals include magnetite, apatite and zircon. The rock is a quartz-albite schist, originally an acid volcanic; discrimination of tuffaceous verses flow origin is not possible in thin section.

QH19013

Location : Metric Grid - 7860 542202

Hand Specimen: Meta-andesitic volcanic of the "Golden Creek Volcanics"

This is a mafic schist, consisting of about 50% blue-green columnar actinolite (20 - 200 µm) in wispy subparallel aggregates, accompanied by patches and interstitial grains of polyhedral to columnar albite (4%) and about 5% each of fine-grained interstitial quartz and K-feldspar. Albite aggregates occasionally pseudomorph equant to columnar phenocrysts ½ - 2 mm in diameter. Accessories include rutile, apatite and 100 - 500 µm patches of sieve-textured ilmenite. The rock is an actinolite-albite schist, probably originally a porphyritic mafic or intermediate volcanic.

QH19044

Location: DDH16A, 182.0 m.

Hand Specimen: Unaltered staurolite biotite quartz muscovite schist of "Clayhole Creek Beds"

1 - 6 mm subhedral porphyroblasts of staurolite and biotite are closely packed in a matrix of quartz (av. 150 µm) and muscovite (av. 100 µm). Quartz grains are polyhedral with well-developed triple point junctions; muscovite flakes are interstitial to quartz

and have a weak to pronounced preferred orientation, with local development of coarser muscovite flakes and sinuous muscovite-rich foliae, which may wrap porphyroblasts. Minor ilmenite and magnetite, and traces of chalcopyrite, occur in the matrix.

Staurolite and biotite are both poikilitic, staurolite intensely so and with inclusions only of quartz and granular ilmenite (somewhat hematitic). Inclusions in biotite are fewer, coarser and include muscovite (which is commonly oriented subparallel to the rock cleavage) and spicular hematite-ilmenite intergrowths. Minor decussate chlorite and muscovite are intergrown with biotite porphyroblasts.

A staurolite-biotite-quartz-muscovite schist.

QH19045

Location: DDH 16A, 175.0 mm

Hand Specimen: Slightly altered staurolite biotite quartz muscovite schist adjacent to the copper ore zone.

1 - 5 mm subhedral prophyroblasts of staurolite, biotite and subordinate cordierite are crowded in a minimal matrix (commonly reduced to narrow webs between porphyroblasts) of quartz and minor cordierite.

Staurolite porphyroblasts are intensely poikilitic (crowded with 10 - 100 µm inclusions of quartz and with scattered granular ilmenite) and commonly interlocking to form aggregates several centimetres across. Cordierite porphyroblasts are likewise highly poikilitic, and occur as separate grains or as attachments too staurolite, and about 50% of the total cordierite in the rock forms as poikilitic overgrowths around and within staurolite crystals. Biotite porphyroblasts are in comparison only weakly poikilitic, but biotite may occur intergrown with cordierite or as isolated but optically continuous patches in cordierite.

Matrix quartz is generally polyhedral but in narrow zones and occasional patches is strongly strained and sutured. Minor cordierite occurs in the matrix as anhedral to cuspate grains interstitial to polyhedral quartz, although where these are abundant the quartz grains are rounded and the mass appears as an incipient porphyroblast.

Chlorite occurs interlaminated with biotite and in scattered flakes in biotite (where it is relatively coarse) and in cordierite-quartz aggregates. Coarser patches of chlorite may contain scattered patches of pyrrhotite, pyrite (some after pyrrhotite) and traces of chalcopyrite. Sporadic $\frac{1}{2}$ - 2 mm euhedral magnetite grains (with lenticular exsolved ?ulvospinel) are restricted to matrix areas.

A single occurence of garnet is noted in this specimen; a 600 μm diameter poikilitic grain with inclusions of quartz and ilmenite, intergrown with coarse biotite and matrix quartz.

A staurolite-biotite-quartz-cordierite rock

QH19046

Location: DDH 16A, 174.0 m

Hand Specimen: Moderately altered chlorite quartz cordierite schist adjacent to the copper ore zone.

Poikiloblastic staurolite (1 - 10 mm) is mantled by cordierite which is generally poor in inclusions.These are set in a matrix of polyhedral quartz with interstitial flakes of chlorite and semi-continuous webs of cordierite. Anthophyllite (optically positive orthorhombic amphibole) occurs in sporadic sheaves of acicular crystals (½ - 2 mm), which show incipient alteration to green biotite. Garnet forms rare poikilitic anhedra.

Opaques are mainly magnetite (200 um - 1 mm euhedra) with exsolved ?ulvospinel lenticles and with occasional inclusions of ilmenite. Ilmenite with intergrown hematite also occurs in scattered 100 - 300 µm grains. Pyrite and chalcopyrite occur rarely, in irregular patches some of the pyrite is porous and probably secondary after magnetite.

A cordierite-staurolite-quartz-chlorite-anthophyllite schist.

QH19047

Location: DDH 16A, 173.2 m

Hand Specimen: Strongly altered chlorite schist immediately adjacent to massive sulphides of the copper ore zone.

