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Received Answered - 2 FEB 1982				E & IL
DEPT. OF MINES REF. No 865/82				

- 2 FEB 1982

REPORT ON WORK COMPLETED ON EXPLORATION LICENCE 19/78 WEDLBOROUGH DURING THE SIX MONTH PERIOD ENDING FEBRUARY 9, 1982

OPEN FILE

DISTRIBUTION:

Department of Mines - Tasmania
Aberfoyle Exploration - Hawthorn
" " - Burnie

COMPILED BY: J. R. SISE
PROJECT GEOLOGIST
TASMANIA.

January, 1982.

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837002

CONTENTS

LIST OF PLATES

INTRODUCTION

Exploration Licence 19/78, located in north-east Tasmania near Weldborough, was acquired with a view to locating economic greisen-style tin mineralisation in the Blue Tier Batholith. (Plate WELD 2)

Aberfoyle report for the year ended August 9, 1980 (J. R. Taylor) describes the regional geology of the area and the objectives in entering the licence.

Details of a limited drilling programme centred on the old Cream Creek workings are described in the progress report for the six months ending February 9, 1981 (R. M. Joyce). Although the drilling had to be abandoned due to the unsuitability of the rig, some geological information was gained and the recommendation was made that further detailed geological mapping and rock chip sampling for trace element geochemistry be undertaken prior to any further sub-surface evaluation by drilling.

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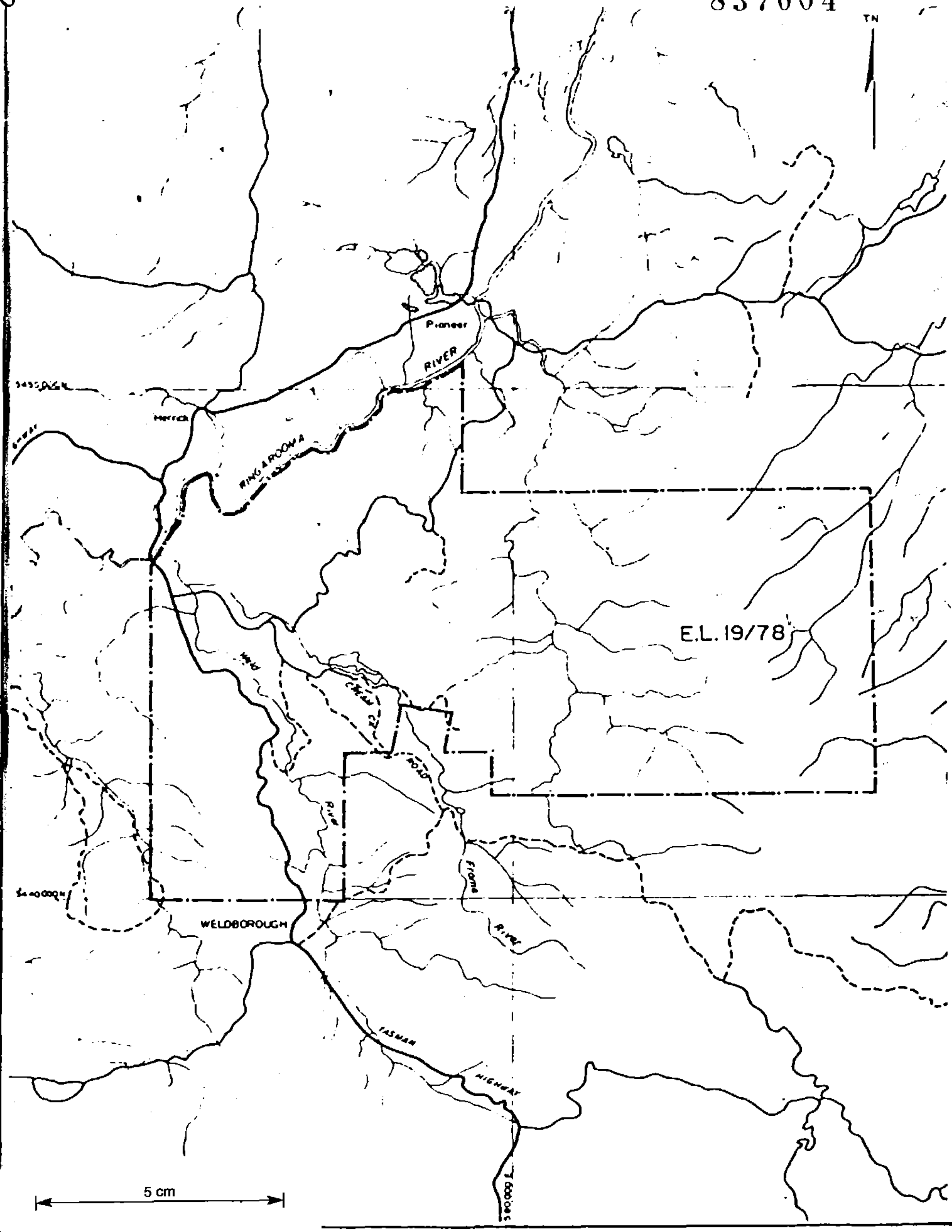

Aberfoyle Exploration Pty Ltd

Drawn: R J E	NORTH EAST TASMANIA	Location code
Traced	WELDBOROUGH E.L.19/78	Date MAY, 1981
Checked	Locality Plan	Scale 1:100,000
Revised by / Date		Plate No WELD 2

WORK COMPLETED IN PERIOD UNDER REVIEW

Work during the past six months culminated with the completion and submission to the University of Monash of a thesis by R. J. Simmons based on field work in E.L. 19/78, Weldborough which was financially and technically supported by Aberfoyle Exploration. The title of the 108 page thesis was 'Alteration and tin mineralisation in the upper Devonian granitoids of north eastern Tasmania' and earned R. J. Simmons an honours degree.

Copyright restrictions preclude the presentation of the thesis to the Department of Mines to support activities on the licences. A brief summary with plans follows:

Thesis now submitted as Appendix 1, Volume II of this report
25-5-82.

1. GRANITES

a) TEMPORAL RELATIONSHIPS (PLATE WELD 12)

Porphyritic Biotite Granite (dbapq) is known to be intruded by Porphyritic Biotite Adamellite (dbapc). These two variants are inferred to be intruded by an Equigranular Biotite Granite (dbae - 'tin granite').

All are crosscut by leucocratic dykes.

b) STRUCTURE (PLATE WELD 13)

The cross-sections show that contacts between dbapq and dbapc are steep (inferred from relationship to contours).

WORK COMPLETED IN
PERIOD UNDER REVIEW ... CONT'D

1. GRANITES

b) STRUCTURE ... CONT'D

Contacts between dbapc and dbae roughly follow contours and are assumed to be sub-horizontal in the east of the area. Immediately south and west of the Cream Creek area this contact is steep (cross cuts contours) and is inferred to represent the contact between dbapc and the flanks of a topographic 'high' in the dbae sheet.

2. MINERALISATION (PLATE WELD 3)

Significant alteration/mineralisation seems to be located around the Cream Creek area and to the north of it along and around Cross Creek Road.

Groves (1972) notes that greisenization at the Anchor Mine is related to highs in the undulation upper dbapc/dbea contact, and this may be what is happening here. The host for the Cross Creek Road greisen alteration is fine to medium grained dbapc and not the 'tin granite' (dbae).

This suggests that the dbapc/dbae contact may be at a relatively shallow depth in this area, the 'tin granite' greisenizing and greisen veining the overlying rocks (dbapc). If this is the case, it is possible that a greisen sheet such as at the Anchor Mine may occur in the area within or capping a ridge of dbae.

WORK COMPLETED IN
PERIOD UNDER REVIEW ... CONT'D

It was planned to complete two percussion drill holes during the six months under review to test the greisen occurrence at the Cross Creek Road. This work was due to be undertaken in conjunction with percussion drilling at nearby Rattler Hill. Due to the lease holders refuting the agreement over Rattler Hill the percussion drilling programme in both areas was postponed.

WORK PROPOSED 12 MONTHS TO FEBRUARY 9, 1983

Exploration will continue with a view to locating tin mineralisation in greisen sheets of the 'Anchor-type' within the Blue Tier Batholith.

1. It is proposed to explore the northern part of the Exploration Licence by geological mapping and regional geochemistry.

2. Percussion/diamond drilling is planned to test the potentially mineralised and greisenised "tin granite" in the Cross Creek and Cream Creek areas.

3. A joint venture partner is being sought to help fund the 1982-1983 programme. Several major Mining Companies have already expressed interest. One has made a field visit and is currently reviewing data.

J. R. SISE
PROJECT GEOLOGIST - TASMANIA.

ABERFOYLE EXPLORATION PTY. LTD.

SUMMARY OF EXPENDITURE

PROJECT : WELDBOROUGH

COST GROUP	HALF YEAR TO 1/6/81	HALF YEAR TO 17/11/81	TOTAL 1981 YEAR	PROJECT TOTAL
SUNDRIES	-	64	64	190
GEOLOGY	6,889	3,457	10,346	19,690
GEOCHEMISTRY	130	551	681	1,297
PERCUSSION DRILLING	-	-	-	7,944
ASSAYS	-	-	-	60
TENURE	264	680	944	1,394
SUB TOTAL	7,283	4,752	12,035	30,575
ADMINISTRATION	1,093	712	1,805	4,600
TOTAL	8,376	5,464	13,840	35,175

Prepared:
Checked :

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REFERENCES

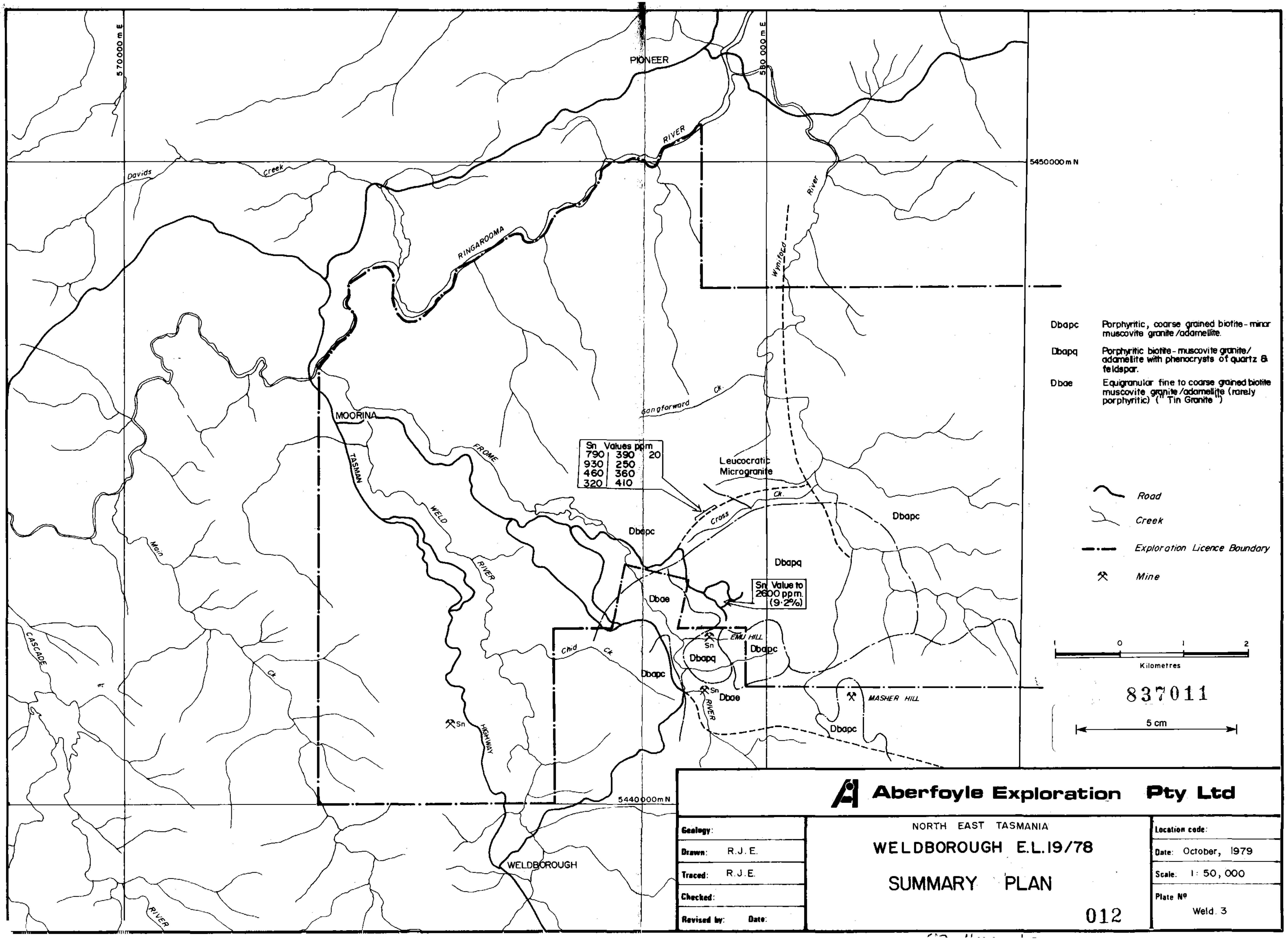
YOUNG, C.H.	1979	Economic Potential and Geochemical Exploration of the Blue Tier Batholith.
TAYLOR, J.R.	1980	Aberfoyle Exploration Pty. Ltd., Weldborough E.L. 19/78, Report for the year ended August 9, 1980.
JOYCE, R.M.	1981	Aberfoyle Exploration Pty. Ltd., Weldborough E.L. 19/78. Progress Report for the six months February 9, 1981. [TCR 81-1511]
SISE, J. R.	1981	Aberfoyle Exploration Pty. Ltd., Statement of work completed on E.L. 19/78 (Weldborough) during the six months period ending August 9, 1981. (one page statement – no specific details)

SIGNED: ________________

J. R. SISE,
PROJECT GEOLOGIST

ENDORSED: ________________

for C. H. YOUNG,
DISTRICT MANAGER



Aberfoyle Exploration Pty Ltd

Geology:	NORTH EAST TASMANIA	Location code:
Drawn: R.J.E.	WELDBOROUGH E.L.19/78	Date: October, 1979
Traced: R.J.E.	SUMMARY PLAN	Scale: 1: 50,000
Checked:		Plate Nº Weld. 3
Revised by: Date:	012	

CROSS CREEK AREA
SPINKS AREA
CREAM CREEK PROSPECT
OLD MILL SITE
JUBILEE HILL
EMU HILL
MASHER HILL
Leucocratic Microgranite
LEGEND
Dbapq Porphyritic biotite (cord) granite with fine grained groundmass, porphyritic in rounded quartz, K-feldspar(with<2% phenocrysts of plagioclase & cordierite).
Dbapc Porphyritic biotite adamellite with med. grained groundmass of quartz, K-feldspar, plagioclase, biotite with phenocrysts of euhedral K-feldspar.
Dbae Medium & coarse grained, equigranular biotite(musc.?) granite. (rarely porphyritic in K'feldspar see text)
Porphyritic biotite adamellite with fine grained groundmass & K-f'spar phenocryst content <15 %
Porphyritic biotite adamellite with fine grained groundmass & K-f'spar phenocryst content ≫15 %
Leucogranite (aplite - microgranite)
Leucogranite(aplite - microgranite) with miarolytic cavities & irreg. pegmatite patches
Outcrop
Float
Geological Boundary (inferred)
Geological Boundary Textural only (inferred
Sluiced/Open cut mine area
Quartz sericite 'greisen
Quartz veining with assoc. sericite alt. envelope
Muscovite/sericite veins
Minor quartz veining with assoc. biotite chloritization
Leucocratic dyke, vertically dipping, 20° E
j Jointing orientation
s Sericite vein orientation
q Quartz vein orientation
Creek
Road
Contour
5 cm
Base sheet and contours enlarged from 1:50,000 Tasmanian Mines Dept Map, Ringarooma
Index to adjoining sheets
837012
Aberfoyle Exploration Pty Ltd
Geology: R.J.S
Drawn:
Traced: J.L.R
Checked:
Revised by: Date:
NORTH EAST TASMANIA
WELDBOROUGH E.L. 19/78
GEOLOGICAL SUMMARY PLAN
014
Location code:
Date: Jan. 1981
Scale: 1:10,000
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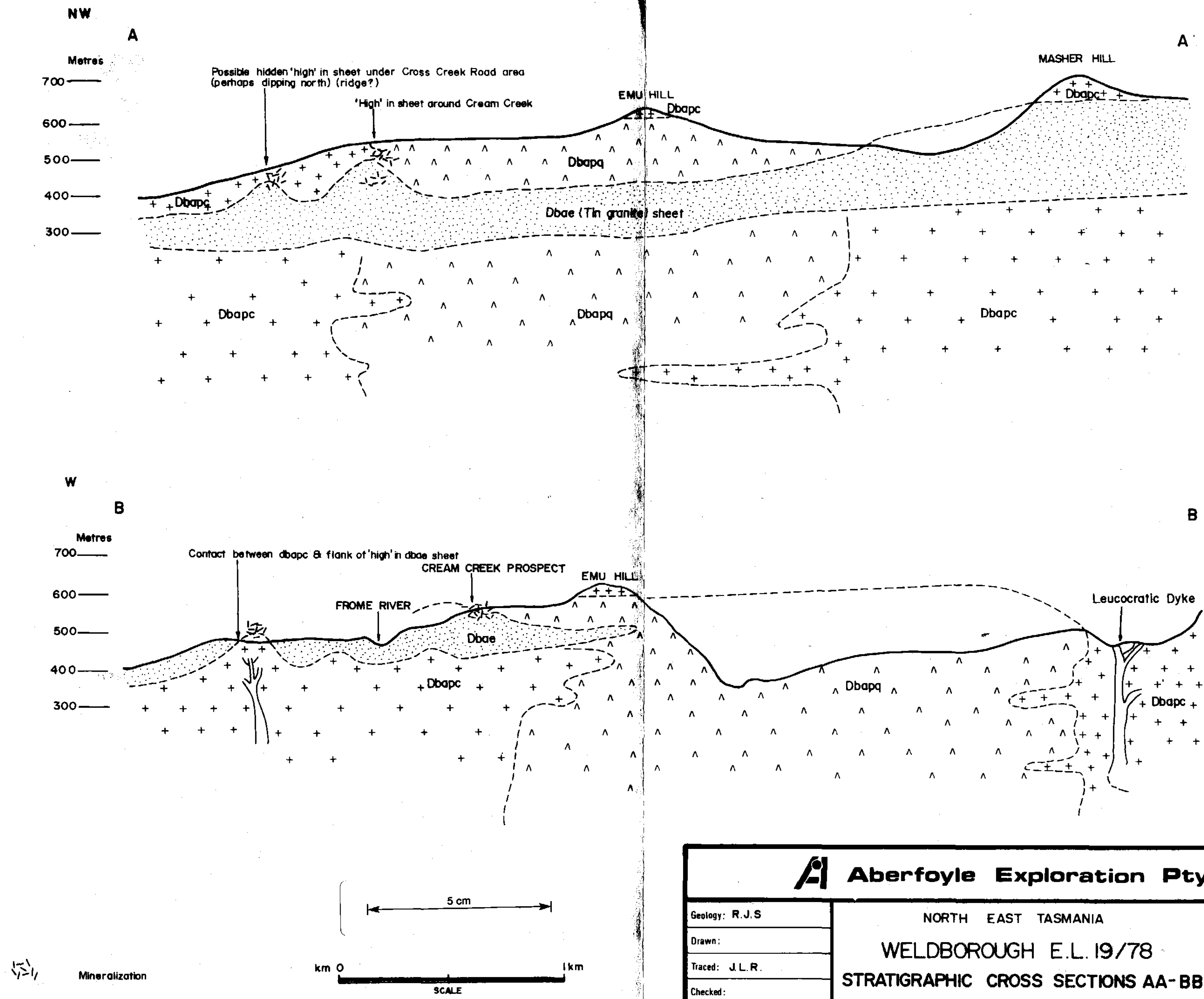
82-1693 1/2



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Aberfoyle Exploration Pty Ltd

Geology: R.J.S	NORTH EAST TASMANIA	Location code:
Drawn:	WELDBOROUGH E.L. 19/78	Date: Sept 1981
Traced: J.L.R.	STRATIGRAPHIC CROSS SECTIONS AA-BB	Scale: As shown
Checked:	(REFER PLATE WELD. 12) 013	Plate No WELD. 13
Revised by: Date:		

ALTERATION AND TIN MINERALIZATION IN UPPER DEVONIAN GRANITOIDS, NORTHEASTERN TASMANIA

R. J. Simmons

THIS THESIS RETAINS NO SPECIAL = CONFIDENTIAL STATUS SINCE THE RELINQUISHMENT OF EL 19/78. 82.

D.J.J.
6-12-82.

See following p. correspondence for [illegible]
P.C.

Thesis submitted in part fulfilment of
Bachelor of Science (Hons.) Degree
Department of Earth Sciences
Monash University

1981

Abertfoyle Exploration Pty Ltd

144 Camberwell Road, Hawthorn East, Victoria 3123 Australia
Telephone: (03) 82 2226 Telex: AA38646

837015

P.O. Box 952,
BURNIE. 7320

14th May, 1982

Mr. H. Murchie,
Director of Mines,
Department of Mines,
G.P.O. Box 124B,
HOBART. Tas. 7001

D of M	A.O.	C.G.	E.O.	D.S.M.E
Received Answered	18 MAY 1982			Registrar
DEPT. OF MINES REF. No.				E & IL

Dear Sir,

Re: Exploration Licence 19/78 - Weldborough

I refer to your letter of 30th April, 1982, your ref: TCR 82-1693, requesting further information on the research investigation by R. J. Simmons.

Please find enclosed a complete copy of the Thesis "Alteration and Tin Mineralisation in the Upper Devonian Granitoids of North-Eastern Tasmania". I understand that as part of a progress report on exploration activity, the five year confidentiality restriction will apply. Similarly, should any use of Simmon's data be contemplated, that his permission be sought or his work referenced in the usual manner.

Yours faithfully,
ABERFOYLE EXPLORATION PTY. LTD.,

J. R. SISE,
PROJECT GEOLOGIST - TASMANIA.

Copy: P.L.F. Collins - Dept. of Mines
R.A. Oxenford - Aberfoyle

Enc.

JS:NB

H.4 YYY2
R.S.
~~R.A.O.~~

NOTE:- ALL CORRESPONDENCE TO BE ADDRESSED TO THE DIRECTOR OF MINES

837016

Our ref: TCR 82-16

TASMANIA

DEPARTMENT OF MINES

RECEIVED - 7 MAY 1982

TELEPHONE: 30 8033

G.P.O. BOX 124 B
HOBART
TASMANIA 7001

Officer: P.L.F. Collins

Telephone: 3259

30 APR 1982

Mr R.A. Oxenford,
Exploration Services Superintendent,
Aberfoyle Exploration Pty. Limited,
144 Camberwell Road,
HAWTHORN EAST,
Victoria. 3123

Dear Sir,

Exploration Licence 19/78 (Weldborough)

I refer to your progress report entitled "Report on Work Completed on Exploration Licence 19/78 Weldborough During the Six Month Period Ending February 9, 1982" by J.R. Sise (January 1982).

The report provides a brief summary of work undertaken for an honours degree by R.J. Simmons at Monash University; the thesis entitled "Alteration and Tin Mineralisation in the Upper Devonian Granitoids of North-Eastern Tasmania". This research investigation by Simmons constitutes most of the exploration activity claimed on the licence during the preceding twelve months. The summary of the thesis provided in the abovementioned report is not adequate as a complete record of all investigations undertaken during the term of the licence. For example details of granite petrology and analytical work are not provided. It is therefore necessary for you to provide a complete copy of the results of Simmon's research. Copyright restrictions do not preclude presentation of a thesis in support of exploration activity. Copies of theses previously have been presented to the Department, possibly by prior arrangement with the appropriate University.

Although theses are examined and published at Universities, when submitted as part of a progress report on exploration activity the five year confidentiality restriction is still applied by the Department.

Copy to be made available as requested with covering letter reaffirming confidentiality and copyright.

Yours faithfully,

(H. Murchie)
DIRECTOR OF MINES

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ABSTRACT

The Blue Tier Batholith consists dominantly of granodiorites, adamellites and granites. The granodiorites (I-types) are genetically distinct from the other granitoids (S-types).

Increasing fractionation of the S-type granitoids from porphyritic biotite adamellite to porphyritic biotite cordierite granite to equigranular biotite granite is reflected in their Rb, Sr, Ba and F trace element variations. Ba and Sr are heavily depleted in the most fractionated rocks indicating that pagioclase and K-feldspar are accreting as cumulate phases.

Enrichment of tin in the most heavily fractionated equigranular biotite granite has been noted elsewhere in the Batholith and in the absence of data to the contrary this granite is considered the source of mineralization in the area. A magmatic hydrothermal fluid rich in tin, flourine and other incompatible elements separated from the equigranular biotite granite, and coalesced during its ascent to the roof of the granite sheet. Meteoric fluid introduced along the granite contacts with other granitoids significantly added to the fluid circulation and eventually produced the fractured controlled greisen style orebodies in the area.

DECLARATION

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university and, to the best of my knowledge and belief, contains no material previously published or written by another person, except when due reference is made in the test of the thesis.

R J Simmons

R. J. Simmons

ACKNOWLEDGEMENTS

The author gratefully acknowledges the following assistance received throughout the year.

Thanks to my supervisors, Dr. Mark Bloom and Mr. Vic Wall for helpful discussion throughout the year, and to Mr. Arthur Day and Mr. John Clemens for their assistance.

My thanks also to the technical staff of the Earth Science Department, particularly Pat McCall and Alf Hohmann, for providing the trace element data, and for assistance with EMP analyses.

Many thanks to the staff of Aberfoyle Exploration, in particular Mr. C. Young, Mr. R. Elson, Mr. J. Sise and Mr. M. Joyce, for remaining enthusiastic through thick and thin. And to the Aberfoyle Group for financial and technical support throughout the year.

I would also like to acknowledge Mrs. Ethni and Miss Cathy Fella, and Mr. John Dargin and many others for their tremendous hospitality and help throughout my stay in Weldborough.

And last but not least thanks to my parents for their financial and moral support throughout the last few years and to my mother for typing my thesis.

CHAPTER 1

INTRODUCTION

1.1 LOCATION AND FIELD WORK

This study is the result of geological mapping of a part of the Blue Tier Batholith in Northeastern Tasmania (Figure 1.1). Mapping was carried out over a ten week period from February to May, 1981, in an area 5 km northeast of Weldborough with occasional visits to the nearby Mt. Paris Mass and Anchor Mine (Figure 1.2) in order to examine known cassiterite bearing greisens.

Outcrop along the major creeks, rivers and hills within the project area is variable but generally good. Outcrop along the smaller creeks, along logging tracks and within the Myrtle Forest, however, is usually poor. Where good exposure is found it is often obscured by a heavy overgrowth of vegetation.

Access in the vicinity of old mine workings is excellent, and many of the original tracks have been extended by logging activity. Toward the Blue Tier, however, no tracks or logging roads exist owing to the steepening terrain.

1.2 PREVIOUS WORK

The Weldborough-Gladstone region has been mined for tin since the late 19th century when placar cassiterite deposits were discovered. Often these revealed the bedrock sources which were themselves consequently worked (Miller, 1979). As a result of this mineralisation, the geology of the region and the mines have been subject to numerous Mines Department reports since the 1890's (Montgomery, 1893; Nye, 1929; Thomas, 1943)

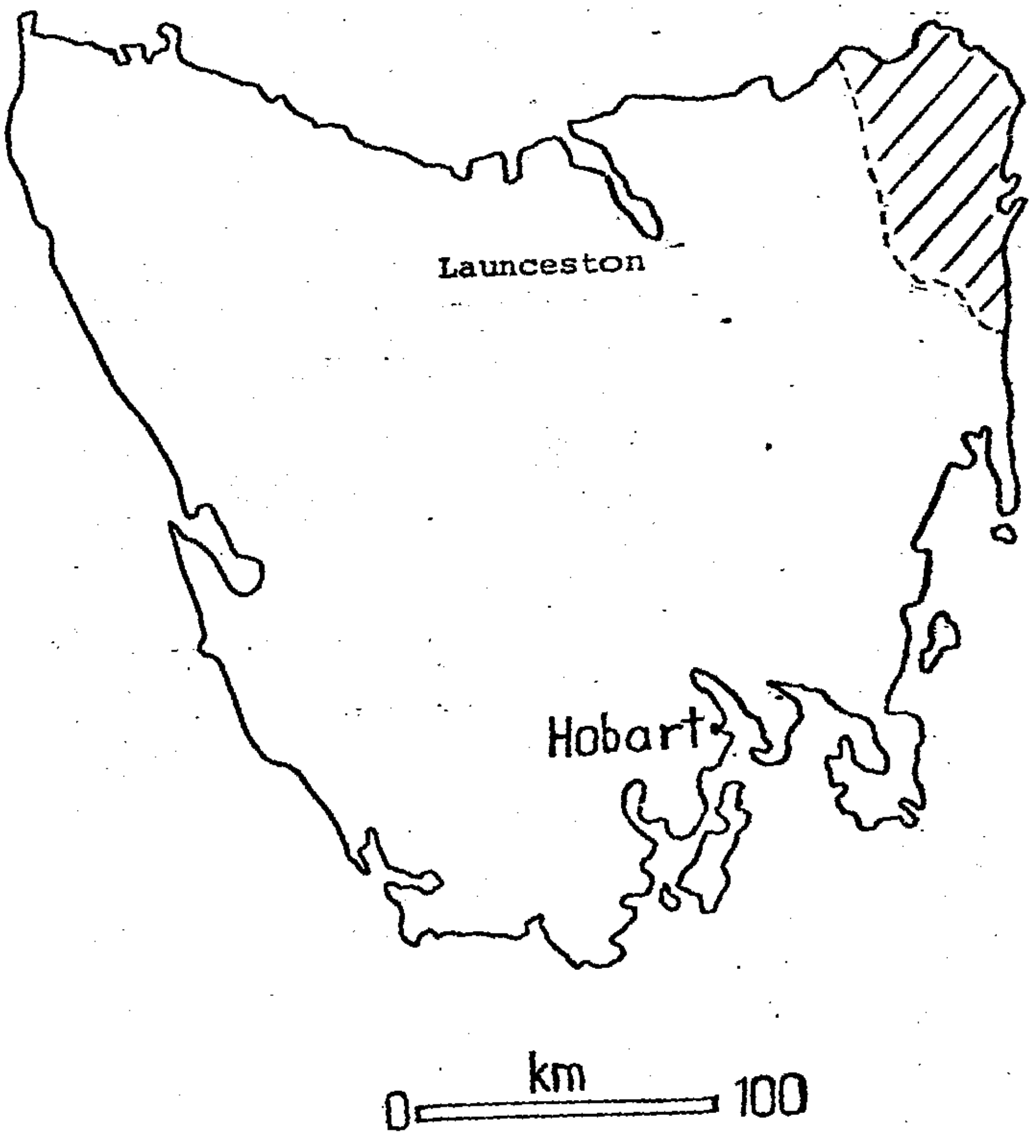


FIGURE 1.1

– Blue Tier Batholith

and in more recent times to company reports based on the results of their exploration programmes.

