USE OF THESES

This copy is supplied for purposes of private study and research only. Passages from the thesis may not be copied or closely paraphrased without the written consent of the author.
A Study of the Base-Metal, Gold and Barite Mineralization in the Silurian Volcanosedimentary Belts of the Canberra Region

by

William David Platts

A thesis submitted for the degree of Master of Science at the Australian National University, Canberra.

June
1988
Statement

The material presented in this thesis is entirely my own work and all sources used have been acknowledged.

William Platts
Abstract

The Silurian volcanosedimentary belts of the Canberra region contain numerous small deposits of base-metal sulphides, iron oxides, barite and gold. Many different styles of mineralization are present including: veins, stockworks, massive stratiform bodies, and stratabound veins and disseminations. Primary features in the deposits and the host rocks are commonly masked by the development of greenschist facies mineral assemblages and a metamorphic foliation. The foliation in some rocks is dominal so that some premetamorphic minerals and textures are preserved and it is possible to infer premetamorphic alteration assemblages and textures.

The distribution of volcanic and sedimentary facies in the Canberra region suggests that the Late Silurian palaeogeography consisted of a meridionally trending, deep-marine trough bounded on its western side by a broad shallow-marine shelf with local subaerial areas. The trough was bounded on its eastern side initially by a shallow-marine shelf and later by a belt of subaerial volcanics. Numerous zones of mineralization, including the Woodlawn and Captains Flat massive sulphide deposits, occur in rocks deposited in the trough. The shallow-marine and terrestrial sequences along both sides of the trough contain only minor, small vein deposits.

The Late Silurian sequence in the Bredbo-Bunyan area consists of basal shallow-marine sedimentary rocks overlain by subaerial volcanic rocks with rare sedimentary rocks followed by a transgressive sequence overlain by interbedded mudstones and volcanic rocks deposited in a deep-marine environment. A number of zones of mineralization, including the Cosgrove Hill, Billilingra, Barite, Driscolls Hill, Harnett and Stonehenge Prospects, form a mineralized horizon along the top of the subaerial volcanic sequence and in the transgressive sequence. Mineralization consists of disseminations and veins of pyrite, base-metal sulphides and gold-rich sulphidic barite associated with zones of sericitic, K-feldspar, advanced argillic and propylitic alteration. In parts of the volcanics below this horizon, including at the Picasso and Stonehenge Prospects, there are narrow zones of sericite, pyrite, ±kaolinite alteration surrounded by broad zones of propylitic alteration. In the basal sedimentary sequence at the Gillans Prospect sericite, pyrite alteration zones are surrounded by propylitic zones which contain pyrrhotite and pyrite. Above the mineralized horizon there are a few jasper zones.

There is no obvious difference in the primary geochemical composition of the volcanic rocks above and below the mineralized horizon in the Bredbo-Bunyan area. The sericitic rocks in the mineralized horizon have gained K and Rb and lost Fe, Mg, Ca, Na and Sr whereas chloritic rocks have gained Fe, Mg, K, Rb, and V and lost Ca, Na, and Sr. The rare earth element (REE) patterns of the volcanic rocks were preserved during low-grade alteration and metamorphism except for zones of intense sericite alteration where the heavy REE were lost during the destruction of hornblende. The sulphur isotope composition of sulphides from below the mineralized horizon form a tight cluster around $\delta^{34}S=+5\%$ whereas those from the mineralized horizon range from $-14.9$ to $+3.5\%$. Barites from the main horizon range from $+20.5$ to $+26.0$ which is lighter than Late Silurian seawater sulphate ($+26\%$). The results suggest that seawater cannot have been the
only source of sulphur in the system and are consistent with the equilibrium oxidation of the sulphide in the hydrothermal fluid, possibly by mixing with seawater. The mineralization in the Bredbo-Bunyan area formed in an epithermal system which operated in a mixed subaerial and submarine setting.

The Peak View massive sulphide deposit occurs in a small outlier of Silurian volcanic and sedimentary rocks 53 km south of Captains Flat. Footwall rocks include volcanic rocks (deposited at least in part as lavas), volcaniclastic rocks and biogenic limestones. There is a broad zone of propylitic alteration with sulphides in veins and disseminations in the footwall beneath the sulphide lens. The mineralized horizon consists of a stratiform massive sulphide lens, fine-grained volcaniclastic rocks and carbonate bodies. The sulphide lens is composed of massive sulphides (pyrite, sericite and chlorite with minor sphalerite, galena, chalcopyrite, quartz and rare tennantite-tetrahedrite and arsenopyrite) with minor pyritic chert and veins of quartz and chalcopyrite. The hangingwall rocks are volcanic rocks, deposited partly as lavas, which contain zones of chloritic, albitic (originally zeolitic?) and sericitic alteration. The hangingwall rocks have a different primary geochemical composition to the footwall volcanic rocks. The Peak View deposit is of the volcanic associated, massive sulphide style and may have formed by convective circulation of seawater below the seafloor.
Acknowledgements