The bulk of the sample consist of tightly packed, subparallel flakes of pale green chlorite (typically 2 x 0.2 mm), with well developed kinking and microfolding. This matrix contains disseminated irregular to subhedral grains of weakly poikilitic staurolite (up to 1 cm long), rimmed and embayed by cordierite, and ovoid patches of cordierite free of residual staurolite. Cordierite is embayed and apparently replaced by matrix chlorite, and also shows local peripheral alteration to a waxy green, "pinite"-like material.

Opaque minerals occur as inclusions in staurolite and cordierite and disseminated in the chlorite matrix. Inclusions in staurolite are ilmenite, sometimes with minor intergrown hematite. Cordierite contains ovoid ilmenite (free from hematite) and pyrrhotite, the latter sometimes intergrown with chalcopyrite or replaced by secondary pyrite.

Magnetite occurs in disseminated euhedra 1 - 5 mm in diameter, with lenticular inclusions of exsolved ?ulvospinel, and with occasional inclusions of ilmenite and sulphides. Pyrite occurs in euhedral primary grains and in irregular porous masses (with minor marcasite) after pyrrhotite; both may be intergrown with chalcopyrite and pyrrhotite in more or less irregular patches or in lenticular tension openings in the rock cleavage. Pyrrhotite in these latter sites may also be altered to carbonate and/or green biotite; minor carbonate also fills deformed, crosscutting veinlets in chlorite.

A chlorite-cordierite-staurolite schist.

QH19036

Location : DDH 6, 210.6 m

Hand Specimen: "Matchbox Creek Microgranite"

Mineralogy: Quartz 40%, Albite 50%, K-feldspar trace, Biotite 6%, Chlorite 2% Opaques 2%, Apatite trace, Zircon trace, Sphene trace, Calcite trace.

Textures: Interlocking, columnar to irregular albite intergrown with (generally intergranular) quartz (both 300 - 1000+ µm). Finer-grained biotite, chlorite (partly after biotite) and opaques are disseminated throughout, but most are concentrated in discontinuous, subparallel foliae. Albite occurs in two forms:

(a) Columnar to irregular grains with generally well developed and regular polysynthetic twinning-sometimes zoned.

(b) Generally irregular grains with irregular or "chessboard" patterned twining. These contain traces of K-feldspar and traces of perthite-like patterns and are probably albitized K-feldspar.

Accessory zircon, apatite and sphene are generally associated with biotite-chlorite patches.

Comments: A metamorphosed, sodium-metasomatised foliated granite.

QH19037

Location: DDH 17, 410.6

Hand Specimen: Lapilli tuff

Mineralogy: Quartz 33%, Albite 50%, Muscovite 10%, Biotite 2%, Chlorite trace, Pyrite 2%, Cordierite 3%, Rutile trace, Zircon trace.

Textures: Polyhedral to irregular quartz (100 - 300 µm), with sporadic disseminated muscovite, biotite, pyrite and columnar albite forms an irregular network through the rock, enclosing irregular to cuspate or lenticular patches of fine-gained (10 - 30 µm) euhedral albite, and cut by subparallel mica-rich foliae. Sporadic cordierite porphyroblasts are almost entirely altered to a serpentine-like phase, and are crowded with inclusions of fine-grained quartz and albite; phyllosilicates and pyrite are less common. Albite-rich patches contain inclusions of quartz, and columnar albite, but seldom of pyrite, or of phyllosilicates except where cut by mica-rich foliae. Accessory rutile is well-crystallised, and zircon generally well-rounded.

COMMENTS: A pyritic quartz albite muscovite cordierite schist, probably originally an albitic sediment. The albite-rich patches are probably disrupted layers, with associated quartz preferentially recrystallised and coarsened.

<u>QH19038</u>

Location: Grid - 9900N 2105E

Hand Specimen: Banded ferruginous rock

Mineralogy : Quartz 50%, Hematite (Magnetite) 40%, Koalinite 5%, Muscovite 5%.

Textures: Irregular to polyhedral quartz (50 - 300 um)intergrown with irregular clumps of original magnetite, now extensively altered to hematite. Koalinite and residual muscovite (both strongly ironstained) occur in 1 - 10 mm laminae with minor quartz and altered magnetite.

Comments: Quartz-hematite (after magnetite) iron-formation.

QH19039

Location : Metric Grid - 7860 522163

Hand Specimen : Acid Volcanic of "Lochlea Volcanics"

Mineralogy: Albite 60%, Biotite 20%, Quartz 10%, Muscovite 4%, Calcite 2%, Rutile 3%, Opaques 1%.

Textures: The bulk of the sample consits of a foliated matrix of fine-grained anhedral albite with abundant disseminated biotite, minor quartz (all 10 - 30 µm) and fine-grained rutile. Sporadic lentiular to ovoid rock fragments up to 1 cm long consist of sutured, sub-columnar albite (commonly with a ghost subtrachytic texture) with occasional columnar albite phenocrysts, and in some cases with disseminated biotite and opaques; less abundant are varieties consisting of random interlocking albite with interstitial albite, minor quartz, biotite or opaques. Albite phenocrysts and euhedral shapes filled by poly-crystalline albite (albitised K-feldspar?). Calcite, quartz and muscovite fill irregular patches , veinlets and tension gashes,

and minor poikilitic, post-foliation muscovite is disseminated through the matrix.
Comments: An albite-biotite rock, probably originally an acid tuff.