The first detailed regional study of the granitoids of the Blue Tier Batholith was carried out by Groves (1971, 1972), resulting in the delineation of eighteen distinct granitoid bodies. A detailed examination of the tin mineralisation at the Anchor Mine was carried out by Groves and Taylor (1973). The most recent Mines Department report is the Geological Survey Bulletin 55 by Groves, Cocker and Jennings (1977), which covers the petrology, geochemistry and age relationships of the Blue Tier Batholith granitoids.

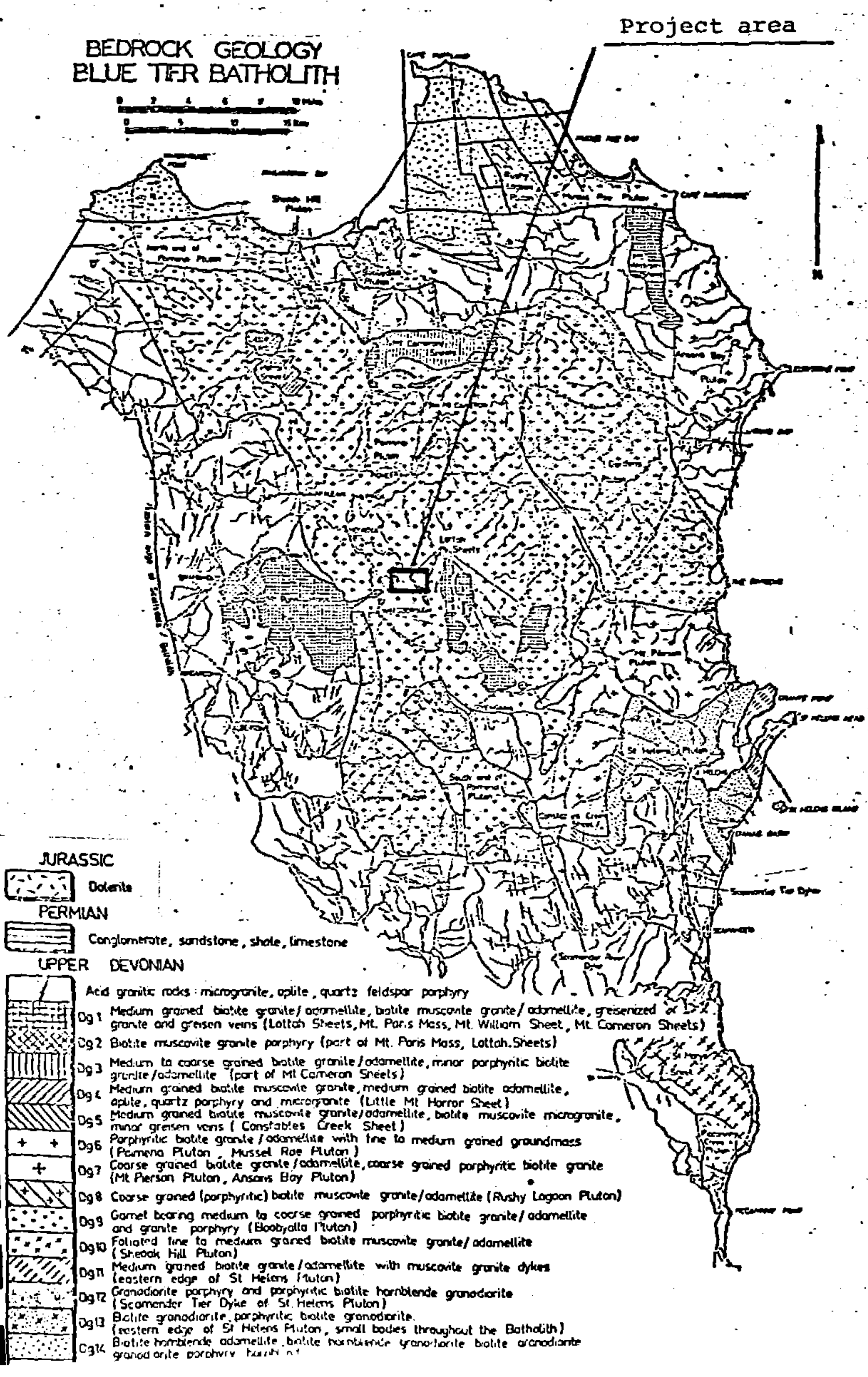
Groves and McCarthy (1978) use the Blue Tier Batholith geology in part as the basis for a general model of tin mineralisation. This model is further supported by detailed trace element data and interpretation (McCarthy and Groves, 1979). The most recent geological map of the area available is the 1:50000 Ringarooma Sheet (published 1977, Groves et al).

1.3 REGIONAL GEOLOGY

The Blue Tier Batholith outcrops over approximately 2000 square kilometres in northeastern Tasmania. It forms part of the southern extent of the Tasman orogenic zone along with the Ben Lomond Granite and the oldest exposed rocks in the region, the Silurian-Upper Devonian Mathinna Beds. The Mathinna Beds consist of interbedded quartz greywhackes and shales representing a turbidite sequence of unknown thickness. Deformation of the Mathinna Sediments during the Tabberabberan Orogeny resulted in the development of symmetrical, angular folds with steep north-northwest trending axial planes.

5 cm

FIGURE 1.2: REGIONAL GEOLOGY



During the Upper Devonian-Lower Carboniferrous, granitoids of the Blue Tier Batholith intruded the Mathinna Beds, truncating folds and producing narrow contact aureoles indicative of a relatively shallow emplacement depth. Granitoids dominantly consist of granodiorites, adamellites and granites with eighteen distinct intrusions mapped by Groves (1977) (Figure 1.2).

Where relative age relationships are found in the field, granodiorites are intruded by adamellites (e.g., the Poimena Pluton intrudes the Pyngana Pluton, and the Mt. Pierson Pluton intrudes the Gardens Pluton). Relative age relationships between the adamellite intrusions are unclear, but Groves (1977) suggests a possible gradational contact between the Poimena and Mt. Pierson plutons. Granitic rocks (Lottah Sheets, Mt. Paris Mass, Little Mt. Horrow Sheet, Mt. Cameron Sheets, Mt. William Sheets) are intrusive into adamellite plutons with which they are in contact (Groves, 1977). Many of these granite intrusions are considered by Groves (1971, 1972, 1973) to be emplaced as relatively flat lying sheets (as suggested by their names) within the adamellites. Screens of Mathinna Beds occur between the Pyngana Pluton and the Mt. Paris Mass and between the Gardens and Poimena Plutons. A roof pendant of Mathinna sediments outcrops on the Mt. Paris Mass.

To the south and west of the batholith, flat-lying Permian sediments crop out and consist of arkoses and quartz conglomerates with interbedded sandstones and siltstones higher in the sequence. Permian sediments are faulted against or disconformably overlie granitoids, Jurassic dolerites or Mathinna Beds. Minor Triassic freshwater sediments and coal outcrop in the St. Mary's area.

The Jurassic was marked by the intrusion of dolerites. They appear to intrude Permian sediments, but may be faulted against the granitoids. Jurassic dolerites crop out to the north and west of the batholith.

Sand, gravels and clays of Tertiary age are well represented throughout the region, and vary from well sorted beach deposits near St. Helens to Tertiary river channel deposits or bedrock depression infill in western and northern and eastern areas. Tertiary sediments are an important source of alluvial tin as deep lead type deposits. Tertiary basalt crops out sporadically throughout the region; it is represented by alkali olivene basalt, nephelene basanites, and tholeiitic olivene basalt.

1.4 AIMS OF THIS STUDY

The primary aims of the project are:

a) To map the granitoid variants within the area in order to determine their spatial and age relationships.

b) To study the nature of the alteration in the area in terms of:

   i) the types of alteration present;

   ii) its spatial relationship to known mineralised areas and granites.

c) To combine the data collected above with trace element data to test the previous model developed by Groves and McCarthy (1979), for the formation of the tin deposits in the area.

CHAPTER 2

PART A: PETROLOGY OF GRANITOIDS AND THEIR INCLUSIONS

2.1 INTRODUCTION

Three major granitoid variants with associated leucocratic dyke material have been identified in the project area. Each of these intrusions can be distinguished on the basis of textures, mineralogy and major and trace-element geochemistry.

Cropping out to the northeast, north, northwest and around Masher Hill and Emu Hill (Map Sheet 1), within the project area, is porphyritic biotite adamellite which represents part of the southern Poimena Pluton. To the south of the area a part of the eastern most Lottah sheet intrusion, an equigranular biotite granite is exposed. Both these variants surround a porphyritic biotite cordierite granite intrusion which crops out as an elliptical feature over approximately 10 square kilometres central to the area. Within this granite irregular coarse grained patches of pegmatitic material up to 0.5 metres across, occasionally crops out. A small outcrop of quartz-feldspar porphory on the Frome River (Map Sheet 1) is the only evidence of subvolcanic activity. Around this area also the equigranular biotite granite grades into a porphyritic rock (see Section 2.2.2). Mafic igneous and metamorphic inclusions rarely occur within the porphyritic biotite adamellite.

2.2 GRANITOID VARIANTS

2.2.1 Porphyritic Biotite Cordierite Granite

Hand Specimen

Phenocrysts of euhedral K-feldspar, rounded quartz, euhedral plagioclase and subhedral-euhedral relict cordierite are surrounded by a fine grained red or white granular groundmass. Plagioclase phenocrysts are altered to equant patches of green sericite while cordierites are now ovoid patches of reddish yellow clay.

Thin Section

Phenocryst phases include orthoclase (5-50 percent) usually approximately 20 percent), quartz (10-20 percent, plagioclase (1-3 percent) and sericite psuedomorphs after cordierite (<1 percent).

Microperthitic, dominantly euhedral (minor subhedral) orthoclase phenocrysts 0.4 to 3.5 cm long occasionally contain inclusions of unzoned plagioclase up to 1 mm in length and rarely euhedral, unaltered biotite up to 0.5 mm. Carlsbad twinning is a common feature of this crystaline phase which frequently exhibites an overgrowth of quartz and orthoclase in graphic intergrowth (Figure 2.1).

Quartz phenocrysts vary in size from approximately 1 cm in diameter down to groundmass size (0.5 - 1 mm). They are often rounded to irregular in outline, occasionally subhedral in form. Fractures and embayment by the groundmass are common features. Extinction is moderately undulose and inclusions of K-feldspar and unaltered biotite occur rarely.

Subhedral-euhedral plagioclase up to 1 cm is highly sericitised. The cores are almost completely altered, making a compositional estimation difficult. A tentative estimation using the Michel-Levy method on one phenocryst is An_{40} as a core composition, while the outer zones vary from An_{31} to An_{16}. Plagioclase phenocrysts may also be partially rimmed by a quartz-orthoclase graphic intergrowth.

Psuedomorphs after cordierites are recognised as an ovoid to hexagonal patch of yellow, iron stained clay or in one section by an hexagonal patch of sericite. Cordierites vary in size from approximately 0.3 - 1.1 cm. (Figure 2.2).

Groundmass phases include quartz, orthoclase, plagioclase, biotite and topaz. Anhedral orthoclase occurs either as discrete, irregular crystals 0.5 - 1.0 mm in length with frequent inclusions of quartz and plagioclase, or as a quartz-orthoclase micro graphic intergrowth (Figure 2.3). Carlsbad twinning is rare in the groundmass orthoclase although some crystals show a vague cross hatched twinning indicative of microcline.

Quartz may be rounded, irregular, subhedral or interstitial in form. Euhedral unaltered biotite inclusions are rare. Groundmass quartz extinction is straight to moderately undulose with no subgrain development.

Euhedral to subhedral, unzoned plagioclase is occasionally partially or completely enclosed by orthclase or quartz. The composition of groundmass plagioclase varies little from calcic oligoclase (An_{24-28}).

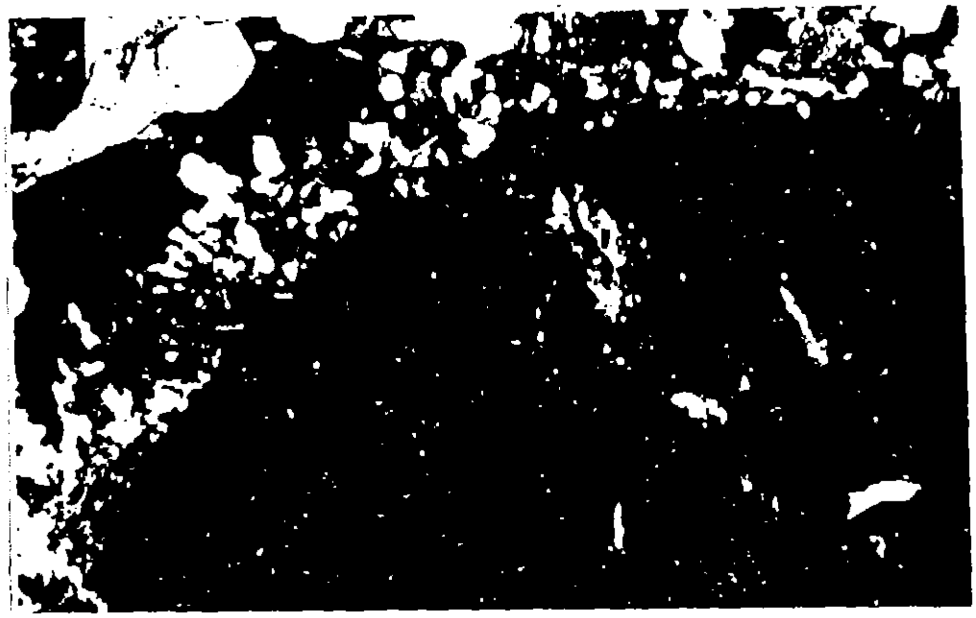


Figure 2.1: Quartz-orthoclase graphic intergrowth surrounding a K-Feldspar pheoncryst (70865)

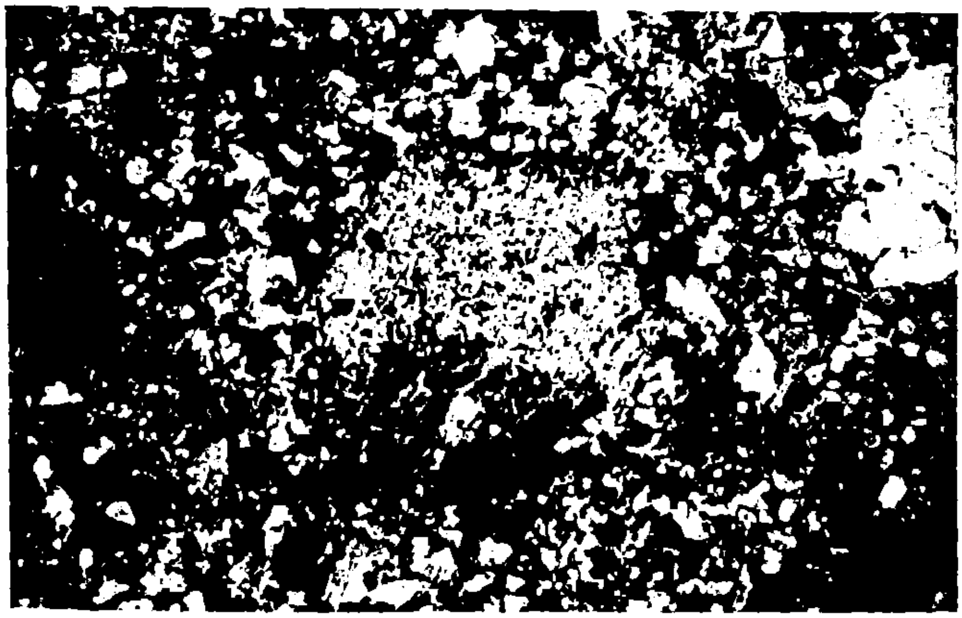


Figure 2.2: Sericite pseudomorph after euhedral cordierite in porphyritic biotite cordierite granite (70849)

Primary biotites (pleochroic $\gamma = \beta$ = red brown α = cream) occur as rare euhedral to subhedral unaltered inclusions in quartz orthoclase phenocrysts or within the groundmass as altered subhedral, ragged crystals coated by quartz or orthoclase.

Secondary biotites (pleochroic $\gamma = \beta$ = light fawn α colourless) are interstitial to groundmass quartz or occur as overgrowths on altered primary biotites (Figure 2.4).

Topaz and white mica are widespread, although relatively minor groundmass constituents. Topaz is characteristically anhedral and fractured. White mica occurs as replacement sericite (see Section 3.2) or as very minor, possibly primary, white mica up to 0.5 mm.

2.2.2 Porphyritic Biotite Adamellite

Hand Specimen

Phenocrysts of K-Feldspar euhedra are surrounded by a fine to coarse, dominantly medium grained groundmass (Figure 2.5). When fresh the rock is grey, but weathers to a dirty grey or yellow, friable rock. K-feldspar phenocrysts vary in abundance from 5 - 40 percent, commonly around 20 percent and may define a foliation through their parallel alignment.

Thin Section

K-feldspar phenocrysts are surrounded by a groundmass of quartz, plagioclase, K-feldspar and biotite. An ubiquitous, although variable, component of this unit, orthoclase phenocrysts exhibit Carlsbad twinning and a fine microperthitic texture. Randomly oriented inclusions of euhedral biotite and plagioclase are common.

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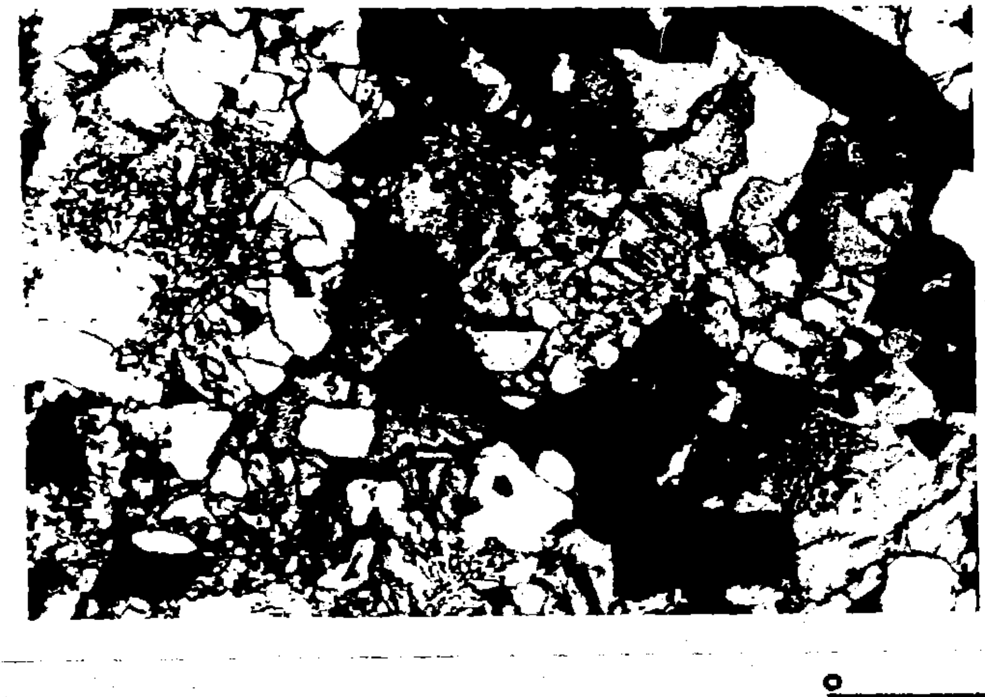


Figure 2.3: Groundmass of porphyritic biotite cordierite granite showing quartz-K-feldspar graphic intergrowth. (70874, cross nicols).

5 cm

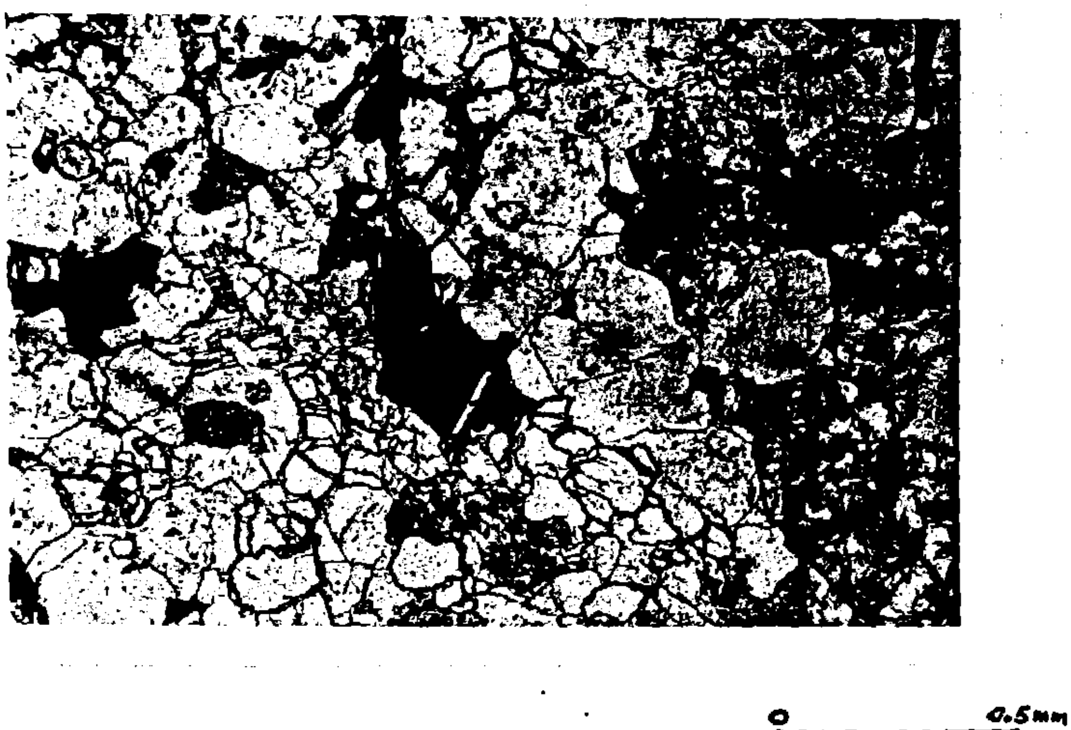


Figure 2.4: Secondary biotites growing on quartz and topaz. (Quartz - clear, low relief, topaz - clear, high relief, cloudy material at top and left is K-feldspar. (70861, plane polarised light).

Groundmass orthoclase, dominantly around 0.4 cm in size is anhedral, irregular in form with inclusions of subhedral to anhedral biotite up to 0.5 mm and more commonly inclusions of euhedral, normally-zoned plagioclase up to 2 mm long.(Figure 2.6).

Unzoned plagioclase (An_{32-36} - Michel Levy method) twinned after pericline and albite laws, is slightly more abundant than euhedral crystals with well developed normal zoning and pericline twinning.(Figure 2.7).

Anhedral, irregular discrete quartz crystals 0.3 - 0.4 cm in size, have moderate to heavy undulose extinction with very occasional deformation banding and subgrain development. Quartz-quartz grain boundaries are sutured while aggregates of recrystallised finer grained quartz (0.1 cm - 0.2 cm) have curvilinear grain boundaries, triple point junctions and straight extinction.

Biotites show a bimodal grainsize distribution. Coarser biotites ($\gamma = \beta =$ deep red brown, $\alpha =$ cream) up to 0.2 cm are anhedral to subhedral ragged grains with very common inclusions of apatite up to 0.2 mm. Pleochroic halos unrelated to any observable inclusions are very common. Finer biotites (0.2 mm - 0.5 mm) form irregular or tabular clusters probably psuedo-morphing an earlier euhedral phase (Figure 2.8). They coat larger biotites, orthoclase and occur intersticially to quartz and K-feldspar. Pleochroic halos are less common within finer biotites, and apatites occur within clusters along grain boundaries. Otherwise coarse and fine biotites are identical in appearance.

837037

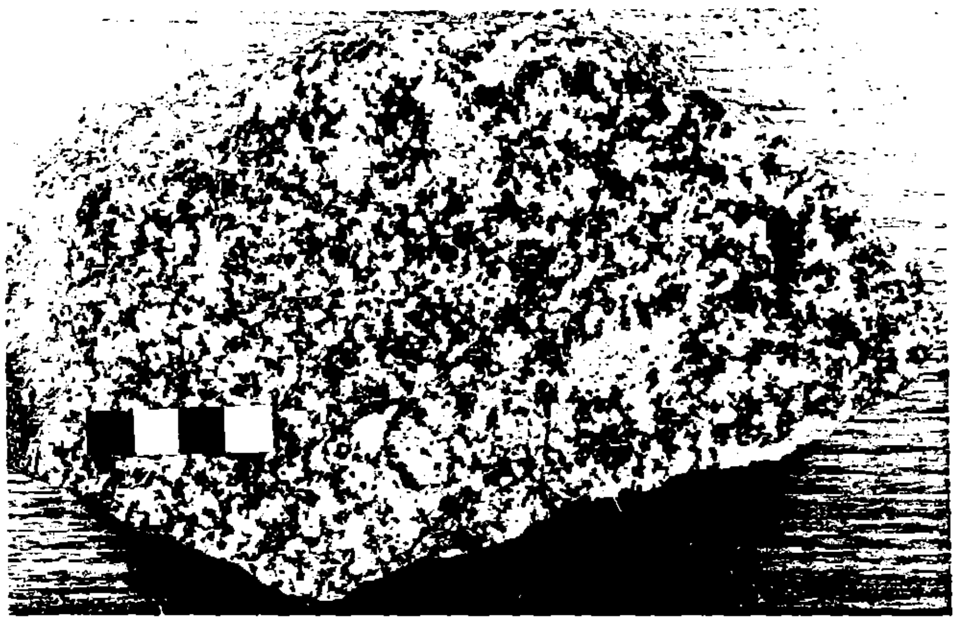


Figure 2.5: Porphyritic biotite adamellite in hand speciman. (Scale bar = 4 cm)

0 2mm

Figure 2.6: Plagioclase and biotite inclusions in K-feldspar.

5 cm

837038

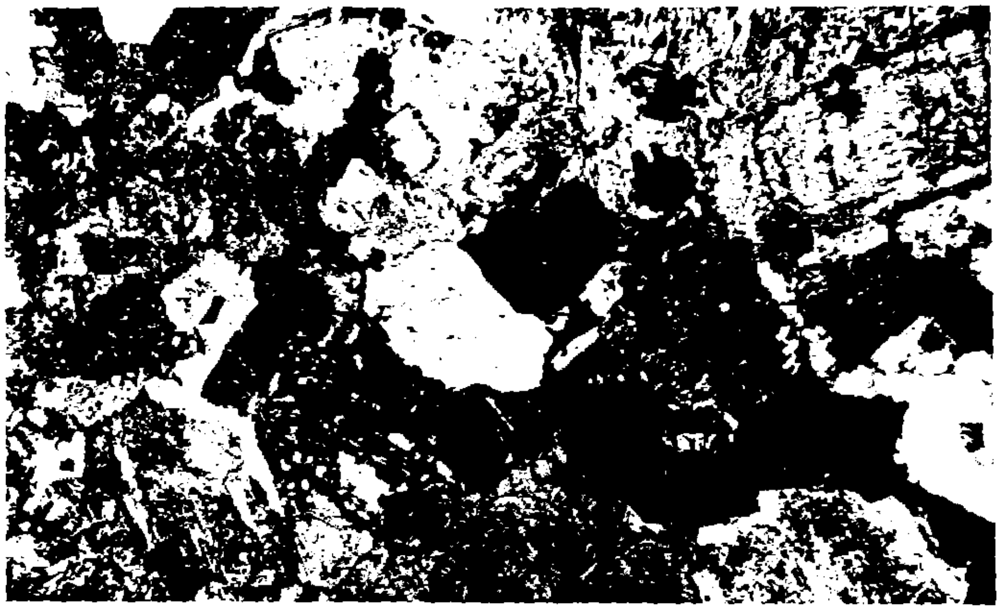


Figure 2.7:

Figure 2.8: Biotite clusters pseudomorphing an earlier euhedral phase.

Chlorite replacement after biotite clusters varies from absent to complete: it is rarely complete and is associated with an elongate opaque, possibly ilmenite.

2.2.3 Equigranular Biotite Granite

Hand Specimen

Equigranular biotite granite is characterised by its granular appearance, medium-fine grainsize (rarely coarse) and pink-green or yellow-white colour (Figure 2.9).

Thin Section

Anhedral-subhedral orthoclase up to 0.4 cm displays Carlsbad twinning and a variably developed microporthitic texture; well developed microperthite may be a result of albitization (Section 3.1.2). Inclusions of unzoned subhedral plagioclase up to 1 mm are common within K-feldspar. Equant to elongate plagioclase is unzoned, euhedral to subhedral and frequently partially enclosed by K-feldspars, more plagioclase or quartz. It varies in size from 0.1 to 0.4 cm in length and in composition from An_{12}-An_{20}, but is predominantly the more sodic. Pericline and albite twinning are apparent, some forms exhibiting more complex twinning (Figures 2.10, 2.11).