There are many people I would like to thank for their assistance with this work:

- **Dr John L. Walshe** for suggesting the project and supervising it.
- My fellow postgraduate students and friends at the A.N.U., including **Imants Kavalieras, Paul Heithersay, Scott Halley, Mr Tan Chi Min, Ann Pickering, Mr Ren Shuang Kui, Bill Kiene, Patrice de Caritat, Ramon Loosveld, Ineke De Bruyn, David Champion, Brian Harrold and Graeme Corlett** for their friendship and discussion of various aspects of the work.
- **Professor Ken Campbell** for providing the facilities at the Geology Department and the Australian National University for granting a Scholarship to me.
- **ESSO Exploration Production Australia Inc.** for allowing me to work in the Bredbo–Bunyan area and for providing me with confidential company information, thin sections and accommodation in the field. **Dr Simon Beams** of ESSO drew John Walshe's attention to the mineralization in the Cooma area and the data he gathered during exploration has been essential to the present study.
- **Western Mining Corporation** for allowing me to work on the Peak View deposit and for providing me with confidential company information, thin sections and a field assistant to assist with core trays.
- **Dr Bruce Chappell, Ross Freeman, Liz Webber and Jack Wasik** for assistance with whole-rock geochemical analysis by XRF and INAA.
- **Chris Foudoulis** for assistance with X-ray diffraction.
- **Henry Zapasnik** and **Radi Popovic** for the production of high–quality thin sections, polished thin sections, polished sections and ultrathin sections.
- **Dr Mike Solomon** of the Bureau of Mineral Resources for providing me with a BMR field assistant to assist with drillcore trays and for arranging the sulphur isotope analyses at the BMR.
- **Dr Sun Shensu** of the Bureau of Mineral Resources for the sulphur isotope analyses.
- **Greg de Ross** of St. Joe Pty Ltd for providing confidential company information.
- **Mel Jones** of Goldfields Exploration Pty Ltd for help with references.
- **Dr Doone Wyborn** and **Mr Tony Henderson** of the BMR for many discussions on the geology of the Canberra region.
- **Professor Ken Campbell and Dr Tim Munson** for assistance with the palaeontology of the Canberra region.
- **Drs Gordon Lister** and **Steve Cox** for assistance with metamorphic microtextures.
- **Dr Mike Rickard** for assistance with the structural development of the Canberra region.
- **Dr Warrington Cameron** for assistance with petrography.
- **Roland Aronsen** and **Marleen Adams** at the Instructional Resources Unit for assistance with the production of maps and diagrams.
- Ludwig Heinrich of MacLaser, for assistance with printing and advice about the Macintosh Plus computer.
- My family, Don, Joan, Helen, Anne, Ian and Zoe, for their support in many different ways.
- Finally to my dog, Gee, who kept a patient vigil during my long hours on the Mac.
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statement</td>
<td>ii</td>
</tr>
<tr>
<td>Abstract</td>
<td>iii</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>v</td>
</tr>
<tr>
<td>Contents</td>
<td>vi</td>
</tr>
<tr>
<td>List of Figures</td>
<td>xxiv</td>
</tr>
<tr>
<td>List of Tables</td>
<td>xxvi</td>
</tr>
<tr>
<td>List of Plates</td>
<td>xxvii</td>
</tr>
<tr>
<td>List of Maps</td>
<td>xxviii</td>
</tr>
</tbody>
</table>

---

### Chapter 1  INTRODUCTION

#### 1.1 BACKGROUND
- 1.1.a The Canberra Region 1
- 1.1.b The Current Genetic Model 1
- 1.1.c The Tasmanian Experience 1

#### 1.2 AIMS 2

#### 1.3 PROBLEMS 2
- 1.3.a Problems with Metamorphism and Deformation 2
- 1.3.b Problems Recognising Mineralization Related to Seawater Circulation 3

#### 1.4 PROCEDURE 3

#### 1.5 LOCATION AND ACCESS 4

#### 1.6 NOMENCLATURE 4
PART 1 Canberra Region Studies

Chapter 2 THE GEOLOGY OF THE CANBERRA REGION

2.1 INTRODUCTION

2.2 THE GEOLOGICAL HISTORY OF THE LACHLAN FOLD BELT

1 Cambrian
2 Ordovician
3 Early and Middle Silurian
4 Middle Silurian to Early Early Devonian
5 Middle Early to Middle Devonian
6 Late Devonian to Early Carboniferous

2.3 INTRODUCTION TO THE GEOLOGY OF THE CANBERRA REGION

2.3.a General
2.3.b The Structure of the Canberra Region
2.3.c Sources of Information
2.3.d Basement