<u>QH19040</u>

Location: Metric Grid - 7860 624247

Hand Specimen : Albitic breccia fragment.

Mineralogy: Albite 55%, Quartz 43%, Muscovite 2%, Rutile trace.

Textures: Sporadic 0.5 - 5 mm subhedral phenocrysts of albite (about 15%) and strained, embayed and corroded quartz (about 10%) are rimmed by broad (0.2 - 2+ mm)coronas of quartz-albite myrmekite, which are intergrown with adjoining coronas or with interstitial granular quartz and albite. Muscovite occurs in sporadic flakes and interstitial patches, occasional semi-continuous foliae and in minor amounts as an alteration product in phenocrysts. As in QH19036, albite is present in two types:

(a) a "normal" albite-twinned variety, forming about 50% of the phenocrysts, and

(b) a finely and irregularly twinned "chessboard" albite, in places resembling microcline twinning but not stained by sodium cobaltinitrite. This variety forms about 50% of the feldspar phenocrysts, and most of the myrmekitic and interstitial albite. Where in contact with type (a) the contact is typically gradational although rapid, with approximate optical continuity between twin sets in the two types. As in QH19036 type (b) albite is suspected to be formed by albitisation of pre-existing K-feldspar although there is no convincing evidence for this in the present sample, other than the presence of both albite types in separate, sometimes adjoining, phenocrysts.

Comments: A granophyric quartz porphyry, possible albitized.

QH19041

Location: Metric Grid - 7860 624247

Hand Specimen: Albitic breccia fragment.

Mineralogy: Albite 55%, Quartz 40%, Biotite 2%, Muscovite 3%, Chlorite trace, Rutile trace, Hematite trace.

Textures: Sporadic ½ - 2+ mm phenocrysts of subhedral albite and corroded embayed quartz, both sometimes with quartz-albite myrmekite rims, occur in a matrix of generally granular quartz and albite with occasional particles of myrekite. Biotite (partly chloritised) occurs in diseminated flakes and patches, Muscovite occurs in isolated flakes, semicontinuous sinuous foliae, and as separate flakes in altered albite. As in QH19040 albite is of two types:

(a) "normally" twinned and

(b) "chessboard" or irregularly twinned.

Type (b) occurs in gradational contact with type (a), and as myrmekite webs and isolated grains, some of the latter clearly preserving a columnar outline and ghost Carlsbad twinning.

Comments: A quartz-albite porphyry, probably an albitised granite porphyry.

<u>QH21568</u>

Location: Metric Grid - 7860 627285

Hand Specimen: Tertiary olivine basalt.

Mineralogy: Plagioclase 45%, Augite 30% Olivine 15% Glass 5%, Opaques 3%, Calcite 1%, Zeolite 1%, Quartz trace, Hematite trace.

Textures: Columnar, euhedral calcic labradorite (100 - 300 µm) is subophitically intergrown with pink, zoned titaniferous augite, and interstices are filled with partly devitrified glass crowded with fine-grained dendritic opaques (locally oxidised). Olivine forms embayed subhedral phenocrysts 100 - 800+ µm in diameter, commonly glomeroporphyritic, and rare plagioclase phenocrysts are also present. Many interstices are filled, and cavities lined, by an unidentified zeolite, and cavities are also partly filled by calcite. Rare xenocrysts of quartz are mantled by titaniferous augite.

Comments : Olivine basalt.

<u>QH21569</u>

Location: Metric Grid - 7860 619322

Hand Specimen: Muscovite biotite leucogranite near Conjuboy.

Mineralogy: Quartz 35%, K-feldspar 35%, Plagioclase 27%, Muscovite 2%, Biotite 1%.

Textures: Rather loosely packed, subhedral columnar plagioclase (generally zoned, sodic oligoclase -> albite) and minor K-feldspar form an open network with interstitial quartz, granular K-feldspar and subordinate plagioclase and quartz-albite myrmekite. Silicates are separate, with grain sizes between 200 µm and 5 mm. Quartz phenocrysts are absent, but minor early euhedral quartz is preserved as inclusions in early plagioclase. Sporadic oxidised biotite is generally interstitial to early feldspars. Muscovite occurs in interstitial patches, coarse tabular somewhat poikilitic flakes and disseminated flakes in partly altered plagioclase, and is probably largely a subsolidus phase.

Comments: Muscovite-biotite leucogranite.

QH21570

Location: Metric Grid - 7860 659284

Hand Specimen: Coarse grained biotite adamellite

Mineralogy: Quartz 20%, K-Feldspar 20%, Plastioclase 35%, Biotite 12%, Hornblende 10% Sericite 2%, Myrmekite 1%, Epidote trace, Apatite trace, Zirocn trace, Sphene trace, Opaques trace.

Textures: Ovoid to columnar micro-phenocrysts of plagioclase (1 - 5 mm) in a matrix of anhedral

K-feldspar (microperthitic) and quartz, with disseminated crystals and clumps of brown biotite and poikilitic hornblende (all 200 µm - 2+ mm). Minor myrmekite particles occur at feldspar grain boundaries. Plagioclase cores are patchily sericitized and contain disseminated secondary epidote; minor epidote also occurs in veinlets and in granules intergrown with mafic minerals.