Quartz is anhedral, irregular in form, around 2 mm in diameter within medium grained samples (70866), 70868) and 0.5 - 1 mm in finer grained types (70850, 70852). In the medium grained samples quartz displays extremely undulose extinction, deformation banding and some subgrain development. Quartz-quartz grain boundaries are sutured and triple point junctions are present. Inclusions of euhedral unaltered biotite ($\gamma = \beta$ = deep red brown, α = cream) up to 0.1 mm are very rare within

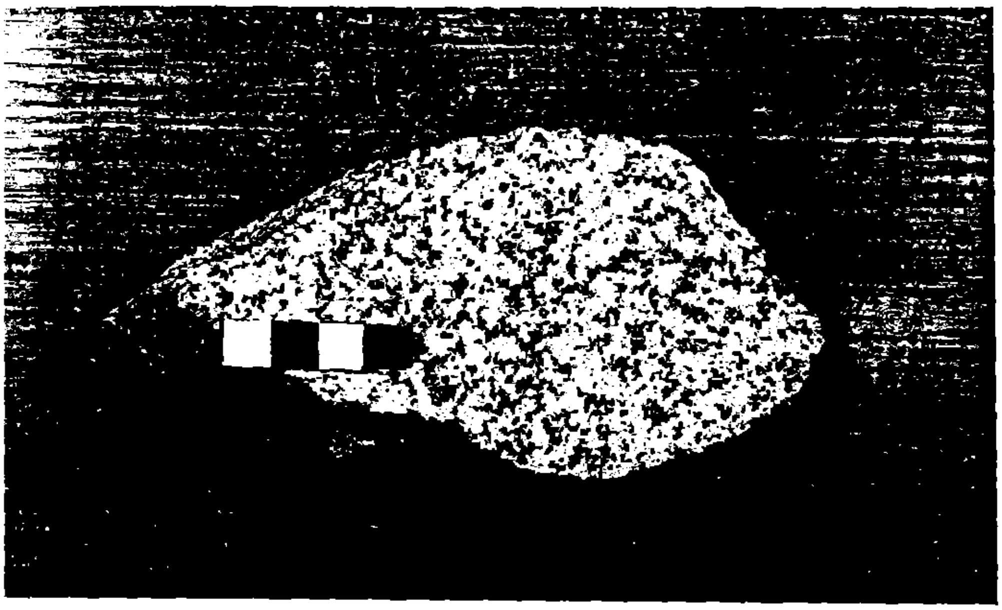


Figure 2.9: Equigranular biotite granite. (Scale bar = 4 cm).

5 cm

Figure 2.10: Interlocking plagioclase crystals in equigranular biotite granite. (70880, crossed nicols).

quartz while plagioclase inclusions vary from abundant (70880) to common (70866).

Biotites are dominantly anhedral, ragged crystals up to 2 mm long. Rare biotite euhedra are coated by quartz and K-feldspar, and contain dirty diffuse pleochroic halos. Anhedral biotites occur interstitially to all other mineral components and also as overgrowths on euhedral and subhedral biotites (Figure 2.12) Euhedral biotites are early in the paragenesis and heavily altered to sericite, producing a "dirty" green-white pleochroism. Later biotites may or may not show sericite alteration, but a green-white pleochroism is apparent and birefringence is extremely high.

Topaz euhedra to anhedra grow up to 1 mm long frequently encrusting K-feldspar (Figure 2.13). Sericite alteration is variable along ubiquitous fractures in topaz,(Figure 2.14) which is usually partially or completely mantled by quartz. In one slide (70880) a quartz-topaz intergrowth terminates a euhedral topaz crystal.

The rock becomes mildly porphyritic occasionally reflecting an increase in the size of K-fledspar which grows as twinned, anhedral grains from 5 mm up to 1.5 cm. Inclusions of plagioclase and quartz in the phenocrysts are abundant (70880).

837042

0 2 mm

Figure 2.11: Equigranular biotite granite with microperthitic K-feldspar, subhedral plagioclase and irregular quartz with undulose extinction. (70866, crossed nicols).

5 cm

0 2 mm

Figure 2.12: Equigranular biotite granite with biotite growing on sericitized biotite, quartz and plagioclase (bottom left) and quartz growing on biotite (top right). (70868, crossed nicols).

Figure 2.13: Euhedral fractured topaz (mantled by quartz) growing on K-feldspar. (70867, crossed nicol).

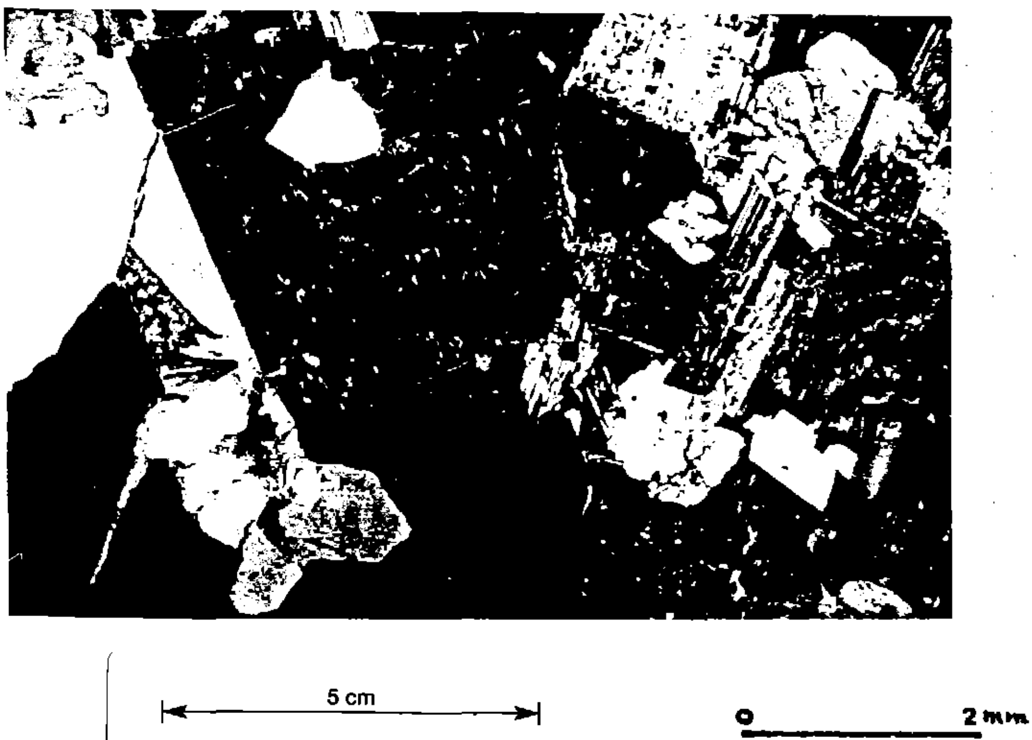


Figure 2.14: Topaz with associated sericite alteration along fractures. K-feldspar encloses plagioclase and quartz. (70866, crossed nicols).

2.2.4 Quartz-feldspar porphory

Hand Specimen

A well developed flow banding, extremely fine grained groundmass and a green colour characterises this rock. The phenocryst content varies from almost absent to over 50 percent of the rock (Figure 2.15).

Thin Section

Equant-elongate quartz phenocrysts from 0.2 mm to 4 mm in size display extremely undulose extinction with deformation banding and subgrain development common features. Quartz grains are occasionally overgrown by K-feldspar that has been heavily altered to sericite along fractures (Figure 2.16). Patches of sericite, psuedomoprhing a subhedral phenocryst, again possibly K-feldspar, are frequent.

Flow banding is defined by trains of quartz phenocrysts 0.1 mm to 0.5 mm in diameter, or by a difference in extinction of layers of the groundmass quartz. The groundmass is extremely fine grained and composed of quartz, and sericite where this is an alteration product.

2.2.5 Leucrocratic microgranites

Hand Specimen

Their characteristic light colour and fine to medium grainsize serve to distinguish these rocks. Miarolytic cavities may be present, irregularly distributed throughout the rock (Figure 2.17).

837045

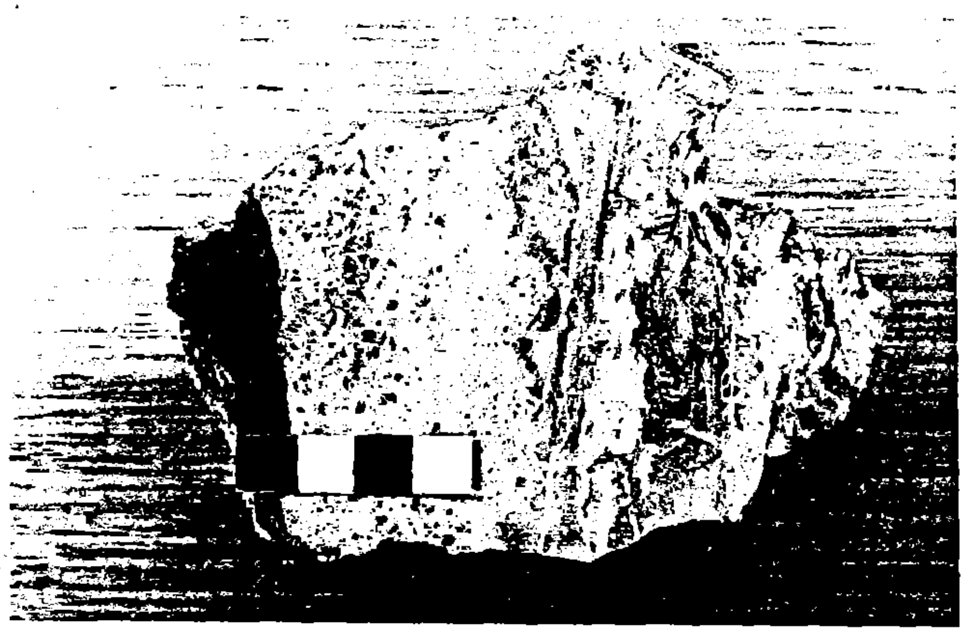


Figure 2.15: Altered quartz-feldspar porphory with flow banding (70883, scale bar = 4cm)

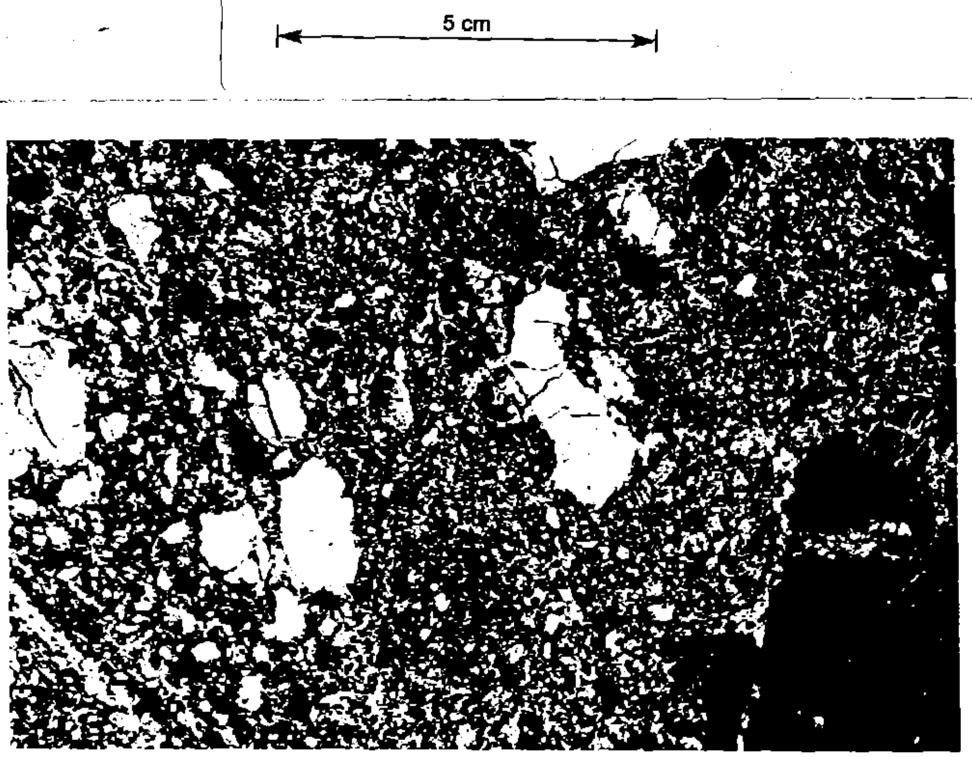


Figure 2.16 : Altered quartz porphory in thin section. K-feldspar coats quartz phenocrysts. (70883,crossed nicols).

Thin Section

Anhedral, K-feldspar, 2 mm to 4 mm in diameter is often intergrown with quartz in a micrographic intergrowth. Carlsbad twinning is rare in K-fledspar, which also may exhibit a microperthitic texture.

Quartz, as anhedral to interstitial grains from 1 mm to 4 mm in diameter displays moderately undulose extinction. It is often micrographically intergrown with plagioclase as well as K-feldspar. Plagioclase of albite to oligoclase composition (An_4 to An_{12} - Michel Levy method) is subhedral to anhedral in form and varies from 1 - 4 mm in length.

Rare biotites (pleochroism $\gamma = \beta =$ red brown $\alpha =$ cream) are elongate up to 3 mm, with no inclusions and rare pleochroic halos. Biotites also occur within miarolytic cavities. They occur as equant clusters, up to 0.5 cm across, with quartz and chlorite. These biotites do not show the deep red brown pleochroism of those described above, and pleochroic halos are absent.

Radiating laths of muscovite have also been found in miarolytic cavities, up to 0.8 cm long. They are unaltered and very common in some rocks (70873).

2.2.6 Aplites

Hand Specimen

The aplites are white coloured, sugary textured rocks which often occur in hand specimen only several centimetres wide. Larger dykes may contain fragments of the granite they traversed (Figure 2.18).

Figure 2.17: Miarolytic cavities in a leucocratic microgranite (Scale bar = 4 cm, 70873)

5 cm

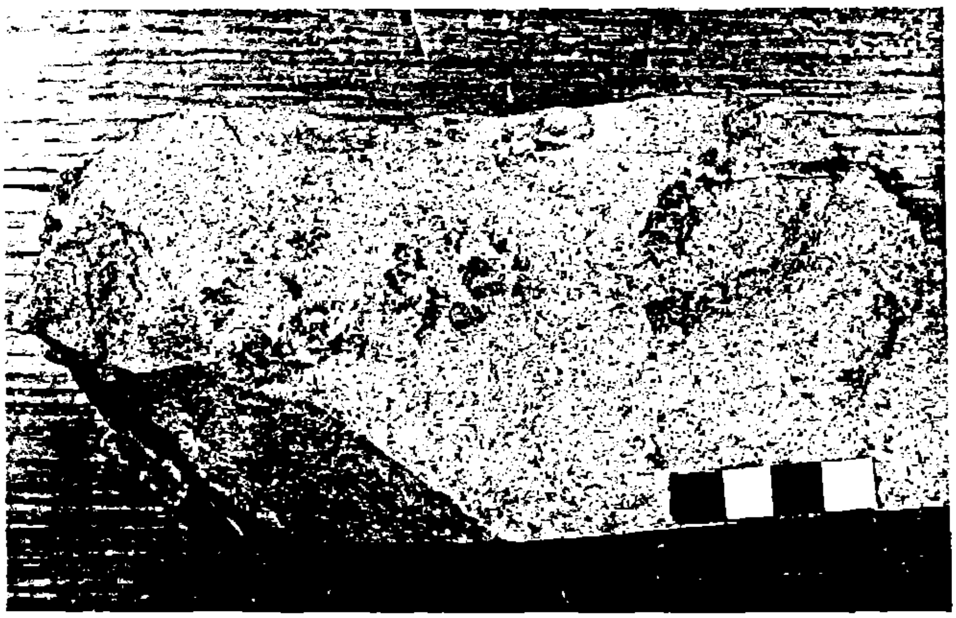


Figure 2.18: Fragments of adamellite in an aplitic dyke (Scale bar = 4 cm, 70853)

Thin Section

The rock contains dominantly plagioclase, K-feldspar and quartz, the latter two components often accounting for 65 to 80 percent of its composition. All components are anhedral and fine grained, typically 0.1 mm to 0.3 mm in size (Figure 2.18). Inclusions of fine grained plagioclase within K-feldspar are frequent. Fragments of the host rock may be incorporated into the dykes as individual crystals with similar size to the host minerals (70853).

Biotite is extremely rare, and when present may be secondary. Alignment of elongate crystals parallel to the dyke wall gives the rock a poorly defined flow foliation (Figure 2.19).

2.2.7 Pegmatites

a) Tourmaline Bearing Pegmatites

Hand Specimen

These pegmatites form as round, dark patches up to 20 cm in diameter within the cordierite bearing granite on the Frome River (Map Sheet 1). Large black tourmaline laths are irregularly intergrown, with coarse K-Feldspar, plagioclase and quartz. The coarser crystals have grown on the inside of a cavity formed by the groundmass of the porphyritic biotite cordierite granite, which in the immediate vicinity of pegmatite is rich in topaz which produces a light green colouration.

Thin Section

Euhedral laths of tourmaline up to 3 cm surround euhedral, elongate, terminated K-Feldspar crystals up to 3 mm long (Figure 2.20). The K-feldspar contains no inclusions and does

837049

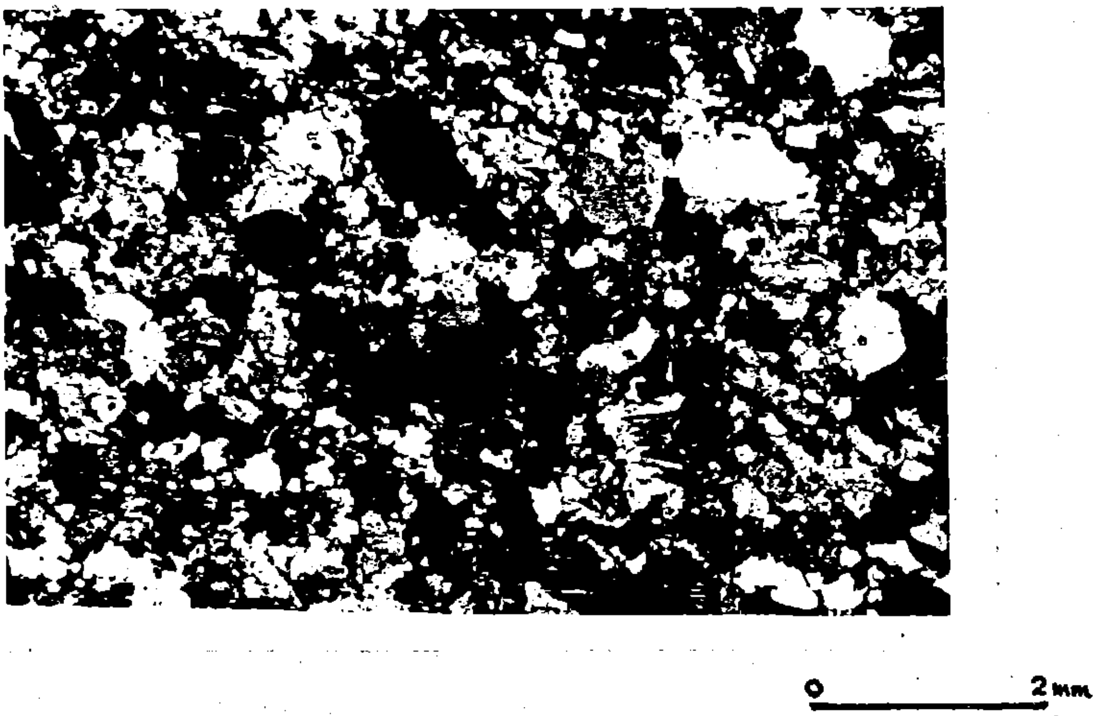


Figure 2.19: Aplite in thin section
(70853)

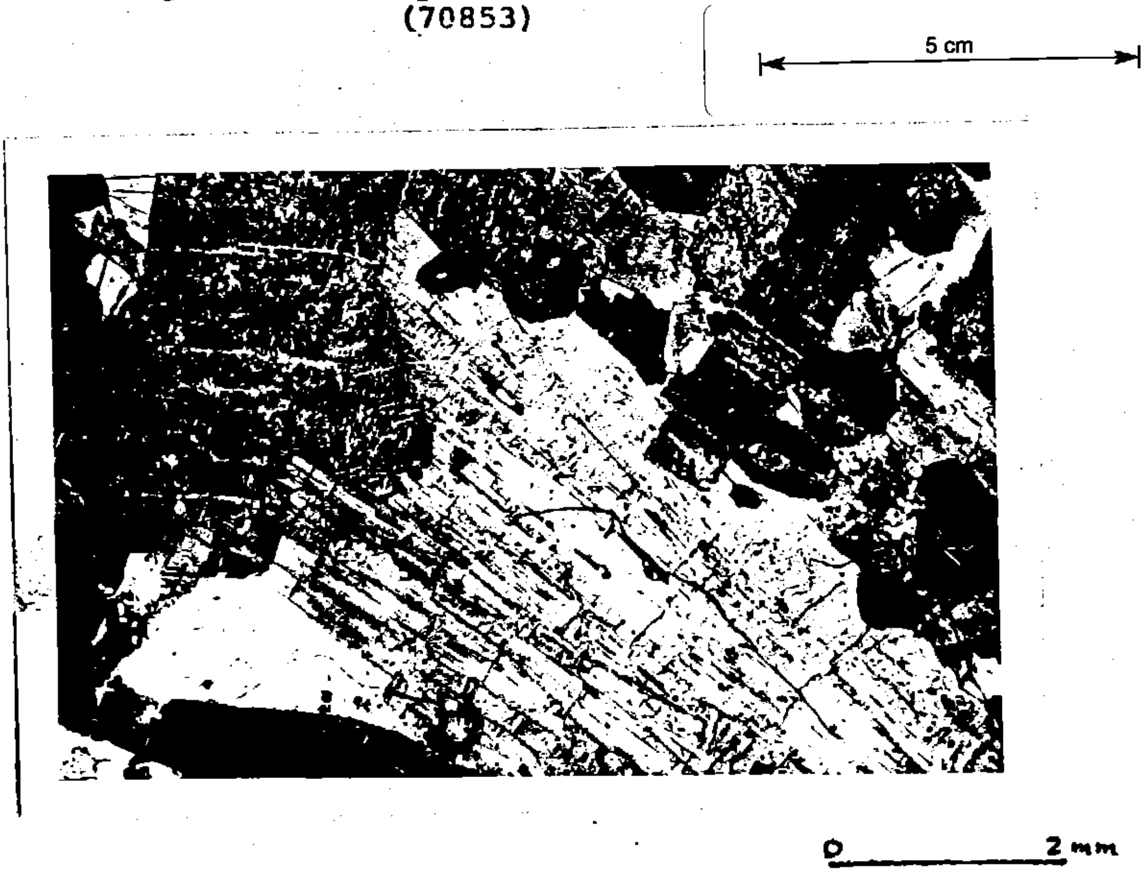


Figure 2.20: Tourmaline bearing pegmatite
(70893)

not exhibit micrographic intergrowth with quartz. These large grains have grown on a rock consisting of plagioclase, K-feldspar quartz and biotite from 0.2 to 3 mm. Plagioclase (An_{4-12}) is euhedral to anhedral and surrounded by anhedral untwinned K-Feldspar or quartz.

The groundmass of the host granite in the immediate vicinity of the pegmatite material contains perthitic K-Feldspar up to 2 to 4 mm in diameter often graphically intergrown with quartz. Subhedral plagioclase of a similar size to K-feldspar is inclusion free. Quartz up to 4 mm in size is anhedral, equant to irregular in form and coated by topaz. Biotites up to 3 mm long are free of pleochroic halos and inclusions and have a light brown-colourless pleochroism. Topaz is anhedral and interstitial to the other components. It is heavily fractured and forms crystals up to 4 mm in size.

b) Tourmaline Free Pegmatites

Hand Specimen

Coarse crystals of equant K-Feldspar, plagioclase and quartz up to 2 cm across, occur as patches in the equigranular biotite granite up to 40 cm long. Individual patches in close proximity to each other may be joined by an irregular narrow pegmatite dyke. Muscovite is commonly present as laths up to 1 cm long.

Thin Section

Large K-feldspars are graphically intergrown with quartz and display a microperthitic texture. Albite up to 4 mm long is subhedral in form and very occasionally graphically intergrown

837051

with quartz. Topaz up to 0.5 cm in diameter is heavily fractures and grows on K-Feldspar. The feldspars are dissected by extremely narrow sericite bearing microfractures and may be locally incipiently altered to sericite.

2.2.8 Mafic Igneous Xenoliths

Hand Specimen

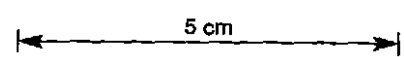
Rounded inclusions of a mafic, igneous textured rock occur within the porphyritic biotite adamellite (Figure 2.21). They are no larger than 5 cm in diameter and are in very low abundance.

Thin Section

The inclusions consist dominantly of quartz, plagioclase and biotite (Figure 2.22). Plagioclase occurs as euhedral to subhedral unzoned crystals from 0.3 to 1.5 mm long and also as equant, euhedral, poorly zoned crystals from 2 to 3 mm in diameter. Biotites are subhedral, ragged crystals from 0.3 to 1.0 mm long. They are free of inclusions, and pleochroic halos are very rare. Biotite pleochroism is dark brown ($\gamma = \beta$) to cream (α). Quartz is anhedral, equant to interstitial in form, with straight to slightly undulose extinction, and surrounds biotites and plagioclase. Biotites are common inclusions in quartz. Very minor K-Feldspar is interstitial to all other components of the rock. It is inclusion free and untwinned.

837052

Figure 2.21: Mafic igneous xenolith in porphyritic biotite adamellite (70848).



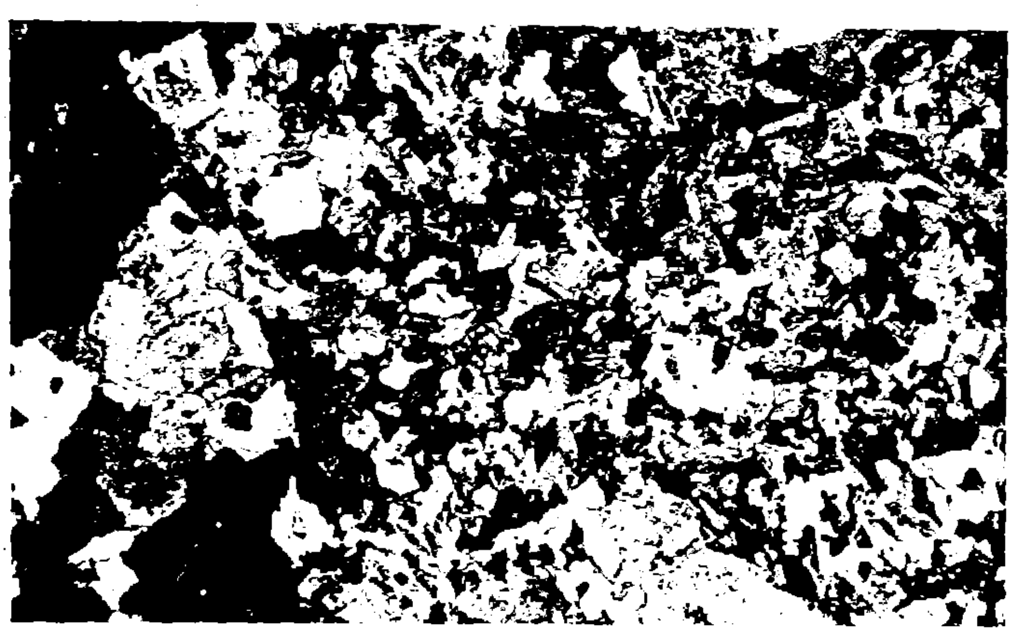


Figure 2.22: Contact between xenolith and adamellite above, in thin section. (Crossed nicols).

2.2.9 High-grade Regional Metamorphic Inclusions

Hand Specimen

One example of this type of inclusion has been found, within the porphyritic biotite adamellite and reflects the rarity of these inclusions in these granitoids. The inclusion is 2 cm across, black, fine to medium grained, and eliptical in shape. A foliation is very well defined. At one end the inclusion-adamellite contact is diffuse, (Figure 2.23).

Thin Section

Gneissic layering is defined by biotite and cordierite rich layers distinct from those layers containing plagioclase K-feldspar and quartz.

Biotites are pleochroic deep red brown ($\gamma = \beta$) to cream (α) and contain abundant pleochroic halos unrelated to any observable inclusions. Between biotite layers a yellow clay after cordierite is elongate parallel to the foliation. Inclusions of hercynite and silliminite within pseudomorphed cordierite are very common.

Equant, xenomorphic plagioclase (up to 1 mm), K-Feldspar (up 0.5 mm) and quartz (up to 0.3 mm) occur interstitially to biotites and between biotite rich layers. Felsic minerals are subordinate to mafic minerals throughout the rock.

Figure 2.23: High grade metamorphic xenolith in porphyritic biotite adamellite

5 cm

Figure 2.24:

Xenolith (above) in thin section.

0 2 mm

[illegible]

	Q	K	P	B	Accessory
Porphyritic biotite admellite[+]	38.5	32.8	21.3	7.5	Ilmenite chlorite
Porphyritic biotite cordierite granite	35-40	30-40	10-15	4 4	Topaz, sericite cordierite
(	37	34	23	4 4	Topaz*
Equigranular biotite granite (	37	39	19	3 3	Topaz*
(	29	28	37	3 3	Topaz*
Average (	34	34	26	3.5	Topaz

+ From Groves, 1973

* 1 to 4% + sericite

CHAPTER 2

PART B: SPATIAL AND TEMPORAL RELATIONSHIPS

2.3 TEMPORAL RELATIONSHIPS

Relative age relationships visible between the granitoids are in large part obscure. A sharp contact between the porphyritic biotite cordierite granite and the porphyritic biotite adamellite (Figure 2.25) crops out on the Wyniford River (Map Sheet 1). Inclusions of the former granitoid are found within the adamellite, showing the cordierite-bearing granite is earlier. Similar inclusions within the adamellite occur near the inferred contact between the above mentioned granitoids immediately north of the upper Cotton Creek (Map Sheet 1). Further evidence for such age relationships from the Wyniford River contact is the presence of coarse pegmatitic material along the contact that has grown on the granite from the adamellite melt.

Outcropping contacts between the equigranular biotite granite and the other granitoids are scarce, but do occur on the Frome River south of the Cream Creek Prospect. Here sharp contacts occur between the equigranular granite and porphyritic granite. Interlayering of the two phases on a scale of tens of centimetres is evident, and they are separated by steeply dipping curvilinear joints which may converge or run parallel to each other. Such structure may represent intrusion of magma into another partially solidified rock. The equigranular biotite granites on the regional scale are considered by Groves (1977) to be the latest major intrusions in the area based on the

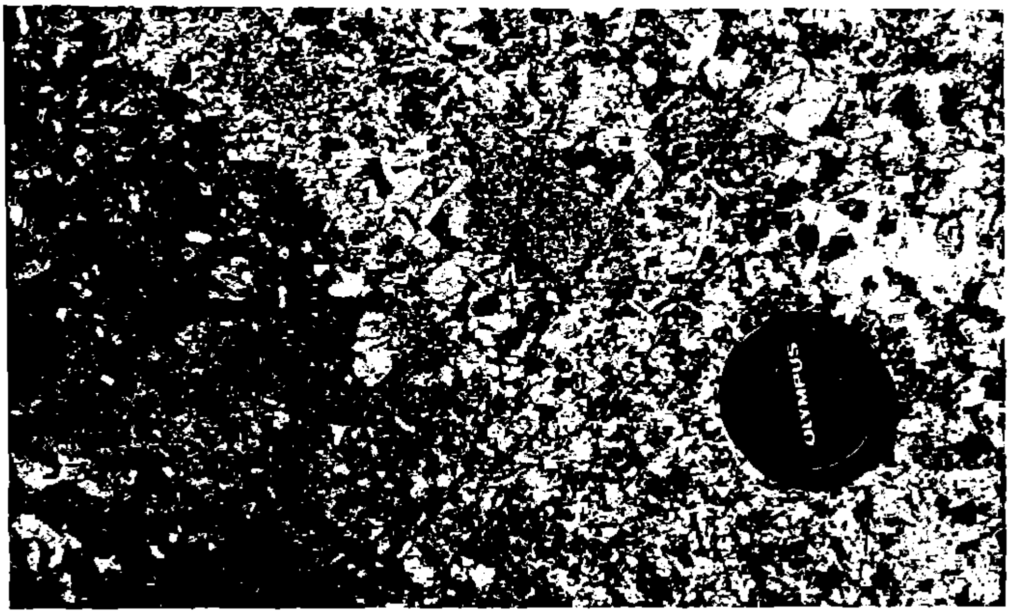


Figure 2.25: Sharp contact between the porphyritic biotite cordierite granite and the equigranular biotite granite. Note xenoliths of the granite groundmass within adamellite.

outcrop pattern. They have also been dated by Cocker (1977) as later than adamellites and granodiorites (based on both biotite and $\frac{Rb^{87}}{Sr^{87}}$ isochron ages); although the biotites are secondary, these dates agree closely with each other indicating that hydrothermal alteration closely followed magmatism (Cocker, 1977). On the basis of this evidence, equigranular biotite granites are taken as later than adamellites and porphyritic granites.

Aplitic dykes commonly traverse porphyritic biotite adamellite and less commonly porphyritic biotite cordierite granite and equigranular biotite granite and are therefore later than these granitoids.

2.4 GRANITOID CONFIGURATIONS

Interpretation of the geometrical relationships between granitoids is based on the following observations between topographic contours and contact relationships (Map Sheet 1):

- The contacts between porphyritic biotite adamellite and porphyritic biotite cordierite granite cut the contours at high angles and therefore are steep. An exception to this relationship is the contact around Emu Hill which follows contours and is horizontal.

- Contacts between porphyritic biotite adamellite and equigranular biotite granite both crosscut and follow contours in different parts of the area. Around Masher Hill and Emu Hill and to the northeast of Masher Hill contacts closely follow contours and are hence subhorizontal. Further to the west of the area and south of Emu Hill steeply dipping contacts cut contours at a high angle.

- The porphyritic biotite cordierite granites and the equigranular biotite granite contact around Cream Creek is interpreted as being steep (as this contact crosses contours).

- Leucocratic phases are observed in outcrop to be steeply dipping, the one exception being a shallowly dipping sheet overlain by adamellite in the upper section of Cross Creek.

2.4.1 Summary and Interpretation

In the western part of the area, contacts are dominantly sub-horizontal, as opposed to the east where they are relatively steep. Contacts between the earlier cordierite bearing granite and the adamellite are nearly always steep, with the exception being the Emu Hill contact which is flat-lying.

The eastern horizontal contacts are in accord with the relatively flat-lying sheet of equigranular biotite granite intrusive into porphyritic adamellite (cross section A-A). The upper contact is around Masher Hill and the lower contact around Cotton Creek to the north. In the west of the area the steep contacts are inferred to represent the flanks of irregularities in the upper contact of the sheet producing "highs" and "troughs". It must be noted, however, that these steep contacts may continue at depth, rather than flattening out into a sheet as shown on the cross section, as is postulated for the contacts at the Anchor Mine (Groves, 1973).

CHAPTER 3

MINERALIZATION AND ALTERATION

3.1 INTRODUCTION

Alteration is here considered as any post-magmatic adjustments in mineralogy owing to chemical reaction between magmatic hydrothermal or meteoric hydrothermal fluids and the granitoids. The identification of alteration relies on textural criteria and the recognition of alteration products.

3.2 REGIONAL ALTERATION

3.2.1 Silicification

Silicification occurs in all major rock units although it is a relatively minor alteration feature in the porphyritic biotite adamellite and the equigranular biotite granite. Within the former rock type silicification is reflected in the introduction of quartz along Carlsbad twin planes and grain boundaries of K-feldspar while within the equigranular biotite granite it is manifest in the form of quartz infiltration along topaz-K-feldspar grain boundaries.

The porphyritic biotite cordierite granite shows frequent silicification in the form of consistent quartz introduction along the Carlsbad twin planes and cleavage within the K-feldspar phenocrysts (Figure 3.1) of this granite. Inclusions within K-feldspar phenocrysts are often mantled by quartz that has encroached along the inclusion-phenocryst grain boundaries (Figure 3.2). Linear trains of quartz within these phenocrysts are related to observable K-feldspar fractures.

3.2.2 Albitization

Albitization is restricted to the equigranular biotite granite in which it varies in its development. Such alteration is best developed in this granite immediately west of Masher Hill (Map Sheet 1, slides 70865 to 70868). Albitization is recognised by the irregular precipitation of sodic plagioclase along K-feldspar grain boundaries and twin planes (Figure 3.3). Occasionally this interstitial plagioclase is linked to coarse microperthite within K-feldspar indicating that at least some microperthite may be secondary (Figure 3.4).

3.2.3 Sericitization

Sericitization is the most common alteration within all the rocks studied. The description of seritization is discussed below for each individual rock type.

3.2.3.1 Porphyritic biotite adamellite

Within the porphyritic biotite adamellite extremely fine grained sericite replaces plagioclase along cleavage. The most heavily altered parts of the crystals are the cores, where extreme alteration may obscure twinning. The alteration is variable; some plagioclase are incipient to moderately sericitized while others are pervasively altered. K-feldspars are unaltered apart from a dusting by clays, and biotites are also unsericitized.

3.2.3.2 Equigranular biotite granite

The plagioclase of the equigranular biotite granite is generally no more than 10 to 15 percent sericitized with the alteration concentrated along cleavage traces, however a range from unaltered to moderately (approximately 50 percent) altered exists. Although no zoning is apparent, the cores of the plagioclase are the most, and often the only sericitized sections of the crystals. Euhedral to subhedral biotites are completely altered along cleavage while later biotites interstitial to K-feldspar and quartz vary from completely altered to unaltered. Topaz is variably sericitized along fractures and often has a reaction rim of sericite.

3.2.3.3 Porphyritic biotite cordierite granite

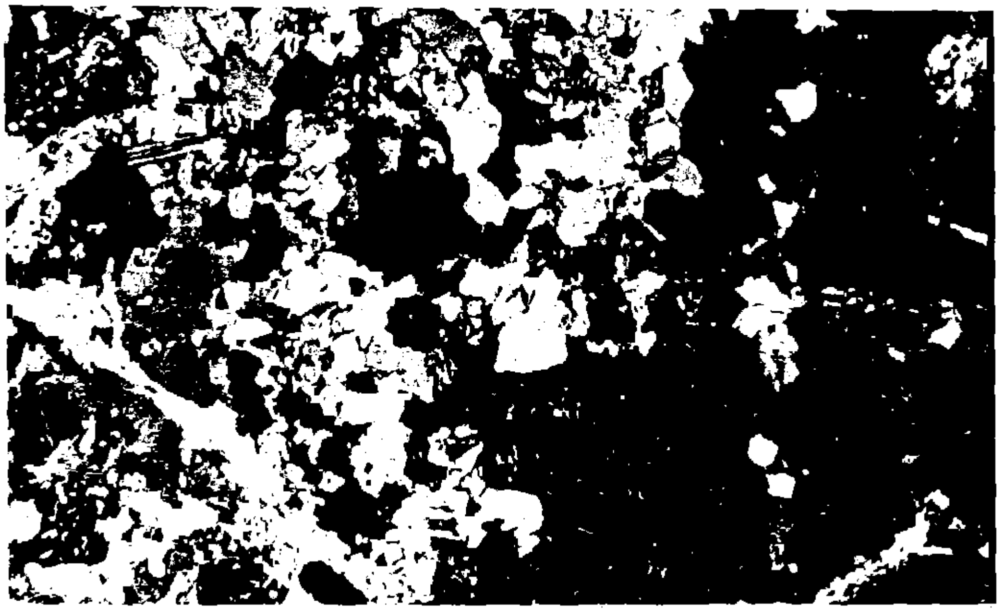
Plagioclase phenocrysts of the porphyritic biotite cordierite granite are intensely altered to fine grained sericite, the intensity of this alteration decreasing from core to margin. The groundmass plagioclase has remained unaltered, while primary biotites are completely altered to sericite along cleavage traces. Sericite often occurs along the groundmass quartz-K-feldspar grain boundaries when these minerals are graphically intergrown.

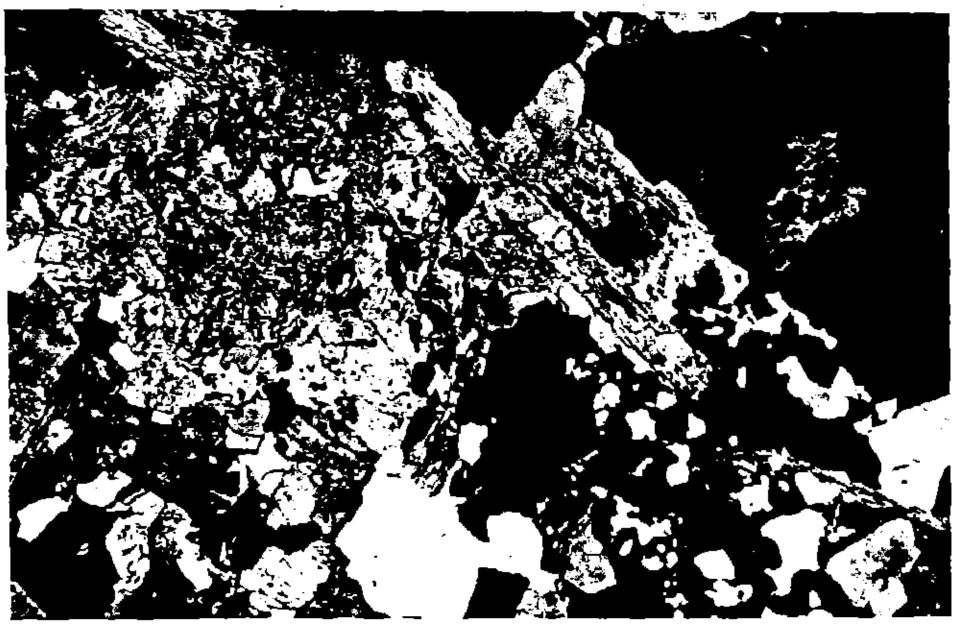
3.2.3.4 Leucrocratic microgranite

Within the leucocratic microgranites, sericitization adjacent to miarolytic cavities is common. Here again, plagioclase is altered along cleavage traces, biotites however, are unaltered.

3.2.4 Secondary Biotites

Secondary biotites are recognised by their light tan - colourless pleochroism, lack of pleochroic halos and lateness in the paragenesis. Within the biotite cordierite granite they occur interstitially to quartz (Figure 3.4) and as overgrowths on later biotites.





837064

Figure 3.3:

Introduction of albite along K-feldspar grain boundaries.

(70865, crossed nicols)

0 2mm

5 cm

Figure 3.4:

Albitization of the equigranular biotite granite. Note replacement perthmites connected to intersticial "albite".

70867, crossed nicols)

0 2mm

Secondary biotites similarly occur within the equingranular biotite granite where they may also form equant aggregates up to 3 mm across representing miarolytic cavities (70880).

3.3 FRACTURE CONTROLLED ALTERATION

3.3.1 Sericite Alteration

Sericite alteration is associated with the following vein types:

(i) Veinlets of very fine grained sericite associated with replacement fourite, are present in rocks cropping out along the Frome River and Upper Cotton Creek (Map Sheet 1). The alteration occurs within the equigranular biotite granite and porphyritic biotite granite and is characterised in hand specimen by the light green colour and irregular traverse of the veinlet across the rock.

In thin section the veinlets are discontinuous lensoidal features often pinching and swelling, crosscutting feldspars (Figure 3.5), and either crosscutting or circumnavigating quartz crystals. At the widest they are 0.2 mm in width; however, they have often split into many smaller veinlets which run roughly parallel to one another, or emanate through host minerals perpendicular to the main veinlet.

The veinlets contain dominantly sericite with some quartz as vein fill, and possibly as wall rock fragments, with minor flourite. Flourite also replaces plagioclase and biotite to a limited extent (Figure 3.6). Biotite is completely altered to sericite in proximity to the veinlets, while plagioclase undergoes little or no sericitization. K-feldspar remains unaltered.

(ii) Fine, black linear veinlets of sericite occur within the porphyritic biotite cordierite granite (Figure 3.7) at locations on the Wyniford River, Cotton Creek and the Frome River (Map Sheet 1). They are not widespread throughout the rock unit, but rather occur patchily grouped together within single outcrops, crosscutting or running parallel to one another. They trend parallel or subparallel to major joint patterns in the area.

In thin section an infill of muscovite or a muscovite selvedge (Figure 3.8) up to 0.2 mm in width is typical of these veinlets, themselves up to 0.2 mm in width. The fractures are well defined and linear when crosscutting phenocrysts, but generally become diffuse when crosscutting the groundmass, while others traverse it with particularly sharp boundaries. Cordierite is completely altered to muscovite in proximity to these veinlets, while biotites are completely altered to a fine sericite, green in plane polarised light, similar to the sericite infill of type (i) veinlets. Plagioclase even when fractured by this veining, is only slightly sericitized or entirely unsericitized. K-feldspar is also unaltered.

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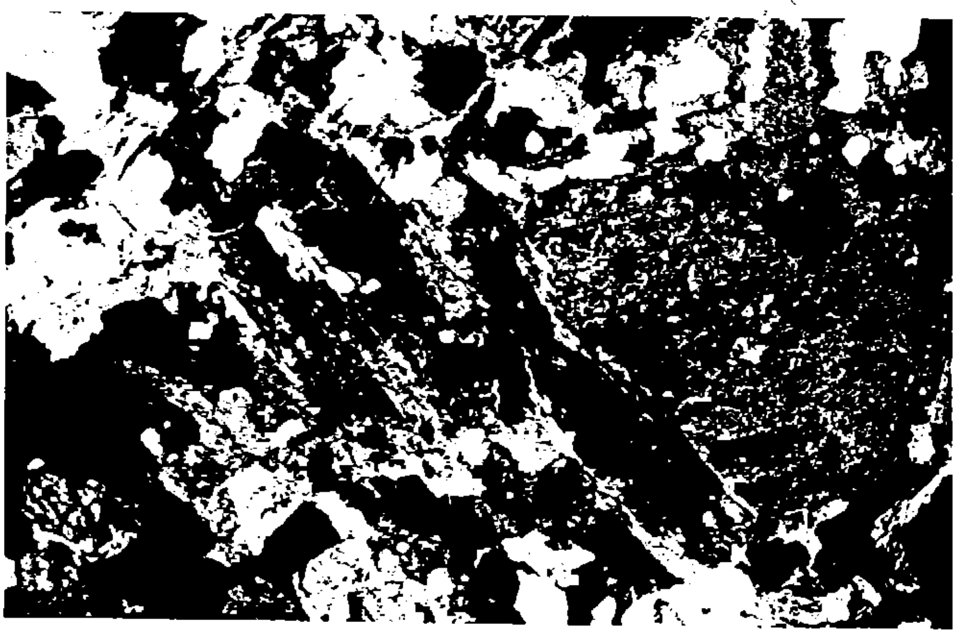
0 2 mm

Figure 3.5: Early post-magmatic sericite veinlet with associated flourite alteration. Note fragmented, unaltered plagioclase and irregular flourite. (70886, crossed nicols)

5 cm



0 2 mm

Figure 3.6: Flourite altering partially sericitised plagioclase and biotite (70887, crossed nicols).

In slide 70849 (Figure 3.8) a set of such veinlets crosscut one another with a perpendicular intersection. The later set has been re-opened and fluid reintroduced depositing what may have been a sulphide on the earlier selvedge mica. This is not a common feature and may be related to mineralisation at the nearby Cream Creek Prospect.

Outcrop observation suggests that these veinlets do not continue for more than several metres, and probably begin and end diffusely within the groundmass as noted above.

(iii) The third type of white-mica bearing veinlet, in which a dark grey alteration envelope 2 to 4 cm wide surrounds the centre line, is particularly distinctive (Figure 3.9). Such alteration can be found on the Cross Creek road, the Cream Creek track, the Wyniford River and the Upper Cotton Creek (Map Sheet 1). It crosscuts porphyritic biotite adamellite, porphyritic biotite cordierite microgranite and leucrocratic microgranite. The veinlets parallel frequent jointing in the host and the only veining of this kind found in outcrop (Cotton Creek) parallels a common regional jointing (315^{o}) and has a vertical dip.

In thin section (Figure 3.10) an almost continuous muscovite selvedge up to 0.5 mm thick occurs on both sides of the veinlets, which range in width from 1 mm to 0.2 mm, where a quartz crystal has been fractured and traversed. The selvedge

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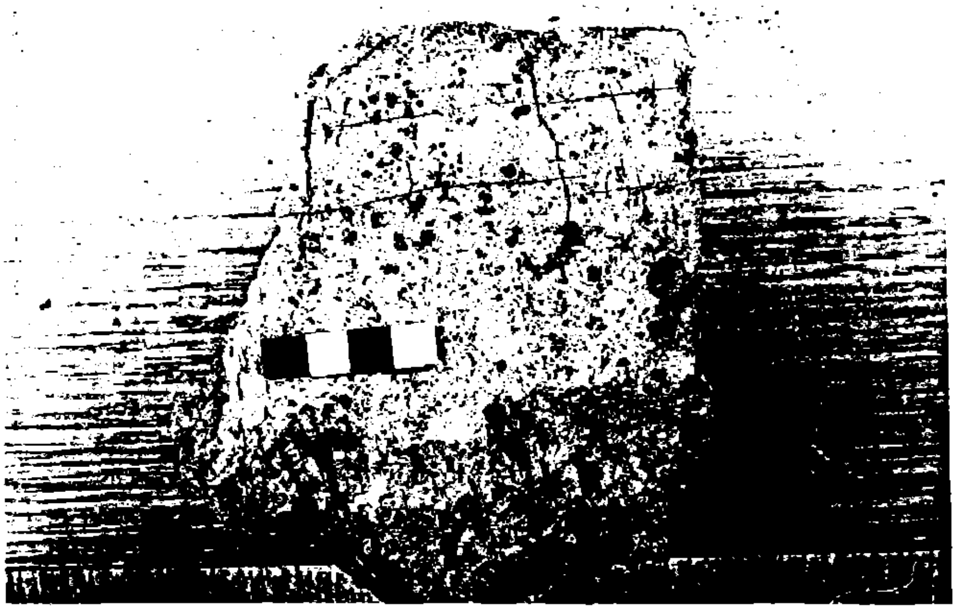

Figure 3.7: Sericite veinlets dissecting and pinking K-fledspar phenocrysts in prophyritic biotite cordierite granite (70849, scale bar = 4 cm).

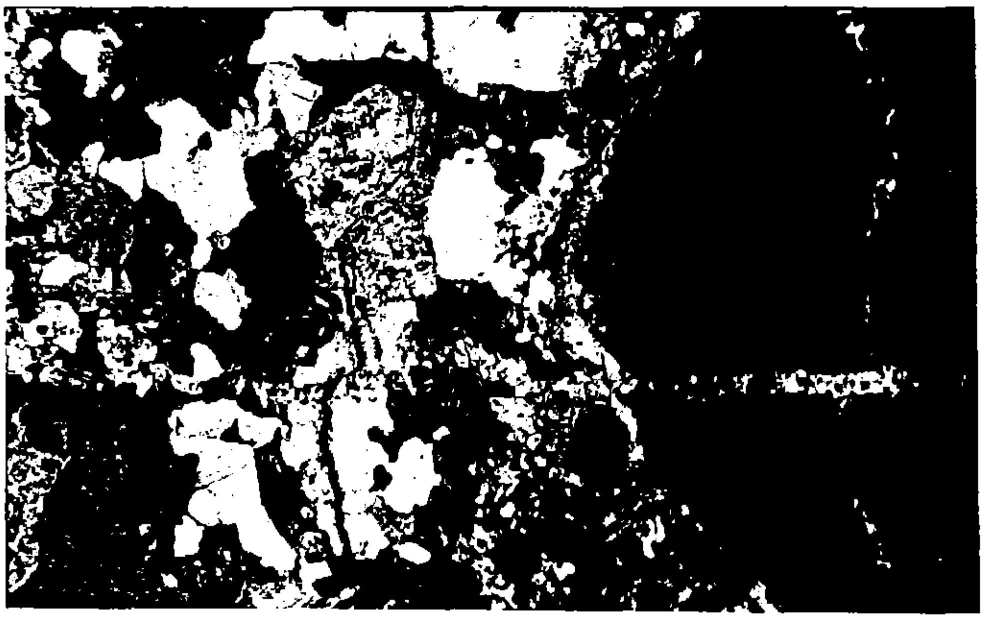

Figure 3.8 Veinlets intersticial, and crosscutting groundmass minerals, (also crosscutting a quartz phenocryst) with sericite selvedge. The veinlet running left to right has been crosscut by the veinlet running vertically. The vertical veinlet has been re-opened, and alters a biotite it has dissected to sericite. (70849, crossed nicols).

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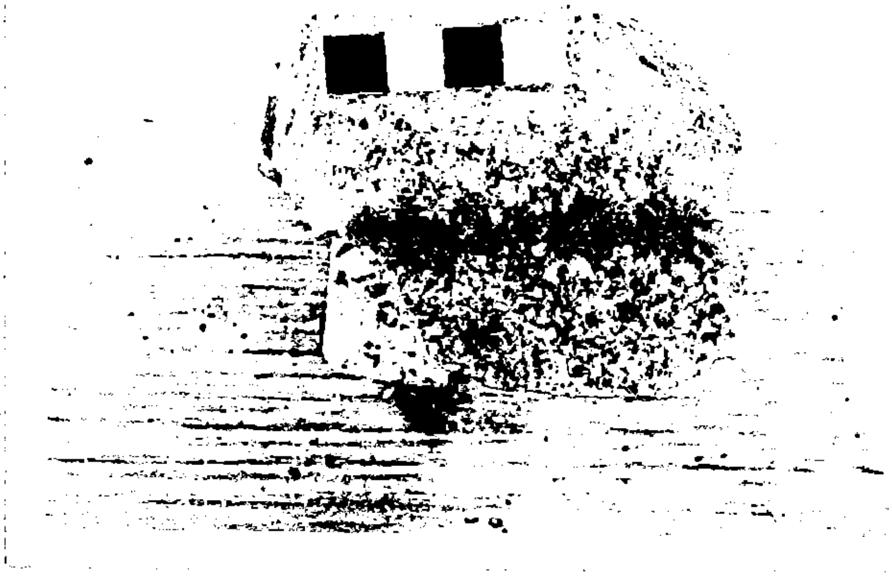

Figure 3.9: Sericite alteration envelope around a sericite veinlet crosscutting porphyritic biotite adamellite (70840).

5 cm

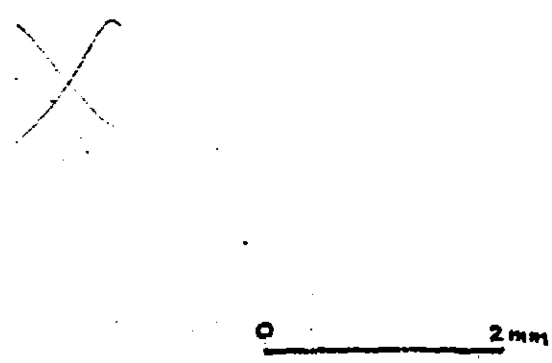

Figure 3.10: Sericite veinlet and alteration in thin section. Plagioclase and biotite are completely altered to sericite. K-feldspar (bottom left) is only partially altered. (70842, crossed nicols).

muscovite is elongate parallel to the vein wall and encrusts sericite that has replaced the wall rock minerals.

Plagioclase is completely altered to sericite within 2 mm on either side of the veinlet. From 2 mm to 8 mm away from the veinlet centre line plagioclase sericitization varies from complete to approximately 25 percent altered. From 8 mm onward away from the vein centre line plagioclase cores are heavily altered to a fine grained sericite similar to that noted in the porphyritic biotite adamellite in Section 3.2.3.1.

Biotites are altered to a green clay material and sericite within approximately 1.8 cm of the veinlet, where unaltered biotites suddenly appear. Altered biotites are green to brown in plane polarised light and are associated with an opaque, possibly ilmenite. Whether or not the clay replaces sericite is obscure. K-feldspar is quite stable regardless of its proximity to the veinlet; however 2 mm of the centre line it has started to alter, the grain boundaries being heavily embayed by sericite.

Micro fractures, extending into the wall rock roughly perpendicular to the veinlets may serve to reinforce the alteration, as evidenced by the fact that these microfractures pinch out at the same distance from the veinlet centre line as the alteration envelope boundary.

(iv) Quartz veins up to 1 cm wide may produce a sericite alteration envelope similar to that described above for type (iii) veinlets. The alteration envelope, however, is a great deal wider (Figure 3.11) and the alteration more pervasive. Examples of this alteration occur as float around the Cross Creek road, the FB Lode and the Cream Creek track.

The veins consist dominantly of anhedral quartz with intense undulose extinction. Radiating muscovite laths fill open spaces, growing on and interstitially to the quartz, or along fractures within it.

Within the alteration envelope biotites have been altered to a green or brown clay and sericite, which sometimes surrounds anhedral tourmaline grains up to 0.5 mm in diameter. Both K-feldspar and plagioclase are absent within approximately 2 to 3 cm either side of the vein centreline, after which K-feldspar remains at least partially unaltered.

Around the boundary of the alteration halo (the boundary is here taken as the few millimetres over which the dark grey area terminates in hand specimen). K-feldspar is unaltered, while plagioclase is at least approximately 60 percent sericitized along cleavage traces and biotite is completely altered to sericite and clays (Figure 3.12).

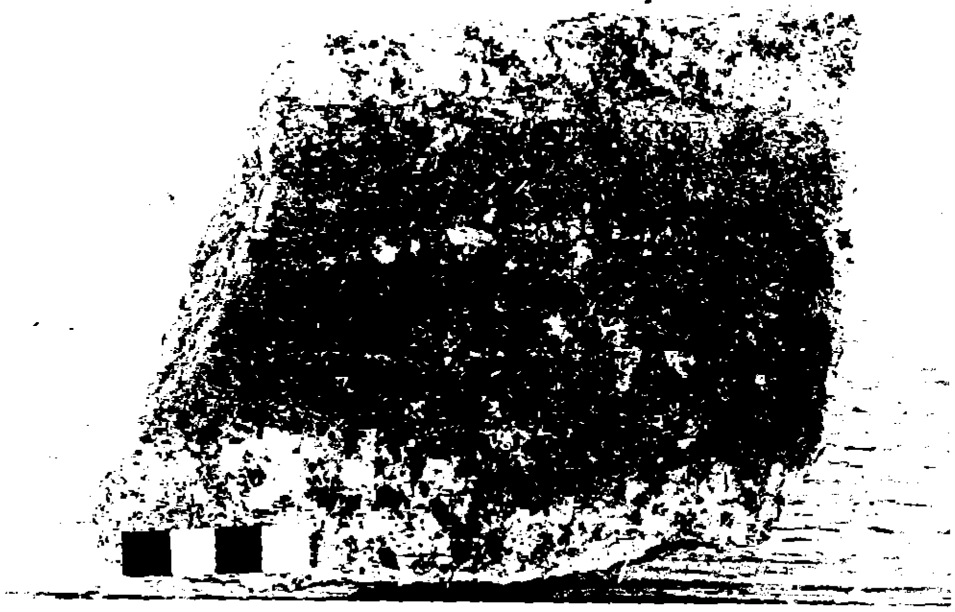

Figure 3.11: Quartz vein with associated sericite alteration envelope crosscutting porphyitic biotite adamellite. (Scale bar = 4 cm) (70854, crossed nicols)

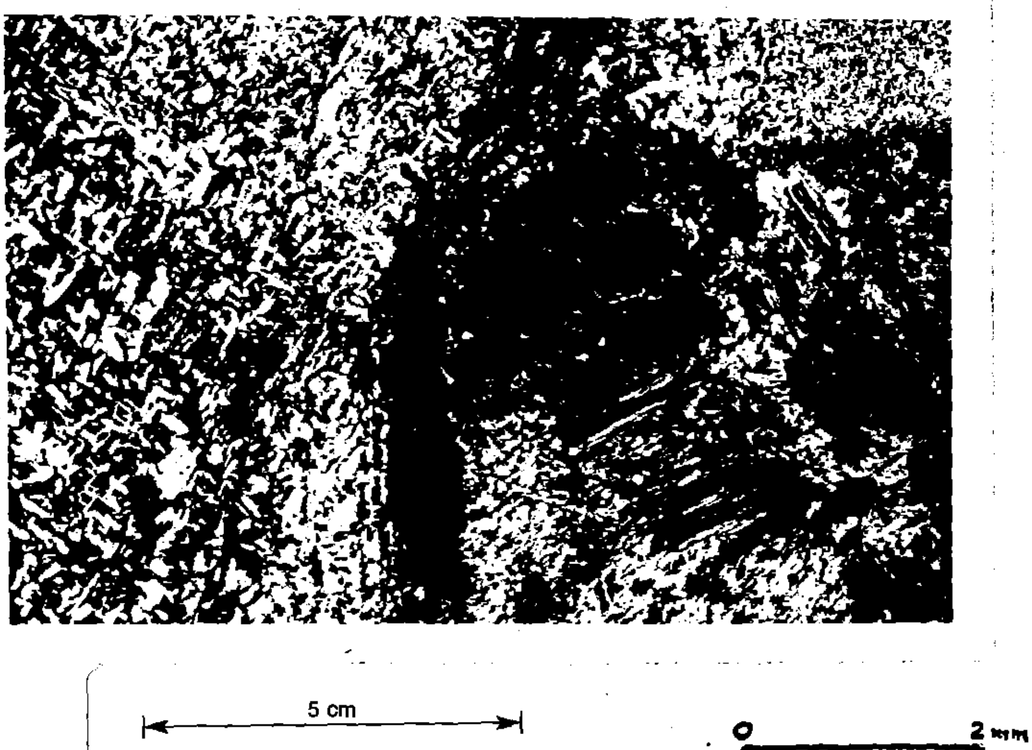

Figure 3.12: Thin section of area A in Figure Plagioclase and biotites are altered to sericite along cleavage. K-felspar is mostly unaltered (70854, crossed nicols).