Comments: A biotite-hornblende granite (adamellite)

QH21571

Location: Metric Grid - 7860 601224

Hand Specimen: Hornblende quartz diorite.

Mineralogy: Plagioclase 47%, Hornblende 40%, Quartz 10% Opaques 2%, Biotite 1%, Muscovite trace, Epidote trace, Chlorite trace, Apatite trace, Zircon trace.

Textures: Subhedral, columnar plagioclase (1 - 5 mm) is intergrown with clumps of green, poikilitic hornblende (½ - 2+ mm), and enclosed minor interstitial quartz. Biotite and opaques are usually intergrown with hornblende. Plagioclase (andesine) has a complex internal zoning pattern and commonly has untwinned, possibly potassic rims. Plagioclase grains are slightly altered to muscovite plus epidote.

Comments: A quartz bearing hornblende diorite.

QH21572

Location Metric Grid - 7860 597226

Hand Specimen: Porphyritic microgranite of "Matchbox Creek Microgranite"

Mineralogy: Quartz 35%, K-feldspar 30%, Albite 30%, Muscovite 4%, Biotite 1%, Opaques trace, Rutile trace, Zircon trace, Sphene trace, Apatite trace.

Textures: Subhedral phenocrysts of microperthite K-feldspar (5%) plagioclase (5%) and ovoid patches of quartz (5%), all 2 - 10 mm occur in a matrix of anhedral quartz, K-feldspar and plagioclase. Feldspar phenocrysts are locally strained and partly recrystallised; quartz particles consist of anhedral, strained, sutured quartz with minor intergranular feldspar and may be recrystallised phenocrysts. Occasional ovoid patches of polycrystalline albite ± K-feldspar ± quartz may be cognate xenoliths.

Albite is extensively replaced by rather coarse poikilitic muscovite, which also occurs in sporadic intergranular flakes. Biotite occurs mainly in semi-continuous foliae associated with apatite, zircon and locally abundant sphene, rutile and opaques.

Matrix silicates are strongly strained and locally show subgrain development.

Comments: A strained and partly altered porphyritic microgranite.

<u>QH21573</u>

Location: Grid - 7950N 1700E

Hand Specimen: Footwall alteration zone.

Mineralogy: Quartz 60%, Muscovite 30%, Hematite 10%, Andalusite trace, Zircon trace.

Textures: Lenticles of generally fine-grained, anhedral quartz (50 - 600 μm, average about 200 μm) with intergranular, irregularly oriented flakes of muscovite are wrapped by anastomosing foliae of subparallel muscovite. These foliae, and fractures and quartz grain boundaries are heavily impregnated with botryoidal hematite, which also fills cavities after euhedral pyrite (originally 2 - 3%) and an unknown poikiloblastic mineral (less than 1%).

A trace of andalusite occurs in poikilitic intergrowth with quartz in one area of the slide, and this may be the precursor of the hematite pseudomorphed grains.

Comments: A quartz muscovite schist. See QH21575 for further comments.

QH 21574

Location: Grid - 8095N 1495E

Hand Specimen: Footwall alteration zone.

Mineralogy: Quartz 50%, Muscovite 35%, Hematite 10%, Porosity 5%

Textures: Bands of polyhedral quartz (average 200 μm) with abundant, subparallel intergranular muscovite are wrapped by foliae of subparallel muscovite. These have a well developed crenulation cleavage superimposed on the main rock cleavage. Grain boundaries are heavily impregnated with hematite, which also lines euhedral cavities after pyrite (originally about 5%) and pseudomorphs 2 - 5 mm poikiloblasts (originally about 2%).

Comments: A quartz muscovite schist. See QH21575 for further comments.

QH21575

Location: Grid - 9380N 1995E

Hand Specimen: Footwall alteration zone.

Mineralogy: Quartz 60%, Muscovite 39%, Hematite 1%, Kaolinite trace, Zircon trace.

Textures: Irregular bands and patches of irregular to polyhedral quartz (average grain size 200 µm) with subparallel intergranular muscovite, are wrapped by semi-continuous anastomosing foliae of subparallel muscovite flakes. The whole rock is weakly hematite-stained, and minor hematite occurs in subhedral-euhedral patches, probably after pyrite. Traces of kaolinite occur in irregular to polyhedral patches, possibly after original feldspar.

Comments: A quartz muscovite schist. This sample differs from QH21573 and QH21574 in that about 75% of the quartz present is crowded with inclusions of fine-grained (5 - 30 µm) muscovite, compared to about 10% in the previous two samples. However, none of these samples show any reliable indication of their pre-metamorphic state.

QH21576

Location: Metric Grid - 7860 614254

Hand Specimen: Microgranite of the "Matchbox Creek Microgranite" (see Figure 22)

Mineralogy Quartz 40%, K-feldspar 25%, Albite 30%, Muscovite 3%, Biotite 2%, Opaques trace, Rutile trace, Zircon trace, Clinozoisite trace.