Minor chlorite psuedomorphing biotite is present immediately outside the alteration halo, however the presence of chlorite in rocks not experiencing this type of sericite alteration obscures its relationship to the alteration described above.

3.3.2 Silicifaction

Introduction of quartz into the host rock is related to vein types (iii) and Iv) above. In hand specimen irregular elongate quartz grains are observed to extend from the veins into the wall rock. The lack of inclusions within quartz grains enclosed by the alteration envelope may be evidence of their secondary nature; however, many primary quartz grains within all potential hosts are relatively inclusion free and this is not diagnostic.

VEINS ASSOCIATED WITH SERICITE ALTERATION

	Vein Type	Type (i)	Type (ii)	Type (iii)	Type (iv)
MINERALS IN PROXIMITY TO VEIN	Cordierite+	No contact	x	No contact	No contact
	Biotite	x	x	x	x
	Plagioclase	-	-	x	x
	K-feldspar	-	-	Minor alteration	x
	Quartz	-	-	-	-
ACCESSORY ALTERATION PRODUCTS		Flourite			Tourmaline

x = altered

\- = unaltered

\+ = the alteration is probably of pinnite psuedomorphing cordierite.

3.3.3 Mineralization

3.3.3.1 Introduction

The style of mineralization associated with the Blue Tier Batholith granitoids has been previously described by Groves (1973) as greisenization.

The term greisen, however, has long been associated with many different styles of tin mineralization and is used here prefixed with the main alteration assemblages (Sheherba, 1970). It should be noted that this does not necessarily imply greisenization in the sense of Taylor (1979, p. 182) and is used in a purely descriptive sense.

3.3.3.2 Alteration assemblages related to Mineralization

Extreme sericite alteration related to increased muscovite and quartz veining of types (iii) and (iv) (cf Section 3) results in the pervasive alteration of the K-Feldspar, plagioclase and biotite over a large area (see Groves and Taylor, 1973). The texture of the original granite is completely destroyed (Figure 3.13), producing a grey rock mainly composed of quartz, sericite and muscovite with accessory tourmaline, cassiterite, and possibly wolframite. Rocks of this type crop out on Cross Creek Road and around the Cream Creek Prospect (Map Sheet 1). The cassiterite bearing samples described below are from the Mt. Paris Mass.

In thin section, anhedral to subhedral quartz up to 5 mm in diameter has straight to moderately undulose extinction. Inclusions of sericite are common. Sericite surrounds quartz, and accessories when they are present and may increase in size up to 0.5 mm, these larger crystals occurring as radiating laths or elongate trains delineating the initial veinlet which produced the alteration. Accessory cassiterite (Figure 3.14) is equant, anhedral to subhedral, up to 1 cm in size with well developed sector zoning and knee twinning. Small euhedral tourmaline laths up to 0.5 mm in length are surrounded by sericite or quartz. Blades of an opaque mineral, possibly wolframite, up to 0.5 mm are present in the vicinity of cassiterite crystals. Samples of quartz-sericite greisen from Cross Creek Road (Map Sheet 1, 70840) contain quartz, sericite, minor clay after biotite, and heamatite probably replacing a sulphide (chalcopyrite, bornite and molybdenite are all accessory sulphides at the Anchor Mine). Figure 3.15 summarizes the vein types associated with mineralization.

3.3.3.2 Style of Mineralization

The style of deposits showing economic significance in the region most closely resembles greisen-style mineralization; however, significant differences are apparent. According to Taylor (1979), greisenization is characterized by intense alteration of the enclosing rocks, abundant formation of topaz, flourite, cassiterite and frequently associated wolframite. Common accessories may include bismuthite, molybdenite, arsenopyrite, tantolite, columbite and minerals of uranium and copper. The deposits consist of regular quartz veins and stockworks.

The major discrepancies between this description and the alteration within the Blue Tier Batholith granitoids are as follows:

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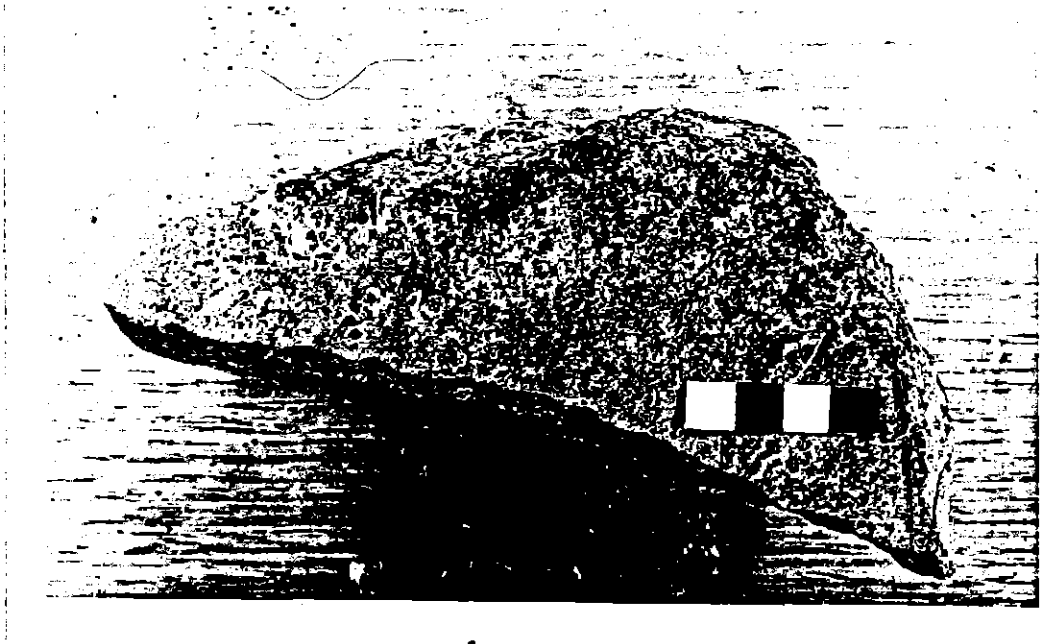

Figure 3.13: Quartz-sericite greisen with accessory cassiterite and tourmaline (70897)

5 cm

0 2 mm

Figure 3.14: Twinned cassiterite in quartz-sericite (tourmaline) "greisen" from Mt. Paris Mass. The needles included in quartz (centre photo) are possibly wolframite (70897) crossed nicols.

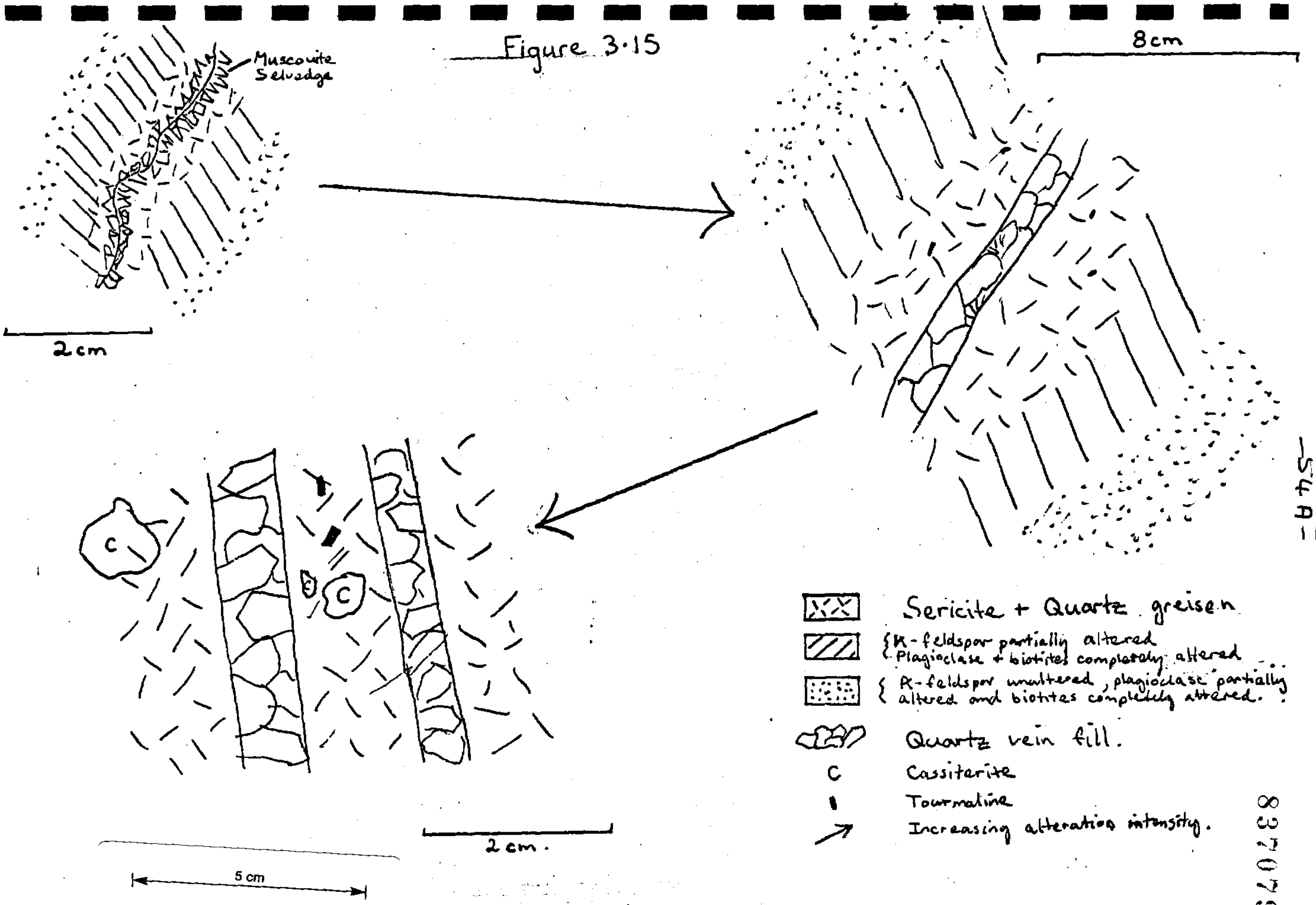
Muscovite Selvedge
2 cm
8 cm
C
C
2 cm.
5 cm
Sericite + Quartz greisen
K-feldspar partially altered
Plagioclase + biotites completely altered
K-feldspar unaltered, plagioclase partially altered and biotites completely altered.
Quartz vein fill.
C Cassiterite
Tourmaline
Increasing alteration intensity.

Figure 3·15

1. Minor flourite is present in some veinlets (type i) but fourite related to the pervasive alteration associated with mineralization is not present as an alteration phase in the greisens observed by this author. Groves and Taylor (1973), however, note the presence of flourite in the Anchor Mine in small quantity.

2. Topaz is not a feature of the greisen alteration associated with the Blue Tier mineralization but rather a late magmatic crystallizing phase (Section 4.3).

The low flourite content reflects the generally low Ca content of the unaltered granites, which is in turn inherited by the greisen assemblages. Topaz, however, is usually stabilized by high flourine fugacities (Glyuk and Anfilogov, 1973) (high F contents of the Anchor orebody are reported by Groves and Taylor,1973),and in the presence of Ca, will be expected to crystallize rather than flourite, if it is stable under the pressure and temperature in the system. Although P-T stability data on topaz are not available a comparison with crystallization of topaz within the Lutwyche orebody N.E. Tasmania, may be useful. The Lutwyche vein system contains early muscovite, topaz, cassiterite and wolframite crystallization followed by sulphide and carbonate deposition with decreasing temperature of the vein fluid (Hellsten, 1979). Estimation of the topaz temperature stability range based on fluid inclusions (Wilkens and Ewald, 1980) yields a temperature interval of 280^{o} to 520^{o} for topaz stability in this environment. The topaz crystallization within the Lutwyche vein system was possibly terminated by a drop in confining pressure of the fluid (Bloom and Simmons, 1980) and hence indicates that topaz stability is possibly highly pressure dependent.

The absence of topaz, therefore, in the Blue Tier alteration can be explained by a drop in confining pressure assuming that the ore forming process was proceeding at a temperature greater than 280^{o}, which is more than likely for a magmatic-hydrothermal derived fluid. This pressure drop is probably related to a fracturing of the host as a result of $P_{fluid} > P_{overburden}$. However, other factors affecting topaz stability cannot be discounted. For example fluid salinity may be another critical factor.

The host mineral for flourine in the greisens, in the absence of topaz and flourite is likely to be sericite as this is capable of containing large quantities of this anion.

3.4 SOURCES OF ALTERATION

3.4.1 Non Fracture Controlled Alteration

The partial replacement of plagioclase by fine grained sericite in the porphyritic biotite adamellite in conjunction with the pristine nature of the biotites suggests that this alteration is probably more a feature of weathering or a low grade deuteric effect. In contrast, the widespread sericitization of early crystallized biotites, accompanied by the less extensive but ubiquitous alteration of plagioclase, in the granites indicates alteration by a meteoric or magmatic hydrothermal fluid. This interpretation is supported by the following observations:

(i) Within the porphyritic biotite cordierite granite, sericitization is common along grain boundaries between some quartz and orthoclase when these are in graphic intergrowth. The intergrowth indicates eutectic crystallization, at which point the magma would be expected to be saturated in volatiles, or to have evolved a separate water-rich fluid phase, which is capable of producing the observed alteration. This is a common feature of pegmatities (Burnham, 1969).

(ii) Alteration along the fractures of the late magmatic topaz within the equigranular biotite granite coupled with the fact that alteration of biotites and plagioclase often extends from sections of the granite that crystallized topaz implies that the lateration is intimately related to the late magmatic crystallization of the rock and hence is indigenous. The evidence for the indigenous nature of the silicification within the granites is:

a) Silicification of the K-Feldspar phenocrysts within the porphyritic biotite cordierite granite along the fractures and cleavage traces of the phenocrysts is optically continuous with their overgrowth of quartz-orthoclase micrographic intergrowth, implying that it is a late magmatic feature.

b) Quartz encrusting topaz must be late in the crystallization sequence of the equigranular biotite granite and if it is an alteration feature (i.e. post-magmatic) then it is likely to be related to this rock.

There is no petrographic evidence that allows the source of albitization to be established. However, its restriction to parts of the equigranular biotite granite may be a reflection of the alteration feature's indigenous relationship to this granite.

3.4.2 Fracture controlled alteration and mineralization

Type (i) sericite veinlets both crosscut and circumnavigate the crystals of their host. This observation combined with the fact that they are in, or close to, equilibrium with plagioclase suggests that they are derived from their host rock and are early postmagmatic in origin (Hibbard, 1980). Similarly, type (ii) veinlets are observed in outcrop to begin and end over several metres, probably diffusing into the groundmass as noted in thin section. These features coupled with the observation that the groundmass plagioclase of the porphyritic biotite cordierite granite is relatively unaltered by the fluid phase involved, are in accord with an early postmagmatic, indigenous source of the fluid that produced these veinlets.

Vein types (iii) and (iv), related to mineralization, are in disequilibrium with the wall rock, resulting in intense alteration of the host. This may reflect the following sources for the fluid:

a) The fluid traversing the host is derived from a different granitoid and hence is in chemical and probably thermal disequilibrium with the host.

b) The fluid is derived from the wall rock but has evolved to the point where it is in disequilibrium with its source rock.

c) The alteration is a result of entrainment and circulation of meteoric water.

The veins associated with mineralization are observed to cross-cut all granitoid variants in the region (this study; Groves and Taylor 1973) and are therefore:

i) related to the latest observed granitic intrusion into the area through possibility (b) above, as postulated by Groves and Taylor (1973) for the formation of the Anchor Mine orebody, or

ii) related to an unexposed granitoid through possibility (a) above.

Several lines of evidence support hypothesis (i):

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- the latest granitoid intrusions throughout the region are the equigranular biotite granite intrusions. The tin deposits are always found adjacent to these intrusions and when within them are always close to their contacts with other granitoids or Mathinna Beds,

- Drilling at the Anchor Mine (Groves and Taylor, 1973) has not encountered any later intrusion below the Anchor orebody that could have given rise to this mineralization either by meteoric water entrainment or by a direct fluid introduction into the host granite. Further, the geometry of the orebody closely follows the roof contact of the equigranular granite host rock.

Within the project area, one line of evidence is available for hypothesis (ii). The porphyritic dyke found along the Frome River near the Cream Creek prospect is the latest intrusion in the area. This dyke is heavily sericitized and hence intrusive activity with related alteration does occur later than the equigranular biotite granite and may represent a possible source of mineralization.

It must be noted, however, that the mineralization in the region need not be formed by the one process and different factors will influence the formation of each individual deposit. For instance, at the Anchor Mine, mineralization is hosted only by the equigranular biotite granite and does not extend into the older adamellite overlying it. At the Cream Creek prospect along Cross Creek Road (Map Sheet 1) and at the FB-Lode, however, porphyritic biotite adamellite is crosscut by mineralizing veins, in close proximity to equigranular biotite granite.

3.5 RELATIONSHIP BETWEEN REGIONAL ALTERATION AND MINERALIZATION

Many greisen style deposits have well developed regional alteration features, typical of apo-granite environments, associated with them (Scherba, 1969). These are developed below the mineralized granite carapace. Albitization and microclimization are widespread features of such environments (Figure 3.16). Albitization is only a very minor alteration within the project area and microclimization was not observed. This does not mean that these alteration types are unimportant in the formation of the Blue Tier mineralization. It may reflect the presently exposed high level within the granitoids, or its development in unexposed rocks.

The major regional alteration types do not crosscut contacts and indigenous features of each granitoid. As a result of this observation entrainment and convection of meteoric water on a regional scale is not considered plausible as a source of mineralization.

Mineralization appears to be strictly fracture controlled. Groves and McCarthy suggest that mineralization at the Anchor Mine resulted from the rise and collection under the roof contact, of a tin rich vapour phase that separated from the equigranular biotite granite.

The ubiquitous sericite alteration and the late crystallizing hydrous minerals observed within the equigranular biotite

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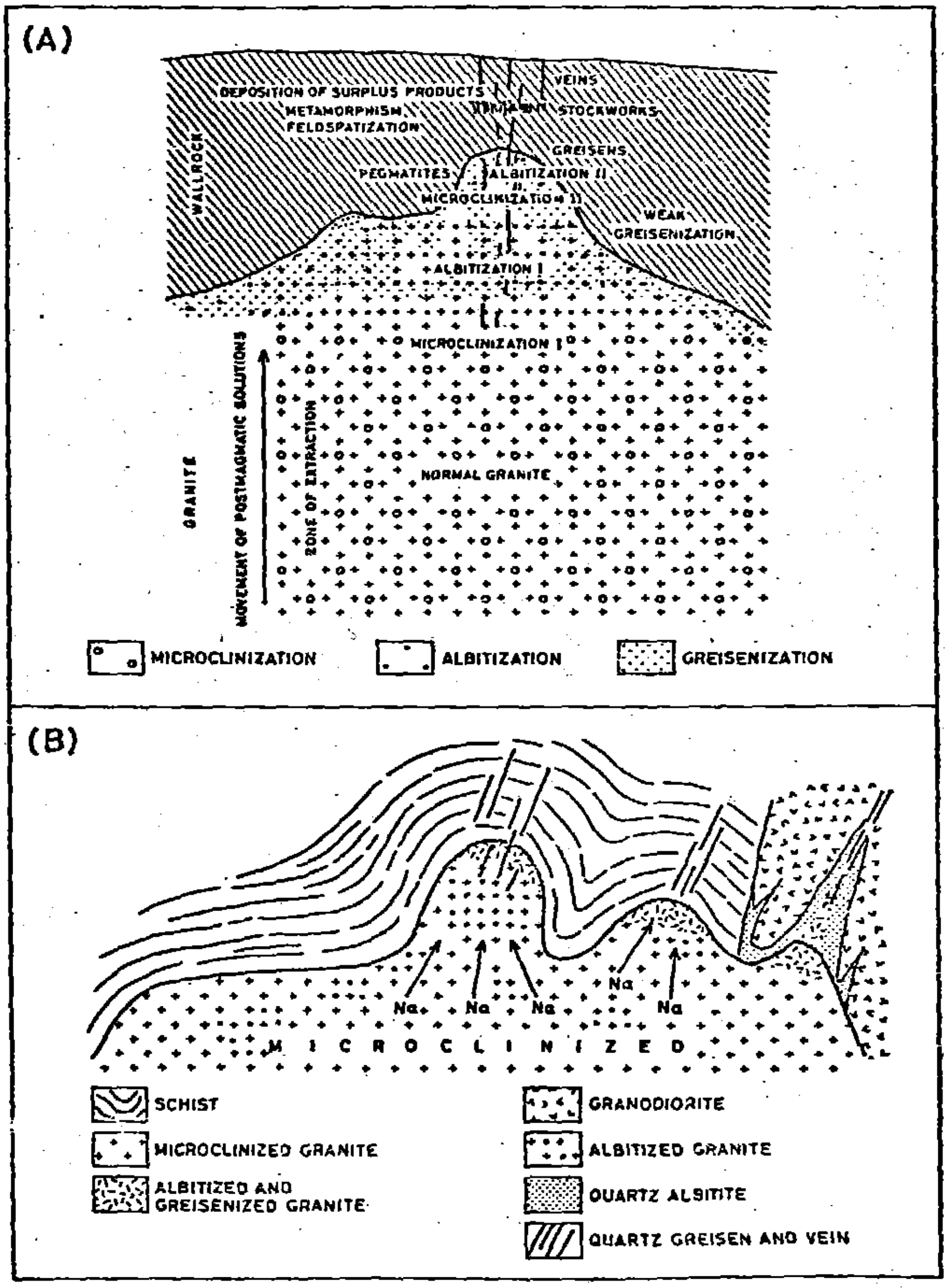

. Aspects of the greisen system.
(A) Alteration effects and vein systems (After Shcherba, 1970)
(B) Development of postmagmatic metasomatism (After Beus and Zalashkova, 1964).

FIGURE 3·16

granite of the project area are in accord with such a model. If the cross section A-A is an accurate interpretation of the geometry of the granitoids, then mineralization is restricted to areas where irregularities in the granite sheets occur. The upper contact geometry at the Anchor Mine similarly plays a major role in control of the orebody orientation there, (Groves and Taylor, 1973). This mechanism is still valid if the observed contacts around Cream Creek continue steeply at depth, as also noted by Groves and Taylor (1973) at the Anchor Mine.

The low initial H_2O content assumed of the equigranular biotite granite (Section 4.1) magma, however, suggests that during formation of the tin orebodies, significant amounts of H_2O were introduced into the rock, possibly from a meteoric source. The close spatial relationship between tin deposits and contacts supports such a conclusion, as Malloe and Wyllie (1975) note that large volumes of meteoric water can travel along such contacts. Criculation along the contact between the hot crystallizing granite and earlier granites may result in crystallization of the pegmatite along the contact noted at the Anchor Mine, and also in sufficient heating of the meteoric water, in order to prevent immediate crystallization of vein material.

3.6 SUMMARY OF ALTERATION AND MINERALIZATION

1. Sericite veins related to mineralization generate pervasive sericite alteration envelopes and when increased in intensity produce quartz-sericite greisens with or without accessory ore minerals.

2. Other vein types in the area are unrelated to mineralization.

3. Regional (non-fracture-controlled) alteration is indigenous to each granitoid in which it occurs and does not crosscut contacts. Convective circulation of meteoric water on a large scale is therefore untenable as an ore forming process.

4. The source of the mineralizing fluid may be related to intrusive activity later than the equigranular biotite granite (previously identified as the source - Groves and Taylor, 1973) but the evidence is tenuous.

5. The fluid which produced the regional alteration of the equigranular biotite granite combined with meteoric water may have produced the greisen orebodies.

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CHAPTER 4

PETROGENESIS

4.1 CRYSTALLIZATION SEQUENCES

Determination of the mineral paragenisis within the major granitoids depends completely on textural criteria, which are ultimately controlled by the crystallization kinetics and composition of each individual system. Crystallization sequences have previously relied on the following textural relationships (Bonwick, 1980):

a) euhedral inclusions within the cores of large euhedral phenocrysts are likely to be nucleated no later than the enclosing phenocrysts:

b) crystals suspended in a melt are likely to grow as euhedral, while during the late stages of crystallization, crystals will mutually interfere and result in an anhedral, interstitial fabric.

These criteria are used in the determination of crystallization sequences for each rock below, and are combined with the alteration described in Chapter 3 to construct paragenetic diagrams.

4.1.1 Porphyritic biotite cordierite granite

The euhedral form of cordierite, plagioclase and K-feldspar is consistent with the crystallization of these phases early in the paragenesis. The lack of groundmass mineral inclusions within quartz phenocrysts indicates that this phase is early, and also applies to the phenocrysts mentioned above. Minor, small, euhedral, unaltered biotite inclusions occur in

K-feldspar and quartz phenocrysts and therefore crystallized before K-feldspar and quartz phenocrysts.

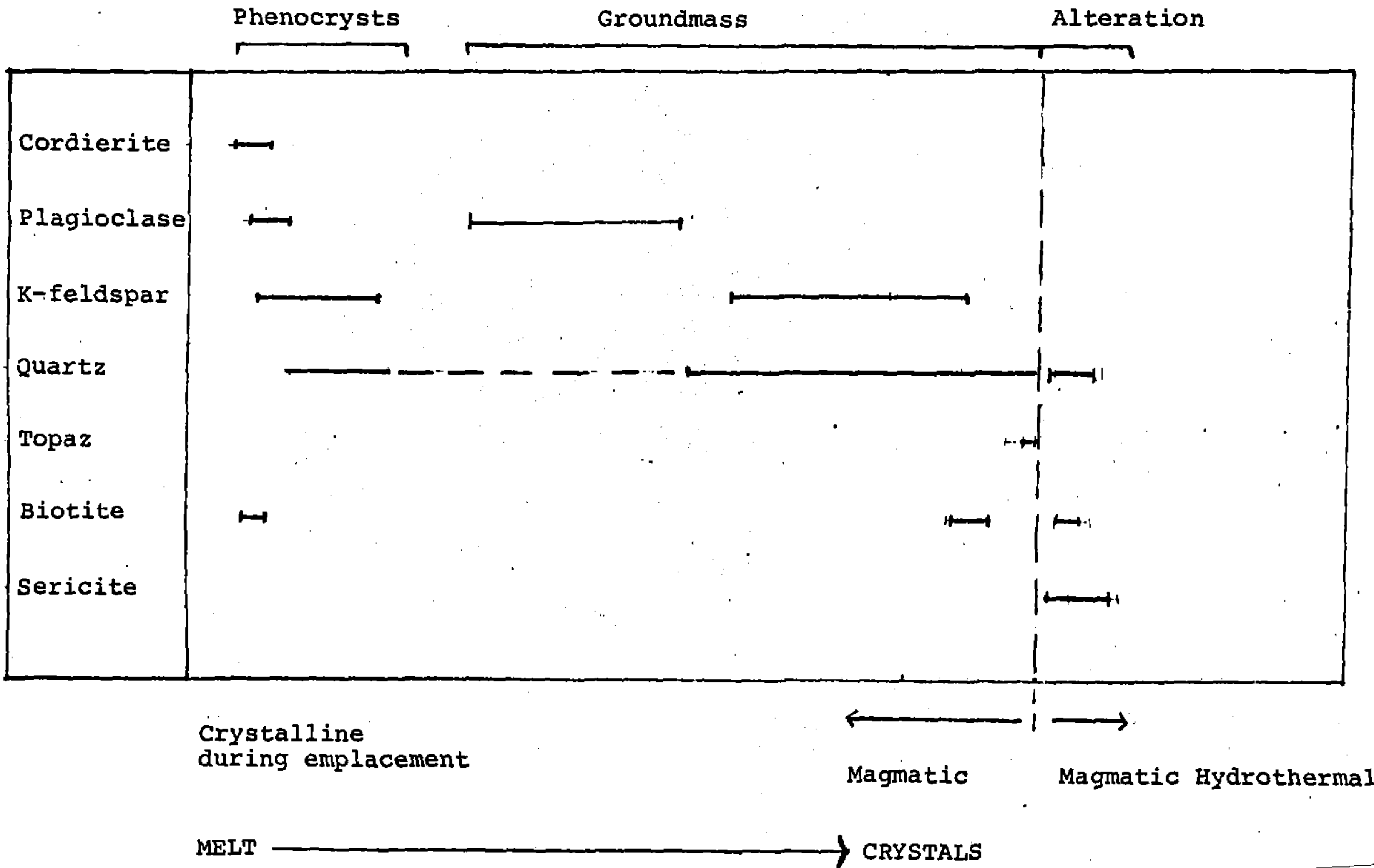
Within the groundmass, plagioclase is euhedral and therefore early in the paragenesis. K-feldspars are anhedral (occasionally enclosing plagioclase) and interfere with euhedral quartz. An overlap in crystallization between quartz and feldspar is indicated. Micrographic intergrowth of quartz and K-feldspar shows that penecontemporaneous crystallization of these minerals occurred. The relative age relation of topaz with groundmass minerals is at least later than quartz. Biotites within the groundmass vary from euhedral (thus early in the paragenesis) to anhedral, secondary biotites (Section 2.1) interstitial to quartz. Groundmass quartz subhedra possibly predated anhedral, rounded quartz grains which themselves are overgrown by interstitial quartz.

The mineral paragenesis of this rock are summarised in Figure 4.1) where postmagmatic alteration is included. The following features are considered consistent with the presence of phenocryst phases during the magma emplacement (as noted on Figure 4.1).

i) The extreme difference in size between pheoncrysts and groundmass.
ii) The lack of groundmass inclusions within the phenocrysts.

If the phenocrysts resulted only from a higher growth rate than the groundmass then inclusions of groundmass incorporated during growth would be expected orientated along the lattice of the phenocrysts and the sharp bimodal grainsize distribution should

Figure 4.1: Crystallization sequence of the porphyritic biotite cordierite granite



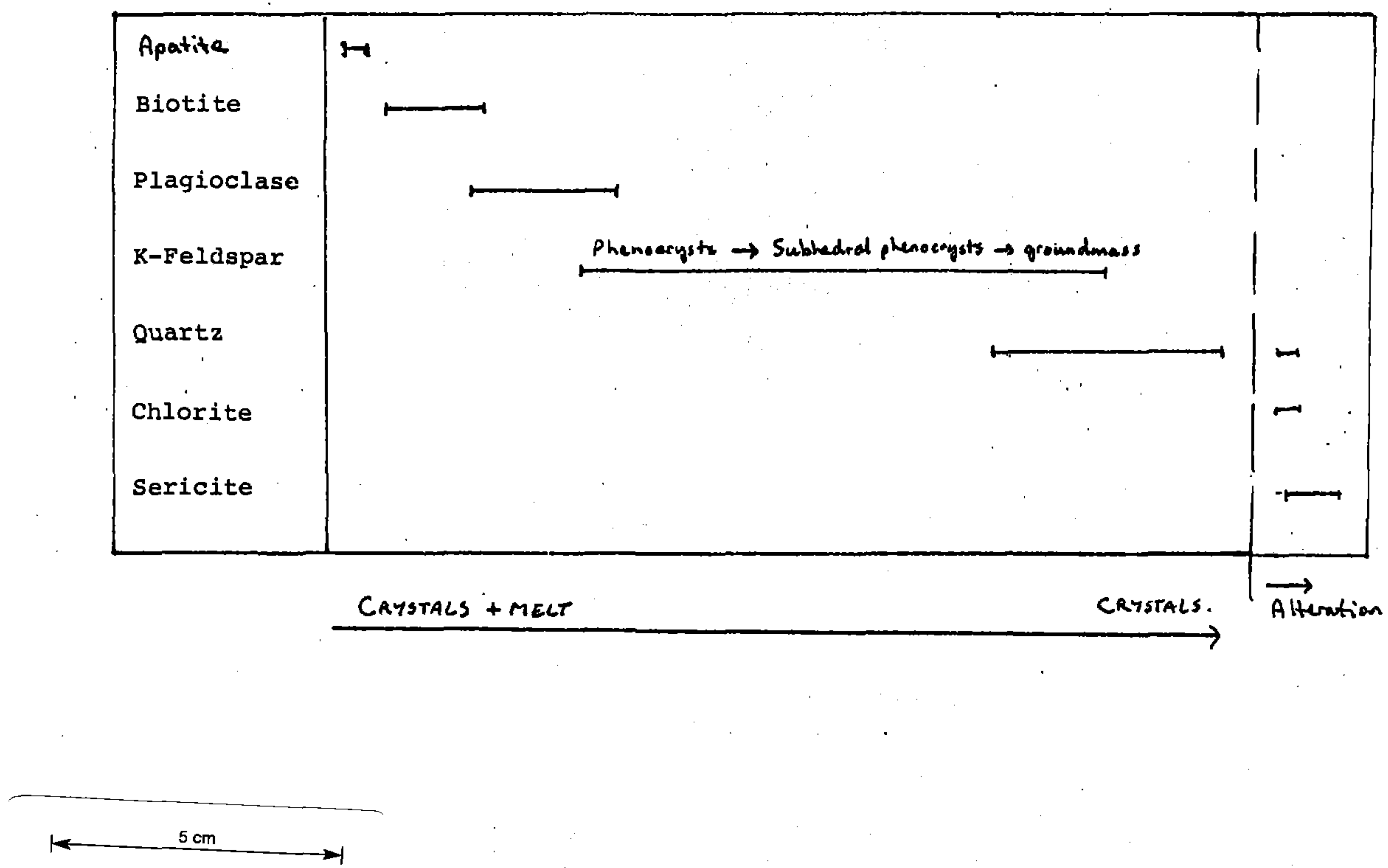
not be as marked. Some K-feldspar phenocrysts do have such inclusions and may have formed in this way, but most are free of groundmass inclusions.

4.1.2 Porphyritic biotite adamellite

Apatite, rounded or hexagonal in cross section or as elongate rods up to 0.2 mm occur as inclusions in euhedral biotites greater than 1 mm long, and are therefore earlier than the biotites. Plagioclase (dominantly euhedral, and therefore relatively early), partially surrounds and rarely encloses euhedral biotites or vice versa, implying an overlap in the crystallization of these two minerals. Euhedral K-feldspar phenocrysts post-date the crystallization of plagioclase and biotite because euhedral plagioclase and biotite occur as inclusions. K-feldspar phenocrysts have continued to grow until quite late in the paragenesis, and a graduation in morphology to subhedral phenocrysts probably exists. Subhedral K-feldspar phenocrysts contain inclusions of biotite, plagioclase and anhedral quartz inclusions, the latter occurring near the phenocryst grain boundaries. This suggests that the latest part of the phenocryst growth overlapped with the groundmass crystallization. This is in accord with experiments by Swanson (1977) on synthetic granitoid melts, indicating that large K-feldspar phenocrysts are capable of growing at near solidus temperatures "pushing aside" groundmass minerals, or more likely including them along grain boundaries.

Anhedral irregular groundmass K-feldspar contains rare inclusions of biotite and surrounds plagioclase, quartz and K-feldspar

Figure 4.2: Crystallization Sequence of the Porphyritic Biotite Adamellite



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phenocrysts. Quartz surrounds K-feldspar, plagioclase and biotite. The irregular, anhedral nature of groundmass K-feldspar and quartz, and their textural relationships suggests these phases are late and overlap in the paragenesis. Alteration minerals are again included in the paragenetic diagram Figure 4.2.

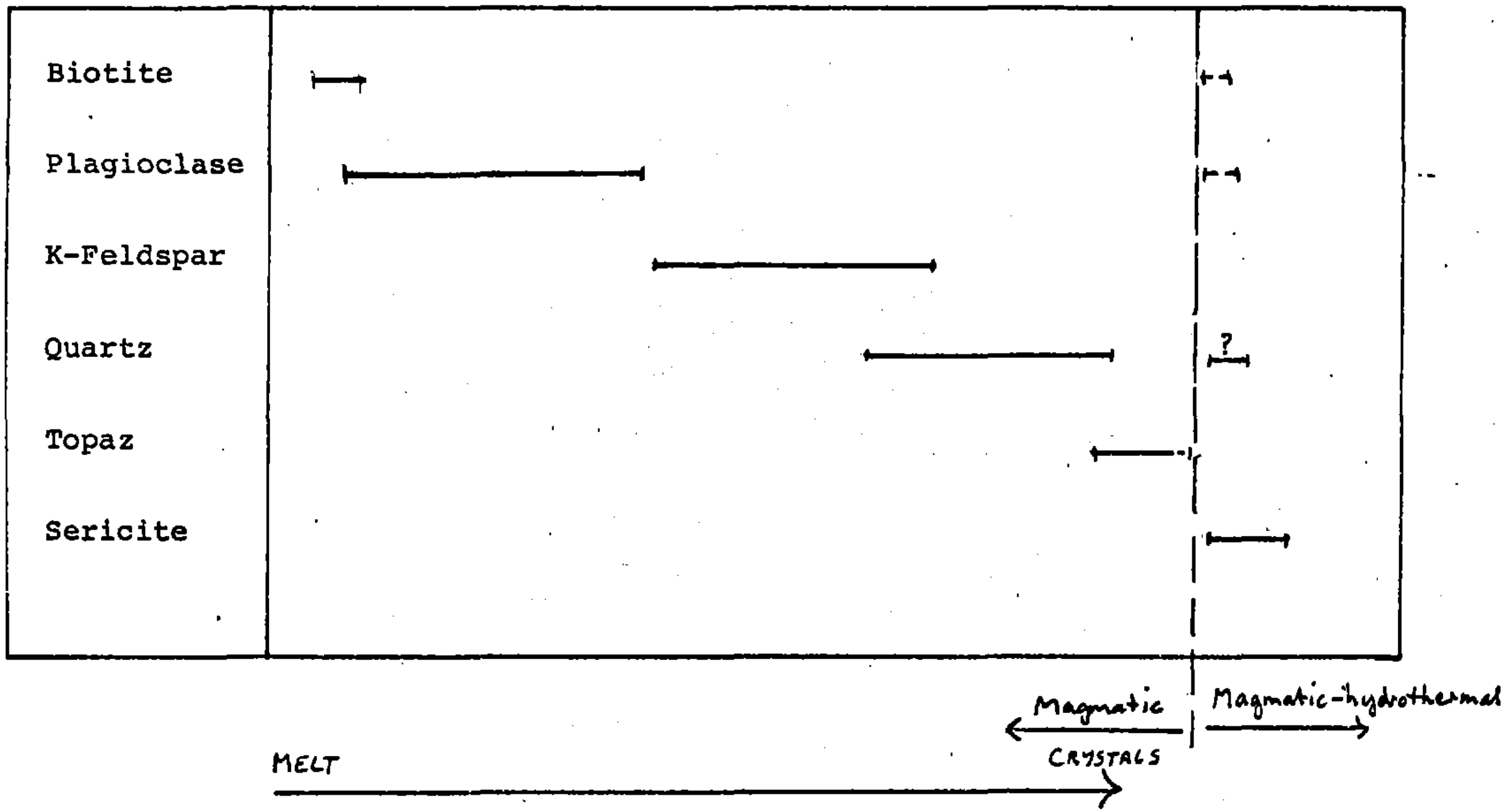
4.1.3 Equigranular biotite granite

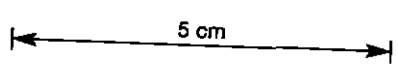
Plagioclase is the dominanting euhedral phase, surrounded by biotite, K-feldspar, later plagioclase and topaz. Minor, euhedral biotite occurs partially enclosed by plagioclase implying a short crystallization overlap of biotite and plagioclase. K-feldspar is anhedral, frequently containing inclusions of plagioclase and so has crystallized later than plagioclase. Linear K-feldspar crystallized before quartz; while inclusions of quartz in K-feldspar, however, suggest an overlap in the paragenesis of these two minerals.

Some primary biotites also occur interstitial to quartz and K-feldspar and hence are later than these minerals. Topaz varies from euhedral to anhedral, but nearly always has encrusted K-feldspar or quartz and as such is later in the paragenesis than these two minerals. Secondary minerals include biotite, sericite and sodic feldspars.

The crystallization sequence of this rock is summarised in Figure 4.3.

Figure 4.3: Crystallization sequence of the Equigranular Biotite Granite





4.1.4 Leucrocratic micro granites

The anhedral nature of all minerals within these rocks is consistent with their contemporaneous crystallization. This is consistent with the presence of micrographic intergrowth between quartz and K-feldspar, and quartz and plagioclase. Muscovite and biotite are present as post magmatic phases within microlytic cavities.

4.2 EMPLACEMENT LEVEL AND PRESENT LEVEL OF EXPOSURE

Groves (1977) notes the presence of narrow, spotted hornfels zones near the Mathinna Bed - granitoid contacts which contain muscovite, biotite, quartz and cordierite, and notes that the presence of cordierite indicates a low pressure, hornblende hornfels facies metamorphism. Cordierite is lacking further from the contact and an albite epidote facies metamorphism is indicated by the assemblage - quartz - muscovite - biotite - chlorite (Groves, 1977). The presence of subvolcanic activity within the area may also indicate intrusion into a high level of the crust, although the porphory dykes may be significantly later than the granitoid intrusions.

The presence of roof pendants and screens of Mathinna Beds around the Mt. Paris Mass and between the Poimena and Ansons Bay Plutons suggests that the present level of exposure is high in the Blue Tier Batholith.

4.3 VOLATILES

4.3.1 Water content

In order to have reached such a high level in the crust the granitoid melts of the Blue Tier Batholith must have been relatively dry at depth, prior to and early, during emplacement. Wet granite magmas will crystallize through a pressure drop during emplacement despite the heat of crystallization (Pitcher, 1979). This reflects the sensitivity of water solubility in the melt to confining pressure (Burnham, 1980).

A low water content during the initial stages of crystallization of the porphyritic biotite cordierite granite and of the equigranular biotite granite melts is indicated by their low biotite contents and the lateness in the paragenesis of many of these biotites (Malloe and Wyllie, 1975). The porphyritic biotite adamellite melt must initially have contained more water than the granitic melts, as the biotites of this rock are early in the crystallization sequence (Malloe and Wyllie, 1975). Crystallization of the biotite, however, probably reduced the water content of the melt which was then emplaced with biotite as a solid phase.

Crystallization of dominantly anhydrous phases will eventually result in the water saturation of a melt that had a low initial water content, and further crystallization will result in the separation of an H_2O-rich fluid phase from the remaining melt (Johns and Burnham,1969). This is consistent with formation of the indigenous regional and fracture controlled alteration features described in Chapter 3.

4.3.2 Flourine

Analyses of the porphyritic biotite cordierite granite and the equigranular biotite granite show these rocks to be enriched in flourine (Tables 5.2,5.3). This is reflected in the pressure of topaz throughout these rocks, which is stabilized by high flourine fugacities (Glyuk and Anfilogou, 1973). The consistently higher flourine content of the equigranular biotite granite, as relative to the cordierite bearing granite, correlates with the higher abundance of topaz in the former rock unit. This implies that topaz is indeed the dominant flourine-bearing mineral phase.

The lateness in the paragenesis of topaz suggests that HF was partitioned into the melt, along with H_2O during the crystallization of mainly anhydrous minerals. The lack of topaz associated with any fracture controlled alteration implies that it crystallized from the magma rather than a hydrothermal fluid. This is in accord with the results of Fuge (1977) and Wyllie and Tuttle (1961) that show HF and NaF to be even more soluble than water in granitic melts. HCl and NaCl, however, have very low solubilities in silicate melts (Wyllie and Tuttle, 1964) and HF and NaF are preferentially concentrated in the melts while the chlorides are expelled from the melt and form separate phases (with or without H_2O).

If the topaz is a magmatic product, then a melt crystallizing K-feldspar that becomes sufficiently enriched in HF may crystallize topaz as a result of the following equilibrium:

$$\underset{\text{Orthoclase}}{2KAl(Si_3O_8)} + 4HF = 2KF + 5\,SiO_2 + \underset{\text{Topaz}}{Al_2(SiO_4)F_2} + 2H_2O$$

The sericite occurring along fractures and rimming topaz is an alteration feature, not a reaction product between topaz and any other mineral in the granite. The topaz then is in equilibrium with K-feldspar, albite, quartz and a vapour phase probably consisting predominantly of H_2O and HF. This equilibrium is represented in area II of the phase diagram of Glyuk and Anfilogou (1973) of the system granite - H_2O-HF (Figure 4.4), placing a maximum of 2 weight percent flourine in the equigranular biotite granite during the closing stages of crystallization.

4.4 SOURCE OF GRANITOIDS

The porphyritic biotite adamellite, the porphyritic biotite cordierite granite and the equigranular biotite granite all classify as S-type granitoids (Chappell and White, 1974). This is based on the following observations:

1) When fresh biotites are found (usually as inclusions in quartz within the granites) they have deep red brown pleochroism, abundant pleochroic halos and apatite inclusions.

2) The rocks are highly corrundum normative (Tables, 5.1, 5.2, 5.3).

3) Xenoliths are rare but when found within the porphyritic biotite adamellite consist of dark mafic types, which either represent granodioritic inclusions or are cagnate clots of early crystallized phases. The latter origin is more likely as hornblende is not found in the inclusions, but is abundant in the granodiorites. The second inclusion type is an aluminous, high grade regional metamorphic xenolith, which may represent source material, possibly Precambrian crustal material, (Compston and Chappell, 1979).

The S-type classification indicates a source rock of deep crustal metasedimentary material, (Chappell and White, 1974).

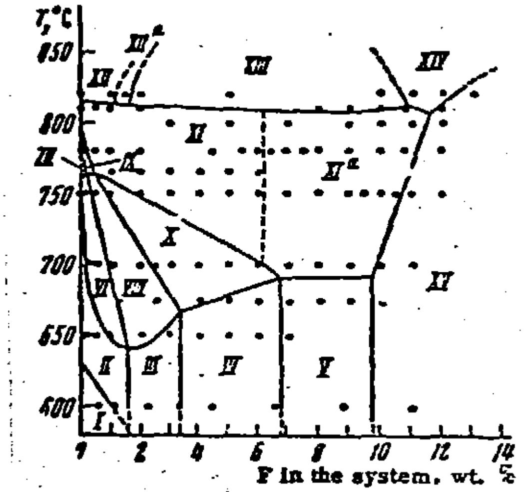


Fig. 1. Phase diagram of the system granite-H_2O-HF at 1000 kg/cm^2 pressure.

Equilibria: I) K - f + Ab + Q + M + v; II) K - f + Ab + Q + T + v; III) Ab + Q + T + v; IV) Q + T + v; V) Q + V; VI) K - f + Ab + + Q + T + L_1 + v; VII) K - f + Ab + Q + T + + L_1 + v; VIII) Ab + Q + T + L_1 + v; IX) Ab + + Q + L_1 + v; X) Q + T + L_1 + v; XI) Q + + L_1 + v; XII) L_1 + v; XIII) L_1 + L_2 + v; XIV) L_2 + v; XV) v. Region XIIa) microliquation; XIa) region of formation of Si(O, F)$_2$ phase. Abbreviations: K - f - K-feldspar, Ab) albite, Q) quartz; T) topaz, M) mica, L_1) silicate melt. L_2) fluorido melt, v) supercritical aqueous solution.

FIG. 4.4

CHAPTER 5

GEOCHEMISTRY

5.1 INTRODUCTION

The major and trace element data for granodiorites, adamellites and granites are first presented in the following section. Before these are interpreted the effects of alteration on the chemistry of the granitoids is examined. Major and trace element analyses and CIPW norms for the porphyritic biotite adamellites, equigranular biotite granites and the porphyritic biotite cordierite granite are listed in Tables 5.1, 5.2 and 5.3 respectively.

5.2 GEOCHEMISTRY OF GRANITOIDS

5.2.1 Major Elements

Harker diagrams of selected major oxides for granodiorites, adamellites and granites are shown plotted on Figures 5.1, a - e. Each rock type plots as a distinct field with little or no overlap between fields except in the case of the granites. The porphyritic biotite cordierite granite and the equigranular biotite granite cluster together as one field in all the diagrams, while granodiorite and adamellite form fields distinct from each other and from the granites.

Trends within individual clusters are mostly ill-defined but when present follow the general trend from granodiorite to granite. The granodiorites decrease in MgO and increase in K_2O with increasing silica content, while FeO, CaO and Na_2O do not display any dependence on silica. Negative slopes

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TABLE 5.1: MAJOR AND TRACE ELEMENT ANALYSES OF THE PORPHYRITIC BIOTITE ADAMELLITE

LE NO.	70848	70882	70846	70845	70833	70836	Average*
jor ents	$\bar{x}$	$\bar{x}$	$\bar{x}$	$\bar{x}$	$\bar{x}$	$\bar{x}$	
2	72.88	72.97	72.28	68.69	73.33	72.74	72.15
	0.27	0.22	0.32	0.26	0.25	0.29	0.27
03	14.54	14.97	14.88	16.99	14.82	16.63	15.47
	2.13	1.77	2.41	2.2	1.86	1.52	1.98
	0.04	-	-	-	-	-	-
	0.72	0.63	0.81	0.69	0.54	0.78	0.70
	1.5	1.55	1.24	1.61	1.08	0.10	1.3
0	3.19	3.01	3.25	3.72	2.77	2.12	3.01
	4.71	4.88	4.80	5.81	5.32	6.14	5.28
	0.36	0.11	0.12	0.10	0.08	x	
ace ments							
	284	293	316	153	341	361	295
	131	121	145	116	140	109	127
	395	395	343	332	419	428	385
			15	10	20	x	9
	10	10	25	25	25	x	18
	60	50	90	50	65	x	63
S							
	33.11	31.59	29.89	19.18	32.78	34.71	30.10
	2.06	1.91	2.07	1.66	2.54	6.29	2.05
	24.77	28.84	28.37	34.34	31.44	37.18	32.51
	27.16	25.47	27.50	31.47	23.44	17.85	24.35
	7.49	7.69	6.15	7.99	5.36	0.50	6.56
	4.27	3.55	4.70	4.22	3.41	3.48	4.03
	0.64	0.52	0.71	0.65	0.55	0.45	5.00
	0.51	0.42	0.61	0.49	0.47	0.55	0.52

*70836 not included

TABLE 5.2: MAJOR AND TRACE ELEMENT ANALYSES FOR THE EQUIGRANULAR BIOTITE GRANITE

SAMPLE NO.	70850	70852	70868	70866	Average
Major Elements	$\bar{x}$	$\bar{x}$	$\bar{x}$	$\bar{x}$	
SiO_2	75.38	76.20	76.04	76.84	76.12
TiO_2	-				-
Al_2O_3	15.01	14.55	14.47	14.03	14.52
FeO	0.79	0.77	0.96	0.67	0.80
MnO	-	0.02	0.02	0.05	0.02
MgO	0.16	0.08	0.14	0.13	0.13
CaO	0.05	0.05	0.04	0.15	0.07
Na_2O	3.76	3.55	3.33	3.52	3.54
K_2O	4.83	4.77	4.8	4.62	4.76
F	0.45	0.43	0.43	0.39	0.43
Trace Elements					
Rb	703	739	794	650	722
Sr	2	4	6	5	4
Ba	22	15	17	17	18
Cu	-	5	-	25	15
Pb	5	10	45	360	15
Zn	50	55	65	70	60
CIPW NORMS					
Q	34.2	36.58	37.44	37.2	36.40
C	3.51	3.46	3.73	2.97	3.42
OR	28.55	28.19	28.43	27.31	28.2
AB	31.81	30.04	28.26	29.78	30.10
AN	0.25	0.25	0.20	0.74	0.32
HY	1.44	1.26	1.67	1.31	1.42
MT	0.23	0.23	0.29	0.2	0.26

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TABLE: 5.3

MPLE NO.	70865	70863	Average	70873	70838
jor ements	$\bar{x}$	$\bar{x}$		$\bar{x}$	$\bar{x}$
	77.12	76.28	76.7	75.6	77.47
	-	0.01	-	0.04	0.20
	13.39	14.09	13.74	14.71	13.96
	0.72	0.9	0.81	0.25	2.72
	0.01	0.01	0.01	-	0.16
	0.06	0.06	0.06	0.09	0.71
	0.29	0.02	0.16	0.24	0.06
	3.36	3.04	3.20	3.5	-
	5.01	5.59	5.30	5.41	4.72
	0.29	0.16	0.23	-	-
ce ements					
	513	486	500	403	782
	8	16	12	13	16
	32	115	74	27	324
	10	-	5	x	x
	40	30	35	x	x
	90	35	63	x	x
s					
	36.26	36.51	36.91	33.83	
	1.91	3.00	2.45	2.66	
	29.61	33.04	31.43	31.98	
	28.43	25.72	27.07	29.70	
	1.44	0.10	0.76	1.19	
	1.13	1.34	1.23	0.48	
	0.22	0.26	0.24	0.07	
	-	-	-	0.08	

70865
70863 - Porphyritic biotite cordierite granite

70873 - Leucocratic microgranite

70838 - Quartz-sericite greisen

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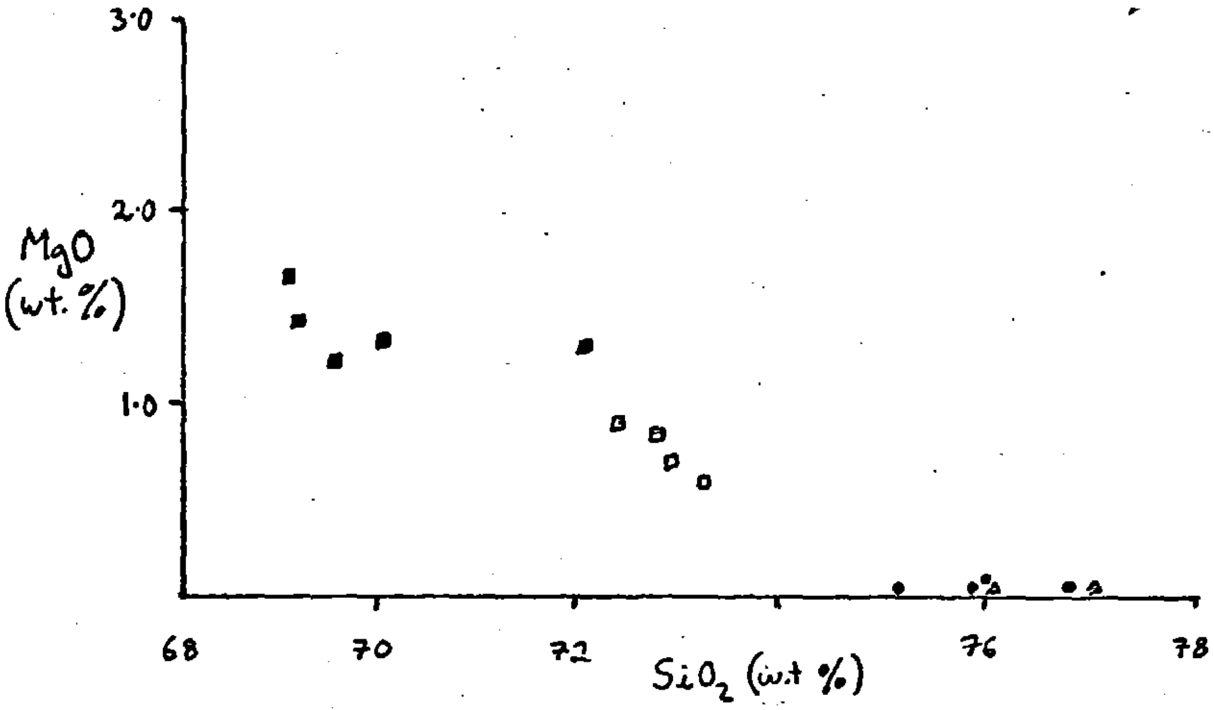

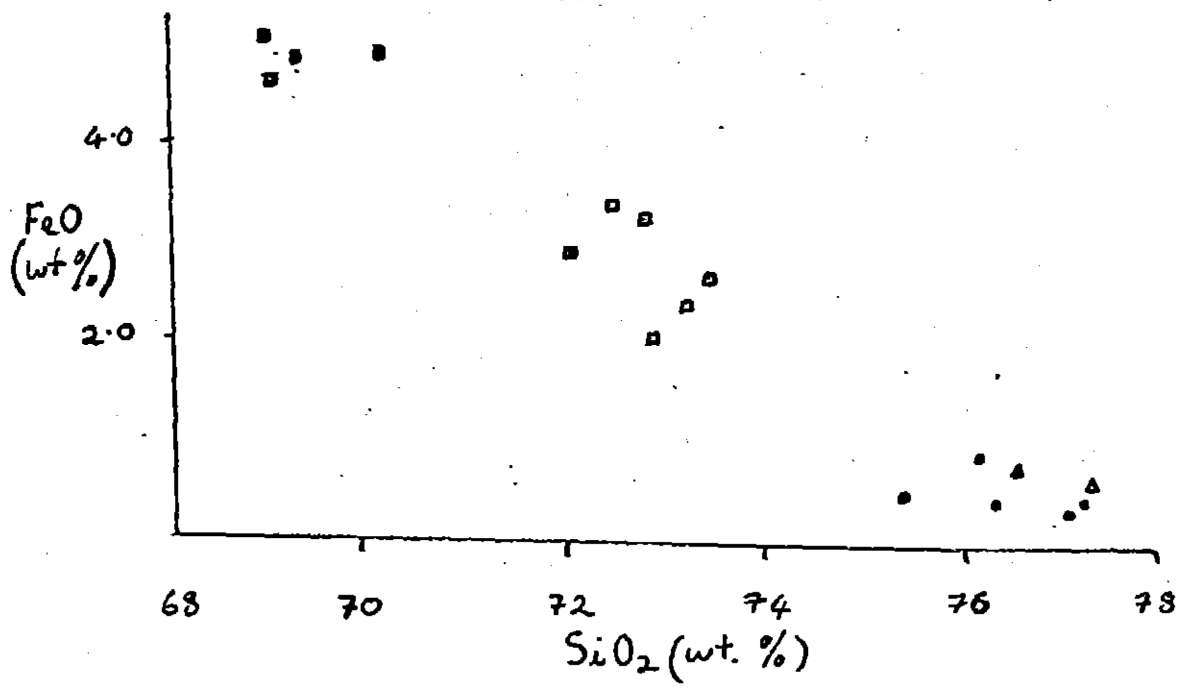

Figure 5·1 (a),(b)