Textures: Matrix. The matrix of the rock consists of interlocking anhedral to polyhedral quartz, albite and K-feldspar, with average grain size about 100 um. Albite is heavily clouded and commonly polysynthetically twinned; orthoclase is fresh or only slightly clouded, and untwinned or with weakly developed microcline type twinning. Minor muscovite and oxidised biotite occur as interstitial flakes, usually 50 - 100 µm long. Partly oxidised opaques and patches of leucoxene (after ilmenite?) occur sporadically. Accessory zircon is sharply euhedral and unzoned.

"Patches". About 10% of the rock consists of ovoid to lenticular patches (1 - 10 mm x ½ - 3 mm) of quartz (60%), albite (30%) and K-feldspar (10%). These are typically polycrystalline, but monomineralic or nearly so, and in the case of the feldspars, consist of interlocking polyhedral grains somewhat coarser than those in the matrix. Quartz grains in these patches are strongly strained and sutured. In the simpliest case of quartz patches, the constituent grains form two mutually intersecting lenticular sets of grains in optical near-continuity, and with c-axes more or less symmetrical about the elongation direction of the patch. Larger patches contain strongly strained cores with tails of elongate, sutured grains. These patches are interpreted as strongly flattened phenocrysts, in some cases originally glomeroporphyritic (indicated by intersecting quartz rich and feldspar rich patches) and probably embayed (suggested by patches/trains of, for example, albite in quartz patches). Secondary(?) muscovite is common in albite patches.

Comments: A sheared and recrystallized porphyritic and igneous rock, of rhyodacite composition. There is no internal evidence which would discriminate between an original intrusive, extrusive or tuffaceous parent.

The proportions of major minerals in QH21572 and QH21576 are similar, and the textural differences could be due to a finer initial grain size, and perhaps more extensive deformation and recrystallisation in the latter. However, the presence of apatite and abundance of sphene in QH21572, and differences in zircon morphology (euhedral-columnar in QH21576, granular and somewhat rounded in QH21572), suggest that these rocks are not part of the same intrusion, although they may be genetically related.

QH 9275

Location: Grid - 8950N 2080E

Hand Specimen: Banded quartzite from footwall silicified zone.

Medium grained quartz-muscovite schist. Abundant granular geothite accompanies the muscovite foliae.

This may have been fine grained pyrite. Scattered euhedral limonite porphroblasts represent crystals of pyrite in the unweathered rock. Minor jarosite occurs. Approximate composition is quartz 60%, muscovite 25%, iron oxides 15%.

QH9276

Location: Costean 1, Grid - 9030N 2162E

Hand Specimen: Koalinized ?sericitic ?tuff adjacent to lead gossan.

A koalinized welded crystal tuff. Abundant anhedral grains of quartz rest in a structureless yellow-brown matrix. Occasional rock fragments consist of fine to medium granular quartz and this material has a resorbed, partly fused appearance. The fragments could be quartzite or quartz-mica schist. One fragment appears to contain some staurolite.

QH9278

Location: Costean 2, Grid - 9000N 2107E

Hand Specimen: Silicified gossan (possibly a silicified collapse breccia fragment)

A very porous gossan showing a strongly layered structure under the microscope. It contains abundant iron oxides (goethite and limonite), large fragments of quartzite and numerous angular quartz grains possibly derived by breakdown of the quartzite. Large crystals of cerussite are developed lying parallel to the "schistosity". The ellipsoidal cerussite bodies are up to 3 mm x 5 mm size. interestingly, the cerussite has stained bright yellow with the sodium cobaltinitrite + HF stain for K-feldspar.

<u>QH9279</u>

Location: Costean 2, Grid - 9000N 2120E

Hand Specimen : Massive lead carbonate/sulphate (see Fig.53) (38.8% Pb, 337 g/t Ag).

The specimen consists mostly of fine to medium grained anhedral crystals of anglesite and this matrix encloses scattered anhedral quartz grains up to 0.3 mm size. Quartz only represents 10 - 15% of the rock and its derivation may be as for QH9278. No cerussite was found but small highly birefringent euhedral crystals of uniaxial +ve sign are cassiterite. The largest crystal noted was 0.3 mm across.

<u>QH9282</u>

Location; Discovery Outcrop, Grid - 9050N 2120

Hand Specimen: Massive lead carbonate/sulphate (see Fig 52). (57.6% Pb, 750 g/t Ag).

As for QH 9279. The cassiterite is present as subhedral to euhedral tabular and prismatic crystals up to 0.3 mm size.

<u>QH9283</u>

Location: Grid - 9400N 2000E

Hand Specimen: Quartz muscovite schist

Quartz, muscovite schist with euhedral cavities indicating original presence of scattered pyrite crystals. Grain size fairly even and about 0.15 mm.

<u>QH9284</u>

Location: Grid - 9040N 2010E

Hand Specimen: Quartz muscovite schist

Quartz, muscovite, biotite schist texturally very similiar to QH9283.

<u>QH9285</u>

Location: Grid - 9040N 2010E

Hand Specimen: Staurolite muscovite schist

A quartz, muscovite, biotite schist similar to QH 9283 and QH9284 but containing isolated porphyroblasts of sieved staurolite up to 2 mm x 5 mm size (see QH 9276 in reference to staurolite-bearing rock fragments in the tuff).