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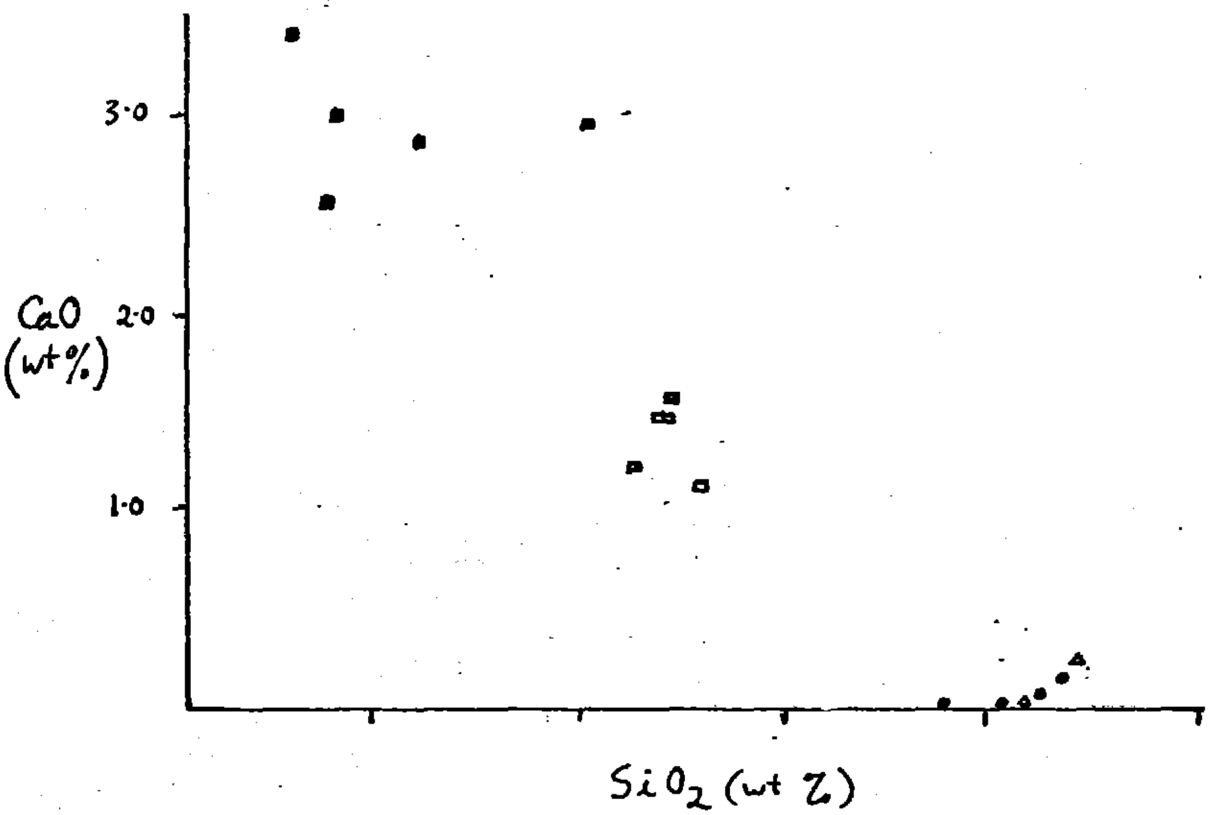

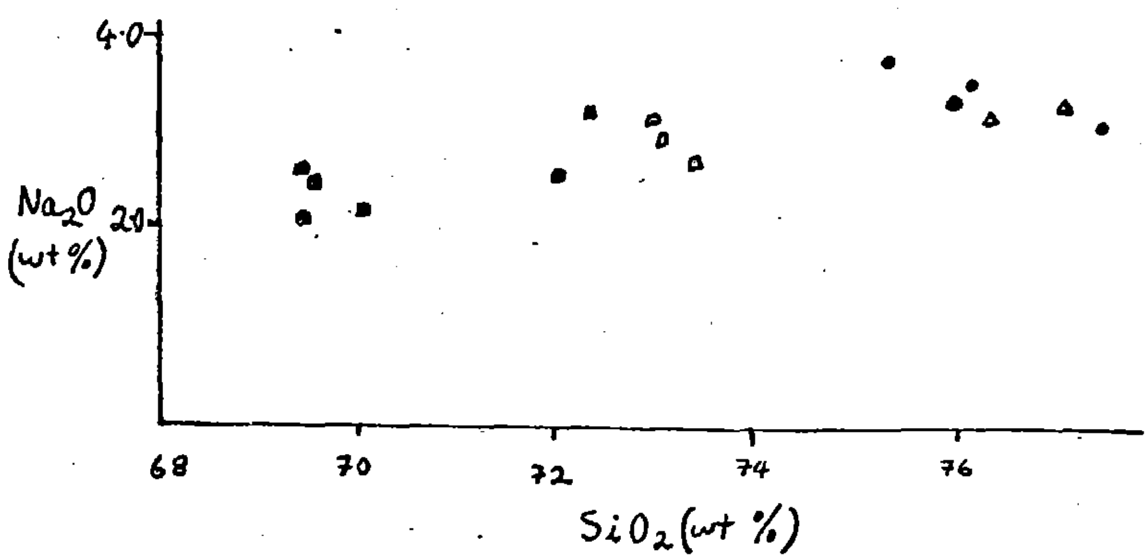

Figure 5·1 (c), (d)

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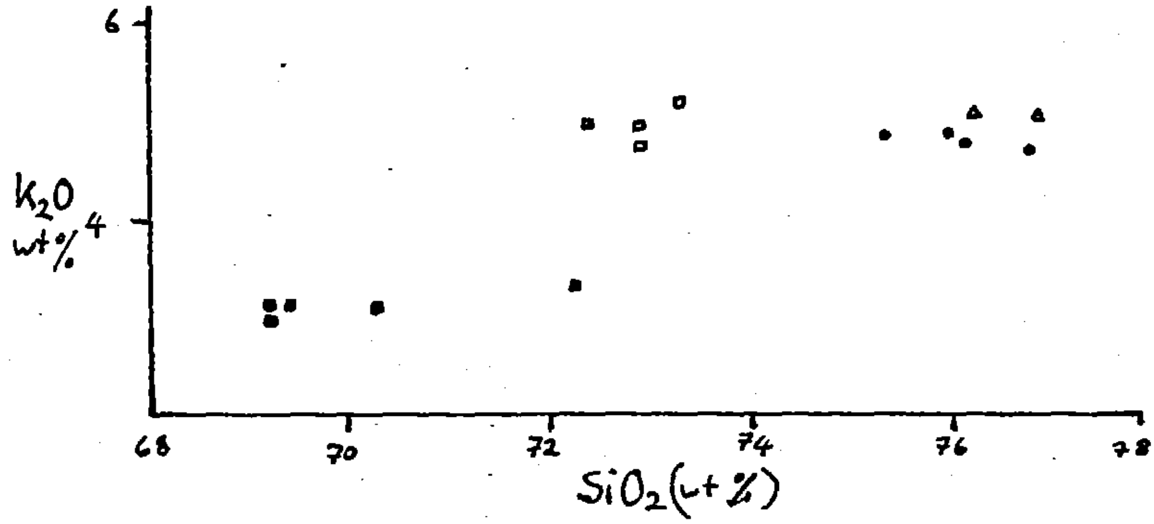

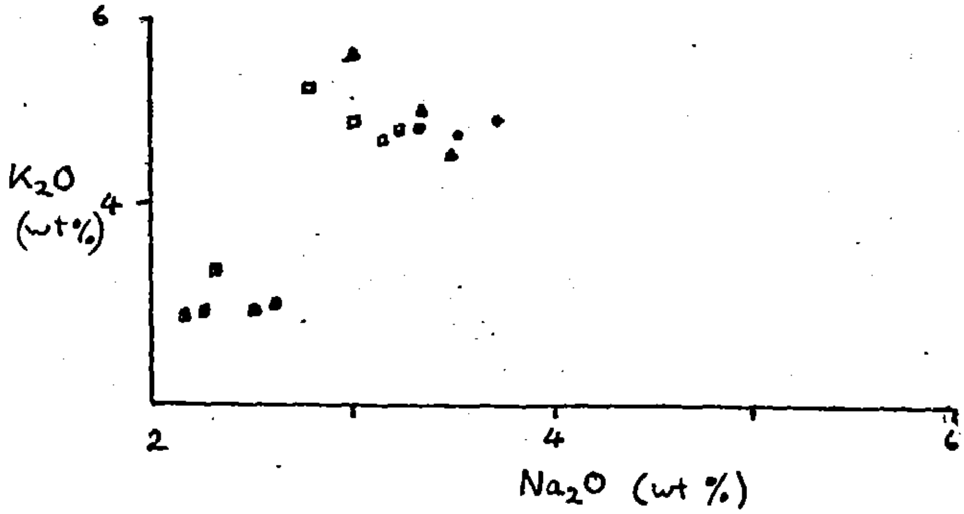

Figure 5·1 (e),(f)

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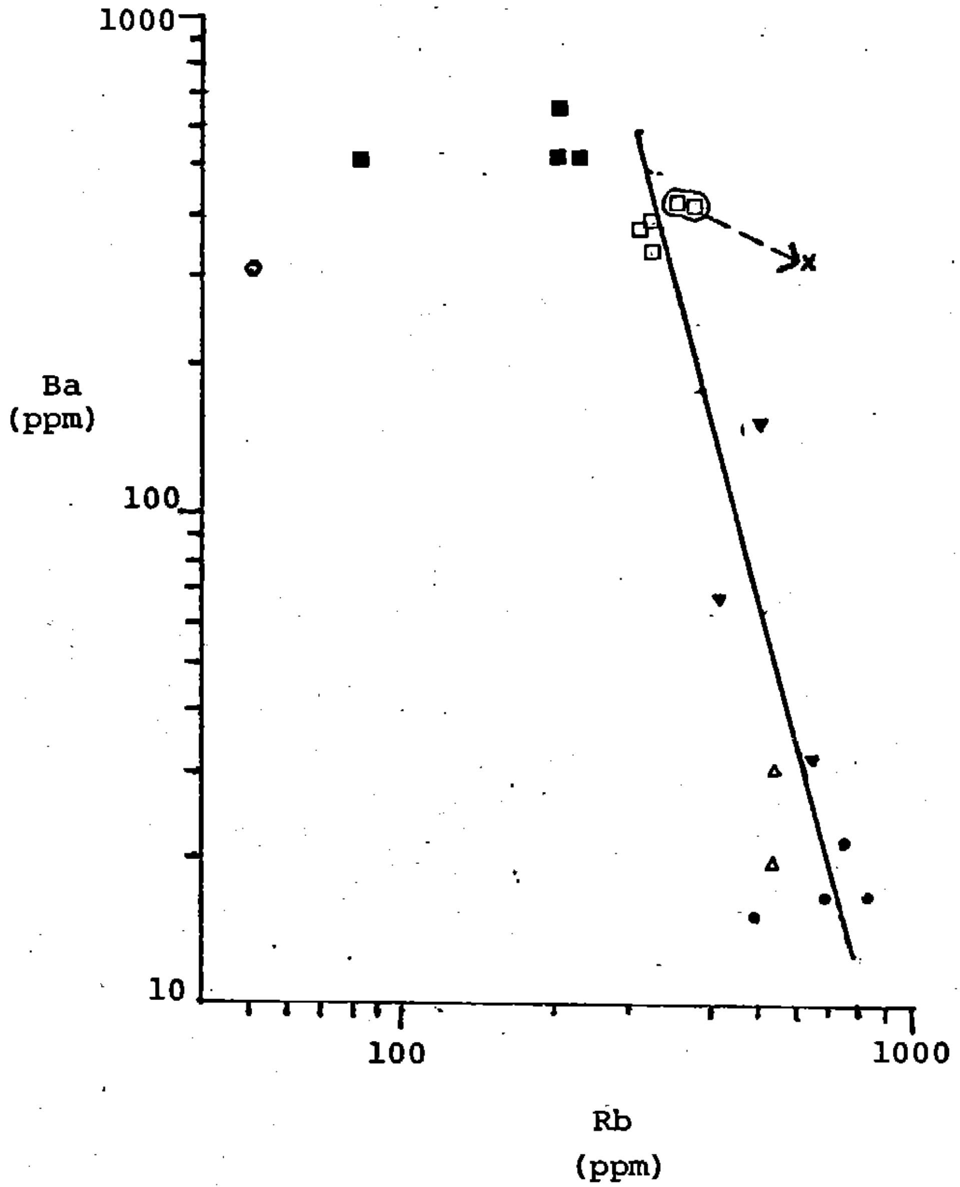

Figure 5.2: Plot of Rb versus Ba for major rock types

■ Granodiorites (from Groves, 1977)

□ – Porphyritic biotite adamellite

▲ – Porphyritic biotite cordierite granite

▼ – Prophyritic biotite cordierite granite – analyses from Aberfoyle Exploration

● – Equigranular biotite granite

– Quartz – sericite greisen

⇢ – Trace element change from host (circled) to sericitised rock.

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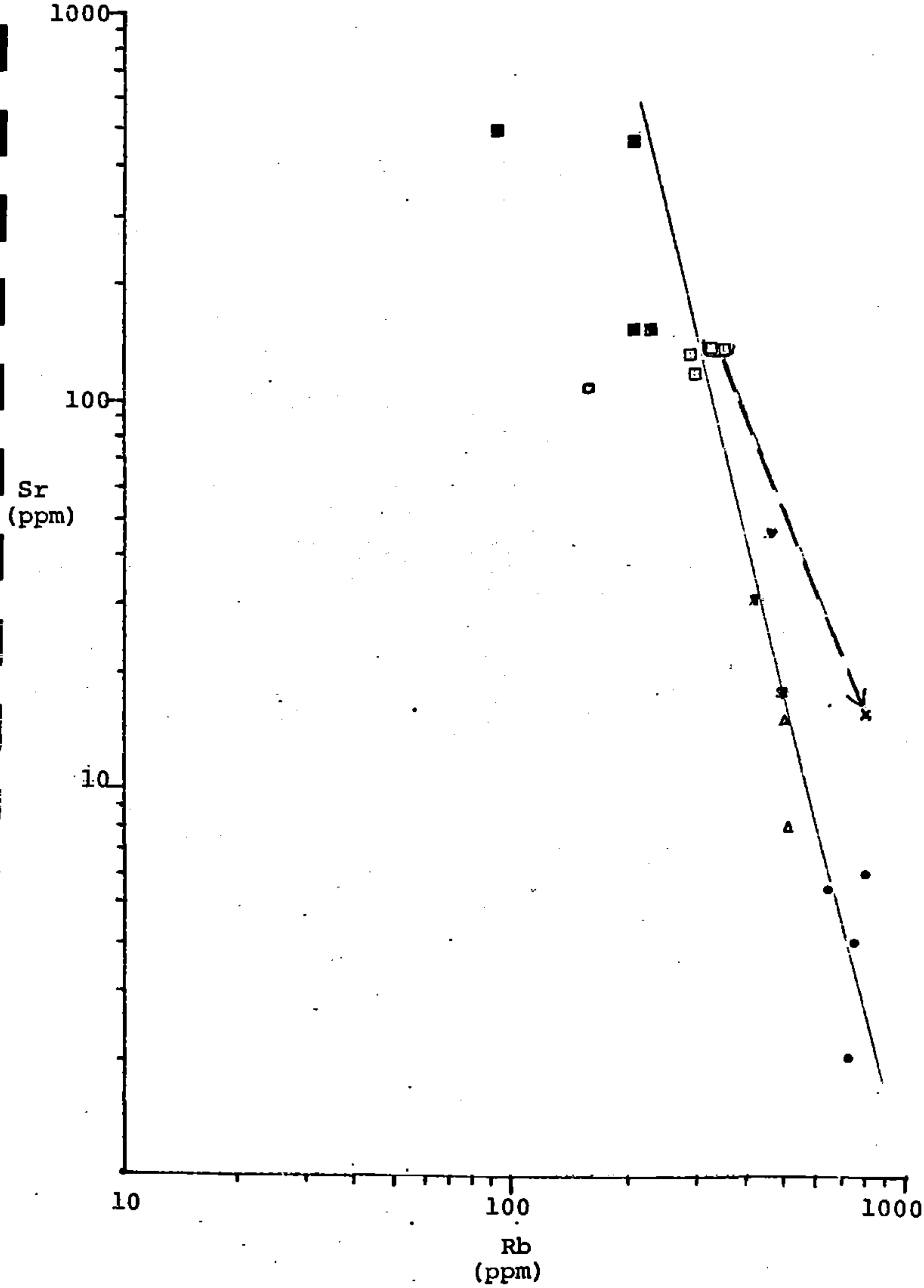

Figure 5.3: Plot of Sr versus Rb for major rock types. Symbols as for Figure

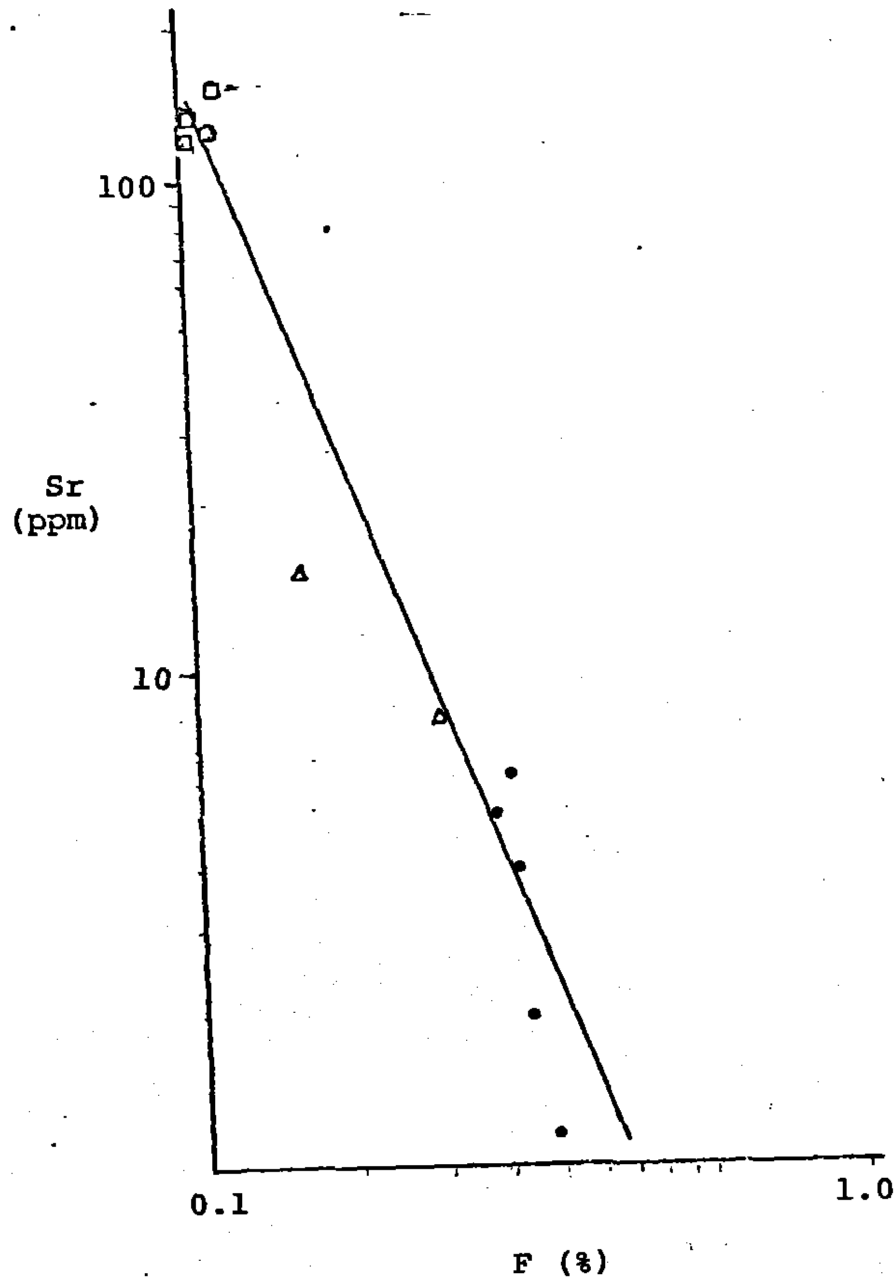

Figure 5.4: Plot of Sr versus F for major rock types
Symbols as for Figure

of MgO vs SiO_2 and FeO vs SiO_2 are evident in the adamellite which do not depict any CaO, Na_2O or K_2O dependence on silica. The granites do not show any correlation between silica and the major oxides, with the exception of FeO which has an ill-defined negative slope against silica.

5.2.2 Trace Elements

The granodiorites and adamellites have Ba, Sr and Rb abundances typical of their repsective rock types, while the equigranular biotite granite contains extremely low Ba and Sr abundances and high Rb and F contents. The porphyritic biotite cordierite g-anite collected from the project area has a variable but low Ba and Sr content and high Rb and F, which may be intermediate in abundance to the adamellites and equigranular biotite granite trace element contents. Samples from the north of the Mt. Paris mass, mapped by Groves (1977) as the same as the cordierite bearing granite in the project area, are also plotted (Young, 1978) and serve to extend the trace element range of this rock, filling the gap between adamellites and granites (Figures 5.2, 5.3 and 5.4).

A linear trend, or log-log plots, from adamellite to porphyritic cordierite biotite granite to equigranular biotite granite is marked by a decrease in Sr and Ba and an increase in F and Rb. Granodiorites express this overall trend of decreased Rb and F and increased Sr and Ba with more mafic rocks but do not extend the straight line trend defined by the other granitoids.

The granites within the project area, however, are altered and their geochemistry may reflect this. Before any interpreta-

TABLE 5.4: TRACE ELEMENT DATA FOR ROCKS

Courtesy of Aberfoyle Exploration Pty. Ltd.

Lithology	Rb	Sr	Ba	F(%)	Sr
Porphyritic biotite cordierite granite+	400	30	70	0.17	20
" " " " +	500	46	150	0.17	20
" " " " +	470	18	15	0.18	20
Porphyritic biotite adamellite*	300	75	170	.06	16
Equigranular biotite granite*	760	20	25	0.17	28
Equigranular biotite granite*	760	5	10	0.12	20

+Used in Figure

tion of the major and trace element data can be made, the effects of hydrothermal activity on their distribution must be determined. This is exemplified by the trace element data of Olade (1980) for the Nigerian Younger Granites. This worker notes that the trace element data reflects the alteration of the Nigerian granites, and are not primary magmatic features.

5.3 GEOCHEMISTRY OF ALTERATION

5.3.1 Major Element Chemistry

Major element changes during the non-fracture controlled alteration of the granites are minimal. The porphyritic biotite cordierite granite is slightly higher in silica than the equigranular biotite granite. This may either be a primary magmatic feature or a result of silicification. The most heavily albitized granites (70868, 70866) are no higher in Na_2O than their less albitized counterparts. No correlation between the freshness of each rock analysed and its major element chemistry is apparent.

The most definitive major element changes will result from the fracture controlled alteration related to mineralisation, where wall rocks are out of equilibrium with the fluid passing through the vein system.

Increasing alteration from the freshest sample of porphyritic biotite adamellite, found near the greisen occurring as float on Cross Creek Road, to the same rock type with heavily sericitized plagioclase and partially chloritized biotites (found close to greisen samples along Cross Creek Road) is reflected in the loss of some Na_20 and a great deal of $Ca0$ relative to K_20 (Figure 5.5 a, b). Complete alteration to a quartz-sericite greisen (Cross Creek Road, 70838) results in the complete, and almost complete, loss of Na_20 and $Ca0$ respectively, while K_20 increases relative to these major oxides. Figure 5.5 (b) shows the increase in $Si0_2$ relative to K_20 expected during sericitization and silicification. Bulk rock analyses, however, (Table 5.3) show that sericitization reflects a decrease in Na_20 and $Ca0$ rather than an increase in K_20 which is in fact decreased during the alteration.

The quartz-sericite alteration of feldspars by a K-bearing aqueous fluid can be expressed:

$$\underset{\text{albite}}{\tfrac{3}{2}\,NaAl(Si_3O_8)} + H^+ + \tfrac{1}{2}K^+ = \underset{\text{muscovite}}{\tfrac{1}{2}KAl_3Si_3O_{10}(OH)_2} + 3SiO_2 + \tfrac{3}{2}Na^+$$

$$\underset{\text{orthoclase}}{\tfrac{3}{2}\,KAlSi_3O_8} + H^+ = \underset{\text{muscovite}}{\tfrac{1}{2}KAl_3Si_3O_{10}\,(OH)_2} + 3\,SiO_2 + K^+$$

Calcium in the anorthite component of plagioclase will behave similarly to the sodium in albite. As a result of the above reactions Na^+ and Ca^{2+} will be transferred from the rock to the fluid. If the orthoclase and albite (anorthite) content of the rock are similar as they are in this case (see modal analyses, Table 2.1 for porphyritic biotite adamellite) then a net decrease in the K^+ content of the wall rock will also result, as is observed.

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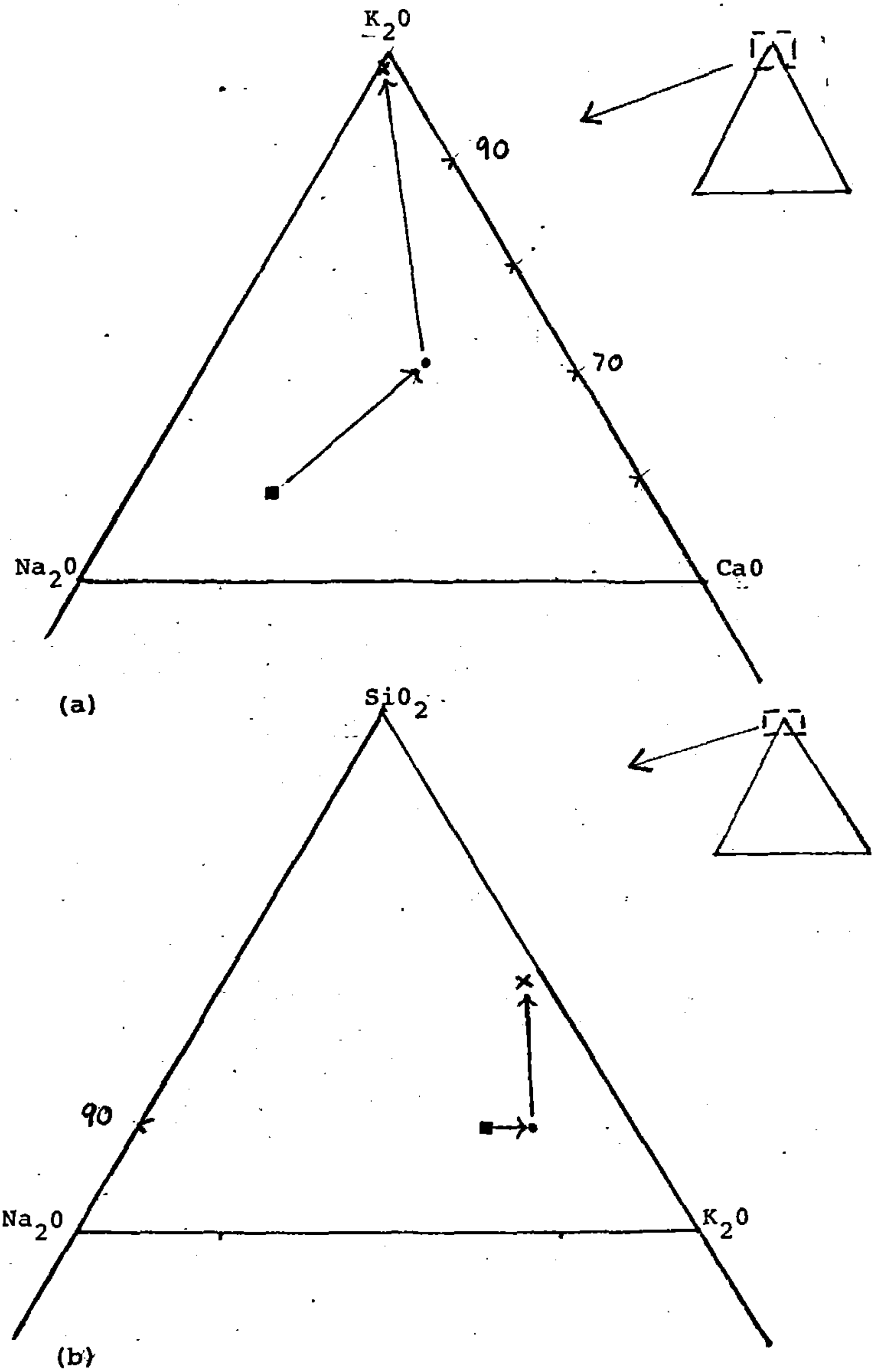

Figure 5.5: Major element changes resulting from sericitization of porphyritic biotite adamellite.

- ■ unaltered (70833)
- • plagioclase + biotite heavily sericitized (70836)
- ✗ quartz-sericite greisen (70838)

5.3.2 Trace Element Chemistry

Trace element changes during alteration of the granitoids can also be deduced from the above example. The porphyritic biotite granite, unaltered by hydrothermal activity contains an average 150 ppm Sr, 340 ppm Rb and 400 ppm Ba. During the intense alteration to a quartz-sericite greisen (70838, Table 5.3) the rock loses total Sr and Rb and gains Ba. Sr drops to 11 ppm, a reduction of about 95 percent (Figure 5.2). This reflects the complete alteration of plagioclase, the dominant Sr-bearing mineral in granitoids. As opposed to Sr, the Rb content increases dramatically with the alteration from around 340 ppm to 780 ppm, an increase of approximately 440 ppm or a-proximately 130 percent. This is a direct result of the increase in the phyllosilicate content of the rock (approximately 60 modal percent feldspars are completely altered to sericite) in which Rb substitutes in the inter-layer sites. The Rb carrier prior to alteration was biotite, approximately 5 modal percent biotite contained nearly 340 ppm Rb. An increase of 60 modal percent sericite, however, results in an increase in Rb of only 440 ppm. Assuming that the fluid flowing through the rock is constantly supplying Rb to the system, then this may reflect:

1) A relatively low solubility of Rb in the hydrothermal fluid.

2) A lower capability of sericite, than biotite, to contain the Rb^+ ion.

3) A strong Rb partition co-efficient in favour of the fluid.

Previous work has shown that white micas are efficient Rb holding minerals (Heier, 1978) and a low Rb solubility in the fluid seems unlikely. Therefore partitioning of Rb into the fluid phase rather than sericite is the most likely explanation for this behaviour.