<u>QH9286</u>

Location: Grid - 9000N 2030E

Hand Specimen: Staurolite muscovite schist.

As above but the staurolite porphyroblasts are much larger (->1.5 mm x 8 mm) and occasionally encased by coarse grained selvedges of quartz, muscovite and biotite. All the schists described so far have a strong schistosity with ample evidence of directed stress having operated during metamorphism.

<u>QH9287</u>

Location: Grid - 9000N 2030E

Hand Specimen: Muscovite schist

A quartz, plagioclase (albite), muscovite, biotite metamorphic rock derived from a feldspathic quartz arenite. The rock contains about 15% vol. albite and 5% micas. The schistosity is weak despite the metamorphic grade.

<u>QH9288</u>

Location: Grid - 10525N 3135E

Hand Specimen: Upper Carboniferous flow banded rhyolite.

(?)Silicified welded tuff. Irregular flow textures and molded fragments are seen in thin section. No quartz or feldspar phenocrysts as seen in rhyolites were seen.

<u>QH9289</u>

Location: Grid 1040N 3340E

Hand Specimen: Upper Carboniferous rhyolitic ignimbrite

A welded tuff carrying lithic fragments as well as fragments of K-feldspar and quartz. The rock probably had rhyolitic origins.

QH9290

Location: Grid - 9000N 2400E

Hand Specimen: "Matchbox Creek Microgranite

Metamorphosed and schistose (gneissic) rock formed by metamorphism of a sodic microgranite. Scattered small patches of muscovite occur throughout the "stretched" plagioclase-quartz groundmass. Minor K-feldspar is present. Average grain size about 0.2 mm. Accessory minerals include biotite, magnetite, chlorite and iron oxide.

QH9291

Location: Grid - 9000N 2600E

Hand Specimen: "Matchbox Creek Microgranite"

Sinmiliar to QH9290 but containing more muscovite, biotite and K-feldspar. In places the rock develops a porphyritic texture. Sphene and magnetite are important accessory minerals.

QH9292

Location: Grid - 84595N 1053E

Hand Specimen: "Dry River Volcanics"

A metamorphosed and recrystallized (?)sodic rhyolite. The term "rhyodacite" is more acceptable because the rock has a fairly low K_2O content. The bulk of the rock (65%) consists of a microgranular aggregate of quartz and albite accompanied by schistose muscovite and biotite. In places aligned, attenuated wisps of muscovite and biotite thread the groundmass. This groundmass encloses numerous recrystallized quartz phenocrysts up to 4 mm size and there is no doubt about their volcanic origin. Some phenocrysts have become stretched and elliptical due to metamorphic stress. Isolated euhedra of magnetite stud the rock.

QH9293

Location: Grid - 8620N 1255E

Hand Specimen: "Dry River Volcanics"

Metamorphosed and recrystallized highly siliceous fragmental rock. Generally the rock is fine grained (<50 um) and composed of quartz and albite with minor biotite and muscovite. Originally the rock was a lapilli tuff (?rhyodacite) composed of angular volcanic fragments up to 3 or 4 cm size. These have been attenuated by shearing and the micas have developed a weak schistosity. The interfragmental spaces are occupied by slightly coarser grained quartz.

QH9294

Location: Grid - 8665N 1175E

Hand Specimen: "Dry River Volcanics"

Most probably a vitric crystal tuff related genetically to QH9293. Metamorphism is similar to QH9293 but the fragmental texture is missing. Occasional small areas of coarser grained quartz might represent recrystallized phenocrysts.

QH9295

Location: Grid - 8625N 1055E

Hand Specimen: "Dry River Volcanics"

Most probably a lapilli tuff of similar origin to QH9293. In this specimen the igneous phenocrysts of plagioclase are well preserved. Abundant biotite and minor muscovite show a schistose occurrence.

APPENDIX 2

BALCOOMA

MICROPROBE

ANALYSES

Table 1 : Analyses of staurolite and cordierite from Balcooma ore zone

(a) Partial analyses - location not specified.

Staurolite :

wt. % ZnO : 3.79, 3.80, 4.22, 3.87, 3.90, 4.14, 3.73, 3.86, 3.89

Cordierite :

wt. % FeO : 4.14, 4.09, 4.61, 4.28, 4.13, 4.25, 4.20

(b) RA 8666 - drillhole and depth not specified.

	1.	2.	3.	4.	5.	6.	7.
SiO_2	47.42	47.17	47.62	47.73	25.78	26.78	26.48
Al_2O_3	32.17	32.20	32.52	32.68	53.29	51.61	51.93
MgO	10.54	10.57	10.52	10.62	2.19	2.81	2.77
Na_2O	0.26	0.23	0.33	0.27	0.11	0.14	0.07
TiO_2	-	-	-	-	0.36	0.36	0.38
CaO	0.01	0.01	0.01	-	-	-	-
K_2O	-	0.01	-	-	-	-	0.01
ZnO	0.08	0.12	0.09	0.08	4.14	3.74	3.86
FeO	4.13	4.13	4.26	4.20	10.35	10.18	10.78
MnO	0.49	0.47	0.42	0.51	0.81	0.76	0.69
total	95.10	94.91	95.77	96.09	97.03	96.08	96.97

1 - 4 : cordierite

5 - 7 : staurolite

Table 2 : Analyses of minerals in RA 9969 (DDH 16A, 182.0 m)

	1.	2.	3.	4.	5.	6.	7.	8.
SiO_2	28.23	28.41	28.10	28.43	38.05	38.06	38.33	37.74
Al_2O_3	52.30	52.42	51.62	52.22	18.85	18.22	18.51	18.23
MgO	1.90	1.82	2.14	1.99	11.12	11.22	10.66	10.19
Na_2O	0.05	0.12	0.12	0.19	1.81	1.65	1.71	1.46
TiO_2	0.56	0.38	0.57	0.59	1.80	1.62	1.74	1.76
CaO	-	-	-	-	-	-	-	-
ZnO	0.04	-	0.02	0.02	-	0.01	-	-
FeO	14.55	14.49	14.92	14.45	20.04	20.74	19.96	20.37
MnO	0.31	0.25	0.27	0.26	0.06	0.08	0.06	0.09
F_2O	-	-	-	-	0.42	0.52	0.57	0.48
Cl_2O	-	-	-	-	0.09	0.07	0.08	0.09
K_2O	-	-	-	-	9.25	8.88	8.64	8.05
CuO	-	-	-	-	-	0.04	0.02	-
total	97.94	97.89	97.76	98.15	101.49	101.11	100.28	98.46

1 - 4 : staurolite

5 - 8 : biotite

Table 3 : Analyses of minerals in RA 9970 (DDH 16A, 175.0 m)

	1.	2.	3.	4.	5.	6.	7.	8.	9.
SiO_2	29.07	28.64	28.54	28.41	28.77	38.39	39.74	39.58	39.63
Al_2O_3	52.78	52.59	52.49	52.83	52.14	18.09	18.19	18.66	18.20
MgO	2.43	2.38	2.36	2.33	2.27	12.38	12.78	12.30	12.61
Na_2O	0.07	0.05	0.02	-	0.05	1.44	2.04	1.97	1.77
TiO_2	0.53	0.54	0.41	0.43	0.53	1.46	1.32	1.40	1.36
CaO	-	-	-	-	-	-	-	-	-
ZnO	0.22	0.20	0.20	0.23	0.16	0.02	0.02	-	0.01
FeO	13.57	13.89	14.22	13.99	13.83	18.42	17.02	17.65	17.96
MnO	0.24	0.32	0.21	0.24	0.19	-	0.06	0.01	0.04
F_2O	-	-	-	-	-	0.62	0.87	0.42	0.42
Cl_2O	-	-	-	-	-	0.10	0.09	0.10	0.07
K_2O	-	-	-	-	-	8.39	8.09	8.04	7.80
CuO	-	-	-	-	-	-	0.01	-	-
total	98.91	98.61	98.45	98.46	97.94	99.31	100.23	100.13	99.87

	10.	11.	12.
SiO_2	38.32	38.66	38.28
Al_2O_3	20.72	20.65	20.58
MgO	4.02	4.00	3.93
Na_2O	0.32	0.25	0.11
TiO_2	-	0.03	-
CaO	1.96	1.70	1.06
ZnO	0.05	0.06	0.07
FeO	30.74	30.89	31.81
MnO	4.01	4.34	4.79
total	100.64	100.58	100.63

1 - 5 : staurolite

6 - 9 : biotite

10 - 12 : garnet

Table 4 : Analyses of minerals in RA 9971 (DDH 16A, 174.0 m)

	1.	2.	3.	4.	5.	6.	7.	8.
SiO_2	26.83	27.74	27.43	49.34	48.70	37.85	37.72	37.34
Al_2O_3	52.90	52.63	53.43	32.58	33.04	20.70	20.63	20.66
MgO	2.37	2.51	2.45	9.32	9.13	4.67	4.48	4.58
Na_2O	0.06	0.02	0.05	0.21	0.28	0.28	0.18	0.34
TiO_2	0.53	0.40	0.59	-	-	0.02	0.01	0.01
CaO	-	-	-	-	-	1.97	1.83	1.80
ZnO	0.54	0.48	0.47	0.01	0.02	0.08	0.01	0.02
FeO	14.15	14.63	14.49	6.72	6.55	31.82	32.02	32.11
MnO	0.12	0.17	0.15	0.04	0.09	3.40	3.48	3.16
total	97.50	98.58	99.06	98.22	97.81	100.79	100.36	100.02

	9.	10.	11.	12.	13.
SiO_2	37.54	49.18	49.50	48.34	27.32
Al_2O_3	20.64	7.24	6.96	6.63	22.50
MgO	4.12	15.76	16.16	15.29	19.51
Na_2O	0.15	3.89	3.65	2.92	0.07
TiO_2	-	0.05	0.04	0.06	0.06
CaO	1.97	0.23	0.20	0.26	-
ZnO	-	0.10	-	0.07	0.04
FeO	32.36	23.95	22.24	24.13	18.27
MnO	3.07	0.58	0.60	0.62	0.01
F_2O					-
Cl_2O					-
K_2O					-
CuO					0.04
total	99.85	100.98	99.35	98.32	87.82