Ba decreases from approximately 400 ppm to 324 ppm, about 15 percent reduction (Figure 5.3). K-feldspar is the dominant Ba-bearing mineral in the adamellites. Complete sericitization of K-feldspar lowers the Ba content of the rock, but not by a significant amount owing to the Ba-bearing capability of the micas, which can substitute for Ba only slightly less efficiently than K-feldspar.

If it is assumed that similar fluids were involved in the regional alateration of the granitoids, then the following effects on the trace element behaviour within these rocks are expected:

a) Plagioclase alteration within the granitoids is variable but generally low; hence the Sr content of the rock is only slightly affected. If the granites originally contained a similar Sr content to the adamellites, then the drop in Sr cannot be explained by alteration alone and hence low Sr must be a primary feature.

b) If the Rb is not as effectively partitioned into sericite as it is biotite, the complete sericitization of biotites will lower the Rb content of the altered rock. If, however, Rb has only low solubility or a high partition co-efficient in the altering fluid then the addition of minor amounts of sericite to the rock will not increase the Rb content of the rock significantly.

c) The K-feldspars in the granites are unsericitized and hence the low Ba of these rocks is a primary magmatic feature.

The trace element date abundances of the granitoids then is a function of their magmatic development, rather than late or postmagmatic alteration processes, and can now be interpreted in this light.

5.4 INTERPRETATION OF GEOCHEMISTRY

The lack of continuity on the major element Harker plots implies that three distinct magmas produced the granodiorites, adamellites and granites. This may, however, reflect a lack of sampling of suitable intermediates. In support of the latter interpretation trace element data does show a continuity between adamellites and granites, if similar rocks to the prophyritic biotite cordierite granite from elsewhere in the Batholith are plotted on Ba vs Rb, Sr vs Rb and Sr vs F log-log graphs (Figures 5.2, 5.3 and 5.4). Granodiorites express the overall trend of increased Sr and Ba and decreased Rb with more mafic rocks, but do not fit the straight line trends expressed by the adamellites and granites.

These observations have been previously interpreted by Groves and McCarthy (1978) and McCarthy and Groves (1979) to represent fractionation, by the primary Blue Tier Batholith magma, of hornblende, biotite, plagioclase and quartz. The result is a cumulate equivalent to the granodiorites and a rest melt that further fractionates in situ to give a cumulate equivalent to the adamellites in the region, and a rest melt of granite composition. These conclusions are based on theoretical trends predicted by fractionation following the Rayleigh Law. The main problem associated with this model is that the granodiorites are not genetically related to adamellites or granites. Several lines of evidence support such a conclusion.

a) Cocker (1977) concludes that the granodiorites have a mafic igneous source, supported by low initial $\frac{Sr^{87}}{Sr^{86}}$ isotopic ratios and by the occurrence of hornblende-biotite diorite inclusions interpreted as relict source rocks material. In contrast the peraluminous granitoids have high initial $\frac{Sr^{87}}{Sr^{86}}$ ratios supporting a pelitic crustal source. McCarthy and Groves (1979) explain the increase in the initial $\frac{Sr^{87}}{Sr^{86}}$ ratio as a result of crystallization from granodiorite to granite over a period of 5 - 10 my. Such a long crystallization period is unlikely, however, particularly at a reasonably high crustal level. Pitcher (1979) quotes crystallization periods of 10^4 - 10^5 years for granitoid magmas and Swanson (1979) suggests that coarse plutonic textures can be formed in a geologically short period of time.

The conclusions above are in accord with the I-S type classification (Chappel and White, 1974) in which the granodiorites classify as I-types (hornblende bearing, mafic inclusions and normative diopside) and the adamellites and granites as S-types (peraluminous and red-brown biotites), both being genetically unrelated.

b) If fractional crystallization of plagioclase was involved in the production of a granodiorite cumulate, then the rest melt would be expected to be considerably depleted in Sr relative to Ca, (the Sr distribution co-efficient for plagioclase is 3.35; McCarthy and Groves, 1979). A plot of Ca vs Sr does not show such a depletion from granodiorite to adamellite over a large range of CaO, however significant depletion from adamellite to granite is present, (Figure 5.6).

5.5 MODELS FOR THE EVOLUTION OF THE GRANITOIDS

While the inclusion of granodiorites in the fractional crystallization trends of the Blue Tier Batholith seems unlikely, the problem of producing the geochemically specialised granites still remains. The following process for the formation of geochemically distinctive granites are considered:

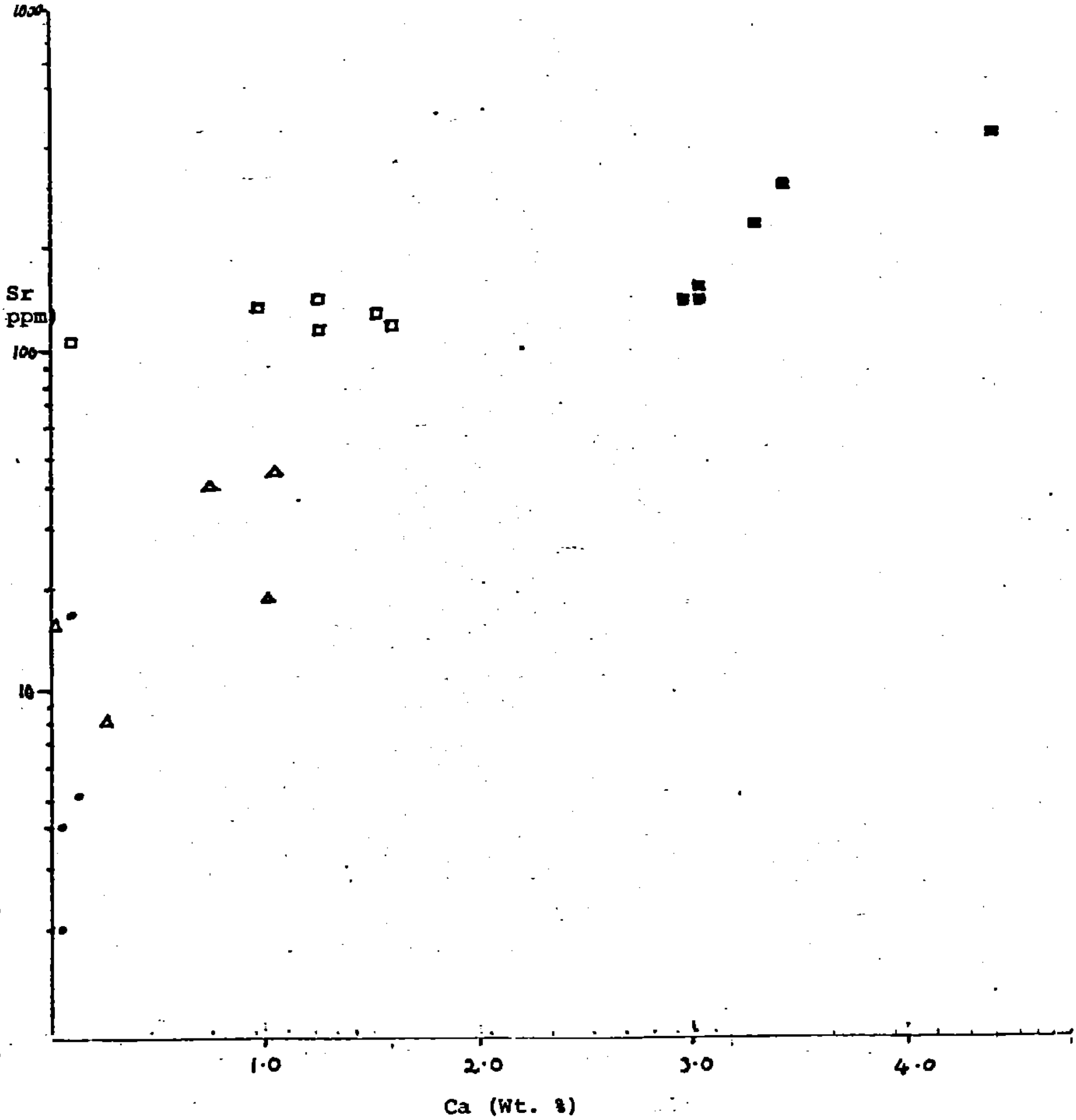

Figure 5.6

(Symbols as for Figure 5.2)

1) Convection-driven thermogravitational diffusion as postulated by Hildreth (1979).

2) Increased melting at the source region.

3) Crystal fractionation from adamellites to granites without the involvement of granodiorite.

5.5.1 Convection-Driven Thermogravitational Diffusion

This mechanism has been proposed (Hildreth, 1979) to explain the distinctive geochemical trends noted in the Bishop Tuff, California. These trends represent enrichment in the roof of the magma chamber in Ta, U, Nb, H_2O and many other elements. Depleted elements include Sr, Ba, Mg and Fe among others, which increase in the later eruptives as the magma chamber is progressively tapped. The magma that is not erupted will crystallize in the magma chamber as granitoids that may reflect the major and trace element zonations.

Thus the granitoids of the Blue Tier Batholith may be reflecting a zonation in the primary Batholith magma, with adamellites representing the lower part of the magma chamber, cordierite bearing granitoids an intermediate position and granites, a high level. If the magma chamber was tapped then the continual enrichment of H_2O in the upper levels, and subsequent eruption (as in the Bishop Tuff) would serve to deplete this volatile efficiently, and eventually the high level granite may crystallize from a melt low in H_2O as noted for the equigranular biotite granite (Chapter 4). The trace element gradients in the Bishop Tuff are very steep over short ranges in SiO_2, as they are in the granitoids of this study and follow the same trends. Also, the major element trends are less well defined than the trace element trends in the Bishop Tuff and Blue Tier granitoids. However, Na_2O is enriched at the top of the magma chamber in the Bishop Tuff while K_2O increases considerably with decreasing silica content. The Na_2O versus K_2O plot in Figure 5.1 (f) shows that the adamellites and granitoids are poorly separated, using this criteria. In this respect the data does not support the suitability of thermogravitational convection driven diffusion to produce the observed trends.

5.5.2 Increased partial melting at the source

High flourine contents within granitoids have been recently used in part to characterise A-type granites (Beams et al, 1981). The source of A-type granitoids is considered to be the residual material that has remained after the production of a previous granite. The temperature needed to generate a second partial melting ep-sode at the source is high, and results in a completely molten, low visosity melt. The lack of xenoliths and high F content of the Blue Tier granites, however, do not reflect an A-type character for the following reasons:

1) A-type granitoids are characterised by Meir enrichment in highly charged cations and REE elements and not enrichment in Rb or depletion in Ba and Sr. A-type granites also have a higher iron content

than other granitoids of the Lachlan fold belt (Berns et al, 1981), while the Blue Tier granites have low iron contents.

2) Hildreth 1979, notes that the first drop of granitic liquid formed during partial melting at the source would contain more than 40 percent of the initial Ba and Sr concentrations, and since no source rock is likely to contain less than a few hundred ppm of Ba and Sr, then low concentrates of these in granites cannot be a result of further partial melting at the source.

5.5.3 Crystal fractionation from adamellites to granites

The straight line trends, on log-log plots, from adamellite to granite is indicative of crystal fractionation. The trend toward very low Sr and Ba must reflect fractionation of plagioclase and K-feldspar respectively if this process is operating as these two minerals have the largest partition co-efficient for each respective trace element.

The presence of euhedral plagioclase, K-feldspar and biotite, indicative of early growth in the melt, within porphyritic biotite adamellite may well represent cumulative material. The groundmass may be trapped intercumulus melt (McCarthy and Groves, 1979). The groundmass of the porphyritic biotite cordierite granite may represent a rest melt component left after fractionation of the above minerals. The wide range in trace element chemistry that this rock type displays may result from a variable ratio of cumulate material to rest melt.

The K-feldspar, plagioclase, cordierite and quartz phenocrysts (probably present during emplacement (Section 4.1) would represent such cumulate material.

An increase in Ba content should correlate with an increase in K-feldspar content and such a relationship is observed. The tendency toward Rb values that are lower than the equigranular biotite granite, for given Sr or Ba values probably reflects the lower biotite contents of the former rock type.

The plot of Sr versus Rb best illustrates the trends. The plagioclase phenocryst content, however, varies significantly and this suggests that the groundmass is variably fractionated and a simple cumulate-rest melt separation is probably not the case. The Sr - F plot (Figure 5.4) indicates that groundmass fractionation is variable.

Topaz is the dominant F bearing mineral and is a groundmass phase in the porphyritic biotite cordierite granite. The flourine trend is sympathetic to the Sr and Ba trends; hence the groundmass is variably fractionated and only when highly fractionated shows similar trace element abundances to the equigranular biotite granite.

The equigranular biotite granite is the most highly fractionated granitoid and contains no identifiable cumulate material. The very low abundances of CaO, MgO, Fe, Sr and Ba and its high F and Rb content reflect its highly fractionated nature. The low FeO and MgO and initial H_2O content of this rock and of the porphyritic biotite, cordierite granite melt suggests that a hydrous phase such as biotite has actively fractionated during the formation of the adamellite cumulate.

5.6.3 In situ fractionation?

In situ fractionation is previously described for the granitoids in other parts of the Blue Batholith.

In situ fractionation as previously proposed for granitoids in other parts of the Blue Tier Batholith (Groves and McCarthy, 1979) is not apparent in the area mapped by this author. If such a process was operating then an outcrop zonation with fractionation increasing from adamellite to granite should be observed. Continued disruption disruption during crystallization often occurs (Bateman and Chappell, 1979) when zoned plutons are formed, however the overall trend and outcrop zonation are still apparent. No outcrop zonation is evident in the mapped area either vertically or horizontally orientated and while the granitoids may well have fractionated close to or at the emplacement site, they have been considerably disrupted after or during crystallization.

CHAPTER 6

SUMMARY AND SYNTHESIS

The Groves and McCarthy (1978) model for tin mineralization relies on fractional crystallization of the primary Blue Tier Batholith magma producing rocks granodiorite to granitic in composition. Distinct sources for the granodiorites as opposed to the adamellites and granites seems likely. The granodiorites classify as I-type granitoids, while the adamellites classify as S-types (Chappell and White, 1974). I-types are possibly derived by partial melting of dioritic material underplating the lower crust, while S-type melts are produced by partial fusion of metasedimentary material. Intrusion of I-type melts into the lower, middle or upper crust can promote partial melting in metasedimentary material as a result of their additional heat input, thus giving rise to the common sequence of intrusion from I-type suites to later S-types. In the Blue Tier Batholith emplacement of the adamellite melts into earlier I-type granodiorites is another example of this common sequence.

Fractionation of a primary melt of S-type character to produce the adamellites and granites within the Blue Tier Batholith, without the involvement of granodiorites, is preferred to explain the major and trace element characteristics of these granitoids. The granites are enriched in flourine and Rb and depleted in Ba and Sr as a result of fractionation, particularly the equigranular biotite granite (Lottah Sheet material) in which Sn is also enriched, (Groves, 1977). This granite is considered the source of tin in the area, (Groves, 1977).

While tin rich granites need not give rise to economic mineralization, tin must be present in quantities in excess of the tin holding capacities of biotites and any other tin bearing minerals in the rock. Equally as important, a tin rich magmatic hydrothermal fluid must be present. (Hesp, 1972) notes the difficulty of leaching tin from biotites and Groves (1977) discounts this mechanism for enriching a fluid phase in tin. Hence a fluid already enriched in tin is necessary to produce economic deposits.

The previous model for the formation of the Anchor orebody, (Groves and Taylor, 1973) is here considered a valid process. The non-fracture controlled alteration within the equigranular biotite granite of the project area, may well have resulted from reaction of the granite with a predominantly H_2O, HF and Hcl rich fluid that separated from the melt, during second boiling. Such a fluid will be enriched in tin, (as is granite) which would probably be transported as flouride or chloride complexes. Coalescence of the fluid after its separation from the melt is an efficient process (Burnham, 1967) and hence collection of such a fluid in the upper levels of the intrusion is possible. However, such a fluid is not likely to be particularly voluminous as the granite is considered to be initially relatively dry. Groundwater introduced along the granite contacts may well interact with the magmatic derived tin rich fluid. Such an interaction will result in a decrease in salinity of the magmatic-hydrothermal fluid, perhaps below the topaz stability limit. The precipitation of cassiterite may also result from the salinity decrease.

APPENDIX 1

ANALYTICAL PROCEDURES

A.1 Electron Microprobe Bulk Rock Analyses

Finely ground powder was fused on an Iridium strip heater, to form a glass. Small pieces of the glass were mounted in an araldite block, polished and coated with carbon for analyses, (Nicholls, 1974). Two glass beads for each sample were scanned and the resultant analyses were averaged. The accuracy of the data is low for some elements near the detection limit. Generally, agreement between analyses was good for elements over 2 wt. percent, and variable but frequently poor below this. Tables A.1, A.2 and A.3 give means and standard deviations for the analyses of each rock type.

TABLE A-1 ANALYSES OF PORPHYRTIC BIOTITE ADAMELLITE

SAMPLE NO.	70848			70882			70846			70845			70833			70836			Average*		
Major Elements	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n
SiO_2	72.88	0.33	10	72.97	0.64	5	72.28	0.59	5	68.69	0.77	5	73.33	0.67	5	72.74	0.61	8	72.15	1.73	6
TiO_2	0.27	0.04	10	0.22	0.04	5	0.32	0.05	5	0.26	0.07	5	0.25	0.07	5	0.29	0.05	8	0.27	0.03	6
Al_2O_3	14.54	0.18	10	14.97	0.41	5	14.88	0.4	5	16.99	0.4	5	14.82	0.35	5	16.63	0.34	8	15.47	1.05	6
FeO	2.13	0.12	10	1.77	0.06	5	2.41	0.12	5	2.2	0.09	5	1.86	0.09	5	1.52	0.12	8	1.98	0.32	6
MnO	0.04	0.05	10	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
MgO	0.72	0.1	10	0.63	0.06	5	0.81	0.09	5	0.69	0.07	5	0.54	0.11	5	0.78	0.5	8	0.70	0.10	6
CaO	1.5	0.05	10	1.55	0.04	5	1.24	0.07	5	1.61	0.08	5	1.08	0.07	5	0.10	0.06	8	1.18	0.57	6
Na_2O	3.19	0.14	10	3.01	0.14	5	3.25	0.07	5	3.72	0.15	5	2.77	0.09	5	2.12	0.09	8	3.01	0.54	6
K_2O	4.71	0.04	10	4.88	1.19	5	4.80	0.12	5	5.81	0.22	5	5.32	0.13	5	6.14	0.14	8	5.28	0.59	6
F	0.36			0.11			0.12			0.10			0.08			x					
Trace Elements																					
Rb	284			293			316			153			341			361			295	52.48	6
Sr	131			121			145			116			140			109			127	14.	6
Ba	395			395			343			332			419			428			385	39	6
Cu							15			10			20			x			9	9	9
Pb	10			10			25			25			25			15			18	8	6
Zn	60			50			90			50			65			x			63	16	6

TABLE A-2 ANALYSES OF EQUIGRANULAR BIOTITE GRANITE

SAMPLE NO..	70850			70852			70868			70866			Average		
Major Elements	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n
SiO_2	75.38	0.34	11	76.20	0.77	7	76.04	1.3	8	76.84	0.78	10	76.12	0.60	4
TiO_2	-	-	-										-	-	4
Al_2O_3	15.01	0.27	11	14.55	0.57	7	14.47	0.85	8	14.03	0.53	10	14.52	0.40	4
FeO	0.79	0.06	11	0.77	0.11	7	0.96	0.11	8	0.67	0.08	10	0.80	0.12	4
MnO	-	-	-	0.02	0.05	7	0.02	0.04	8	0.05	0.07	10	0.02	0.02	4
MgO	0.16	0.11	11	0.08	0.07	7	0.14	0.11	8	0.13	0.08	10	0.13	0.03	4
CaO	0.05	0.04	11	0.05	0.06	7	0.04	0.03	8	0.15	0.03	10	0.07	0.05	4
Na_2O	3.76	0.13	11	3.55	0.2	7	3.33	0.15	8	3.52	0.14	10	3.54	0.18	4
K_2O	4.83	0.11	11	4.77	0.16	7	4.8	0.18	8	4.62	0.20	10	4.76	0.09	4
F	0.45			0.43			0.43			0.39			0.43	0.03	4
Trace Elements															
Rb	703			739			794			650			722		
Sr	2			4			6			5			4		
Ba	22			15			17			17			18		
Cu	-			5			-			25			15		
Pb	5			10			45			360			15		
Zn	50			55			65			70			60		

TABLE A-3.

SAMPLE NO.	70865			70863			AVERAGE			70873			70838		
Major Elements	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n
SiO_2	77.12	0.8	8	76.28	0.99	8	76.7	0.59	2	75.6	0.36	6	77.47	0.96	4
TiO_2	-	-	-	0.01	0.03	8	-	-	2	0.04	0.05	6	0.20	0.08	4
Al_2O_3	13.39	0.45	8	14.09	0.57	8	13.74	0.49	2	14.71	0.24	6	13.96	0.80	4
FeO	0.72	0.07	8	0.9	0.07	8	0.81	0.13	2	0.25	0.05	6	2.72	0.11	4
MnO	0.01	0.04	8	0.01	0.04	8	0.01	0.00	2	-	-		0.16	0.07	4
MgO	0.06	0.07	8	0.06	0.09	8	0.06	0.00	2	0.09	0.07	6	0.71	0.09	4
CaO	0.29	0.02	8	0.02	0.04	8	0.16	0.19	2	0.24	0.05	6	0.06	0.10	4
Na_2O	3.36	0.18	8	3.04	0.2	8	3.20	0.23	2	3.5	0.07	6	-	-	4
K_2O	5.01	0.17	8	5.59	0.21	8	5.30	0.41	2				4.72	0.10	4
F	0.29			0.16			0.23	0.09	2				x	x	
Trace Elements															
Rb	513			486			500			403			782		
Sr	8			16			12			13			16		
Ba	32			115			74			27			324		
Cu	10			-			5			x			x		
Pb	40			30			35			x			x		
Zn	90			35			63			x			x		

70863)
70865) Porphyritic biotite cordierite granite

70873 Leucocratic microgranite

70838 Quartz-sericite greisen

APPENDIX 2

LIST OF SAMPLES

SPECIMEN NO.	LOCATION	SPECIMEN TYPE	ROCK TYPE
70831	Cross Creek Road	HS	PBA
70832	Cross Creek Road	HS, TS	PBA
70833	Cross Creek Road	HS, TS	PBA
70834	Cross Creek Road	HS, TS	QSG
70835	Cross Creek Road	HS, TS	LM
70836	Cross Creek Road	HS, TS	PBA
70837	Cross Creek Road	HS, TS	PBA, AD
70838	Cross Creek Road	HS, TS	QSG
70839	Cross Creek Road	HS, TS	PBA
70840	Cross Creek Road	HS, TS	PBA
70841	Cross Creek Road	HS, TS	PBA, AD
70842	Cross Creek Road	HS, TS	PBA, SV (iii)
70843	Cross Creek Road	HS, TS	PBA
70844	Cross Creek Road	HS, TS	PBA
70845	Cream Creek Track	HS, TS	PBA
70846	Cream Creek Track	HS, TS	PBA
70847	Emu Hill	HS, TS	PBCG
70848	Emu Hill	HS, TS	PBCG
70849	Cream Creek Track	HS, TS	PBCG, SV (ii)
70850	Frome River	HS, TS	EBG
70851	Emu Flats	HS, TS	EBG
70852	Emu Flats	HS, TS	EBG
70853	Emu Flats	HS, TS	PBA, AD
70854	FB - LODE	HS, TS	PBA, SV (iv)
70855	Wyniford River	HS, TS	EBG
70856	Wyniford River	HS, TS	EBG

70857	Wyniford River	HS, TS	QV
70858	Wyniford River	HS, TS	PBCG
70859	Wyniford River	HS, TS	PBCG
70860	Wyniford River	HS, TS	PBCG
70861	Wyniford River	HS, TS	PBCG
70862	Wyniford River	HS, TS	PBCG
70863	Wyniford River	HS, TS	PBCG
70864	Wyniford River	HS, TS	PBCG
70865	Wyniford River	HS, TS	EBG
70866	Wyniford River	HS, TS	EBG
70867	Wyniford River	HS, TS	EBG
70868	Wyniford River	HS, TS	EBG
70869	Wyniford River	HS, TS	LM
70870	Wyniford River	HS, TS	PEG
70871	Cotton Creek	HS, TS	PEG
70872	Cotton Creek	HS, TS	LM
70873	Cotton Creek	HS, TS	LM
70874	Cotton Creek	HS, TS	LM
70875	Cotton Creek	HS, TS	LM
70876	Cotton Creek	HS, TS	LM
70877	Cotton Creek	HS, TS	PBA
70878	Cotton Creek	HS, TS	PBA
70879	Cotton Creek	HS, TS	EBG
70880	Cotton Creek	HS, TS	EBG, SV (i)
70881	Cotton Creek		
70882	Harpers Creek	HS, TS	PBA
70883	Frome River	HS, TS	PORPH.

70884	Frome River		EBG
70885	Frome River		AD
70886	Frome River		
70887	Frome River		
70888	Frome River	HS, TS	PBG
70889	Frome River	HS, TS	EBG
70890	Frome River	HS, TS	EBG
70891	Frome River	HS, TS	EBG
70892	Frome River	HS, TS	PBCG
70893	Frome River	HS, TS	PEG
70894	Anchor Mine	HS, TS	EBG
70895	See Regional Map	HS, TS	Granodiorite
70896	See Regional Map	HS, TS	PBA
70897	Mt. Paris Mass	HS, TS	QSG

Key:

PBA - Prophyritic biotite adamellite

PBCG - Porphyritic biotite cordierite granite

EBG - Equigranular biotite granite

PEG - Pegmatite

AD - Aplitic dyke

LM - Leucocratic microgranite

SV - Sericite vein (types i, ii, iii, iv)

QSG - Quartz sericite greisen

HS,TS - Hand specimen and thin section

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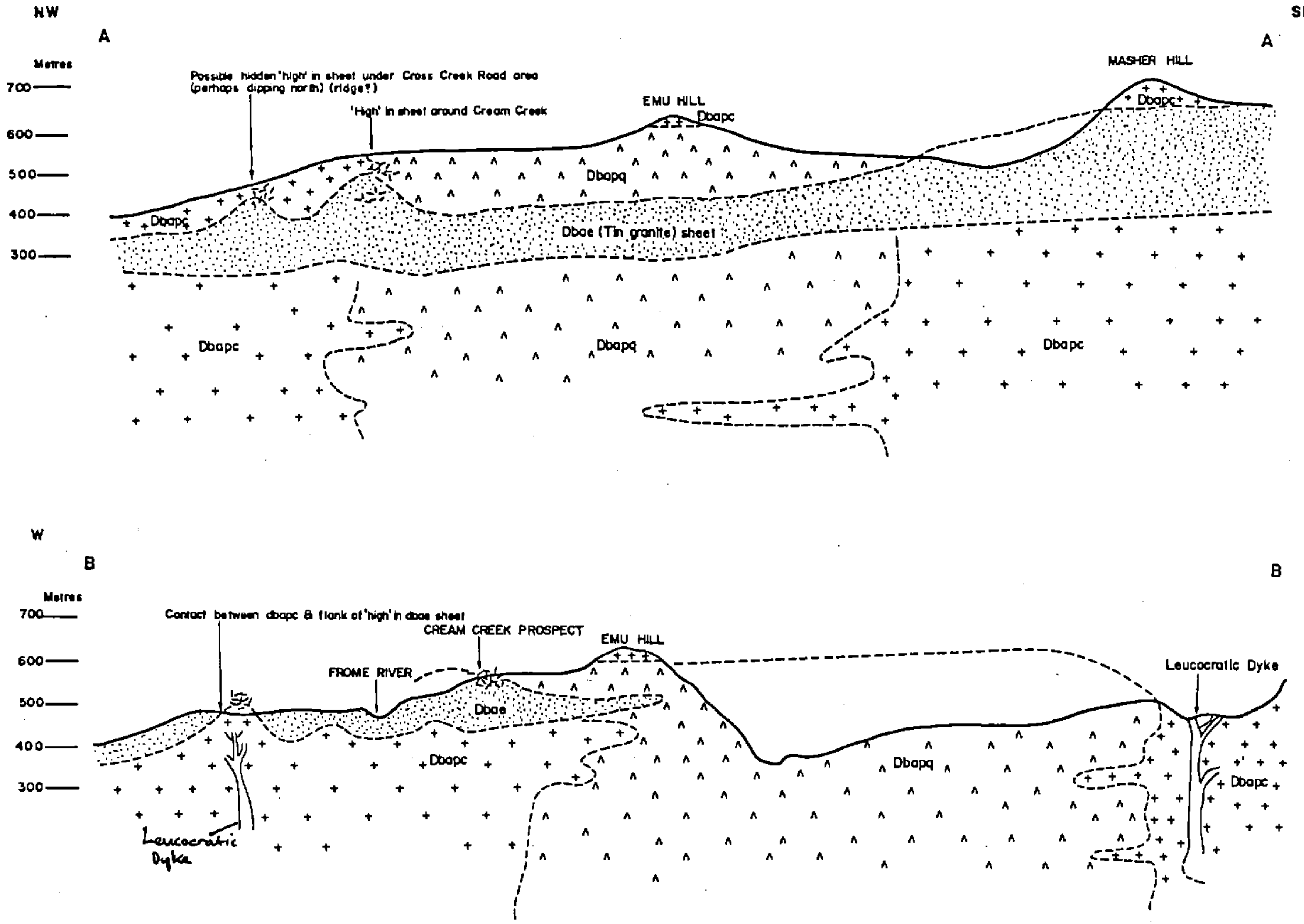

5 cm

Mineralisation

km 0 — 1km
SCALE

Aberfoyle Exploration Pty Ltd

Geology: R.J.S	NORTH EAST TASMANIA	Location code:
Drawn:	WELDBOROUGH E.L. 19/78	Date Sept 1981
Traced: J.L.R.	STRATIGRAPHIC CROSS SECTIONS AA-BB	Scale As shown
Checked:	(REFER PLATE WELD. 12)	Plate Nº WELD. 13

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