1 - 3 : Staurolite
4 - 5 : Cordierite
6 - 9 : Garnet
10 - 12 : Anthophyllite
13 : Chlorite

Table 5 : Analyses of minerals in RA 9972 (DDH 16A, 173.2 m)

	1.	2.	3.	4.	5.	6.	7.	8.
SiO_2	27.29	27.85	28.76	28.17	49.96	50.01	50.49	50.78
Al_2O_3	51.66	51.84	51.99	51.99	32.15	31.84	32.14	32.35
MgO	2.73	2.76	2.80	2.77	9.67	9.50	9.45	9.40
Na_2O	0.07	0.05	0.08	0.08	0.13	0.16	0.11	0.12
TiO_2	0.46	0.46	0.47	0.38	-	-	0.01	0.01
CaO	-	-	-	-	-	-	0.01	-
ZnO	0.65	0.63	0.61	0.50	-	0.04	-	-
FeO	13.52	13.59	13.57	13.66	5.60	5.87	5.77	6.26
MnO	0.13	0.23	0.18	0.16	0.10	0.11	0.08	0.09
total	96.51	97.41	98.46	97.71	97.61	97.53	98.06	99.01

	9.	10.	11.	12.	13.	14.	15.
SiO_2	38.98	38.81	38.50	26.91	27.01	26.88	26.83
Al_2O_3	20.58	20.81	20.89	22.22	21.36	22.74	23.68
MgO	4.08	4.24	4.06	19.84	18.75	19.41	20.24
Na_2O	0.10	0.11	0.05	0.13	0.30	0.07	0.05
TiO_2	0.04	0.01	0.03	0.06	0.06	0.05	0.05
CaO	1.98	1.58	1.59	-	-	-	-
ZnO	0.06	-	-	0.06	0.01	0.02	0.08
FeO	28.90	29.66	29.65	18.86	20.61	18.22	17.93
MnO	5.69	5.30	5.29	0.12	0.16	0.06	0.05
F_2O				0.23	0.09	0.27	0.09
Cl_2O				0.04	0.07	0.05	0.02
K_2O				0.04	0.04	-	-
CuO				0.04	0.02	0.04	0.06
total	100.41	100.52	100.06	88.55	88.48	87.81	89.08

1 - 4 : staurolite
5 - 8 : cordierite
9 - 11 : garnet
12 - 15 : chlorite

Table 6 : Analyses of detrital staurolite from Matchbox Creek

	1.	2.	3.
SiO_2	26.76	26.01	26.35
Al_2O_3	53.74	53.56	53.62
MgO	2.33	2.24	2.31
TiO_2	0.52	0.71	0.60
CaO	-	-	-
ZnO	0.10	0.12	0.07
FeO	13.85	14.60	14.22
MnO	0.43	0.47	0.39
total	97.73	97.71	97.56


8400N
8600N
8800N
9000N
9200N
9400N
9600N
9800N
10000N
1700E
1900E
2100E
2300E
2400E
very coarse staurolite porphyroblasts
chloritic and siliceous
10 - in places
chloritic and siliceous in places
siliceous
A
B
C
D
DDH23
DDH24
DDH12
DDH32
DDH35A
DDH5
DDH1
DDH3
DDH2
DDH2A
DDH2B
DDH39
DDH31
DDH 16,16A
DDH9A
DDH U840
Laterite
Microgranite
Gossan
Quartz Feldspar Porphyry
Chlorite Schist, Chlorite Quartz Schist ± Magnetite, Garnet, Cordierite, Staurolite
Staurolite Rich Metasediments ± Andalusite Some Siliceous Weakly Chloritic Areas
Quartzite, Quartz Muscovite Schist ± Andalusite Gahnite Rich Areas
Staurolite Poor Metasediments ± Andalusite ("Greywacke Sequence")
Metavolcanics And Metasediments
Stream Channel
Geological Contact
Fold Axis
Fault
Drill Hole
Strike and Dip of Bedding
Strike and Dip of Foliation
Strike and Dip of Crenulation Foliation
Plunge of Crenulation Lineation
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N (mag)
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2000E
2300E
9000N
500RL
D
C
A
2000E
2300E
8900N
Geological Contact
Fold Axis
Fault
Drill Hole Trace
Drill Hole End, Point of Entry/Leaving Section
Facing Relative to Hole Direction
Microgranite
Gossan, Collapse Breccia, Secondary Copper
Massive Sulphides (Copper)
Massive Sulphides (Zinc/Lead/Copper)
Quartz Feldspar Porphyry
Chlorite Schist, Chlorite Quartz Schist
± Magnetite, Garnet, Cordierite, Staurolite
Staurolite Rich Metasediments ± Andalusite
Some Siliceous Weakly Chloritic Areas
Quartzite, Quartz Muscovite Schist
± Andalusite, Gahnite
Staurolite Poor Metasediments ± Andalusite
("Greywacke Sequence")
Metavolcanics And Metasediments
REVISIONS
No.
BY
REVISION
APPROVED
GEOLOGY
SCALE
1:2000
DESIGNED
K.J.H
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K.J.H
CHECKED
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BALCOOMA
GEOLOGICAL SECTIONS
REVISION

Figure 29.