2.4 SILURIAN FACIES AND STRATIGRAPHY

2.4.a Facies
2.4.b The Age of Units
   1 Introduction
   2 Goobarragandra Block
   3 Tantangara Block
   4 Nungar-Brindabella and Cotter Blocks
   5 Canberra Block
   6 Bredbo Block
   7 Captains Flat, Rocky Pic and Cullarin Blocks
   8 Bombay Block

2.5 DEPOSITIONAL HISTORY OF THE CANBERRA REGION

2.5.a Ordovician
2.5.b Benambran Deformational Event
2.5.c Early Llandovery
2.5.d Late Llandovery
2.5.e Quidongan Deformational Event
2.5.f Latest Wenlock and Late Silurian
2.5.g Bowning Deformational Event
2.5.h Early Devonian
2.5.i Tabberabberan Deformational Event 26
2.5.j Middle and Late Devonian 26
2.5.k Kanimblan Deformational Event 26
2.5.l Mesozoic and Cainozoic 26

2.6 INTRUSIVE HISTORY OF THE CANBERRA REGION 27

2.7 METAMORPHIC AND STRUCTURAL HISTORY 28
2.7.a General 28
2.7.b Metamorphism 28
2.7.c Folds and Foliations 28
   1 Ordovician 28
      Early Folds 28
      Main Folds 29
      Later Folds 29
      Other Features 29
   2 Middle and Late Silurian 29
      First Folds 29
      Later Folds 30
   3 Devonian 30
   4 Other Features 30
2.7.d Faults 30
2.7.e The Age of Folding, Metamorphism and Faulting 30
   1 Observations 30
   2 Summary 33

2.8 THE LATE SILURIAN TECTONIC SETTING 33
2.8.a Constraints 33
2.8.b Tectonic Models 34

Chapter 3 A REVIEW OF THE MINERALIZATION IN THE
SILURIAN BELTS OF THE CANBERRA REGION 35

3.1 INTRODUCTION 35
3.1.a Aims 35
3.1.b Procedure 35
3.1.c Limits 36
3.1.d Previous Reviews 36
3.1.e Specialist Studies 36
3.2 MINERALIZATION

3.2.a Goobarragandra Block
   1 Geology
   2 Mineralization
      Stockwork Copper Deposits
      Gold, ±Copper Veins
   3 Notes on Genesis

3.2.b Tantangara Block
   1 Geology
   2 Mineralization
   3 Notes on Genesis

3.2.c Nungar–Brindabella Block

3.2.d Cotter Block

3.2.e Canberra Block
   1 Geology
   2 Mineralization
      Pyrrhotite Deposits in the Canberra Formation
      Base-Metal Veins in the Hawkins Volcanics
      Base-Metal Veins in the Laidlaw Volcanics and the Yass Basin Sequence
      Red Hill Skarn
      Gold-Bearing Quartz Veins
      Base-Metal Sulphide, Fluorite Deposits
   3 Notes on Genesis

3.2.f Bredbo Block
   1 Geology
   2 Mineralization
      Mineralization in the Cappanana Formation
      Mineralization Along the Eastern Margin of the Bredbo Block
      Mineralization in the Colinton Volcanics
      Mineralization in the Rothlyn Formation
   3 Notes on Genesis

3.2.g Cullarin Block

3.2.h Southern Rocky Pie Block

3.2.i Captains Flat Block
   1 Geology
   2 Mineralization
   3 Notes on Genesis
3.2.j Northern Rocky Pic Block  
1 Geology 46  
2 Mineralization 46  
   *Mineralization in the Sedimentary Sequence Below and Laterally Equivalent to the Volcanics* 46  
   *Mineralization in the Volcanics* 47  
   *Mineralization in the Currawang Basalt* 48  
   *Mineralization in the Covan Creek Formation* 48  
*Other Prospects* 49  
3 Notes on Genesis 49  

3.2.k Bombay Block  
1 Geology 49  
2 Mineralization 49  
   *Contact -Aureole Deposits in the DeDrack Formation* 49  
   *Barite Veins in the Volcanics* 50  
*Other Prospects* 50  
3 Notes on Genesis 50  

### 3.3 METAMORPHISM AND DEFORMATION  
1 Woodlawn 50  
2 Deposits in the Northern Rocky Pic Block 51  
3 Captains Flat 51  
4 Currawang East 52  
5 Other Work 52  

### 3.4 DISCUSSION OF THE REGIONAL MINERALIZATION  
3.4.a Previous Work 52  
3.4.b Classification of Deposits 52  
   1 Mineralization in Carbonates and Associated with Calc–Silicate Minerals and/or Intrusive Bodies 52  
   2 Other Mineralization in Carbonates 52  
   3 Mineralization on Faults 53  
   4 Stratiform and Stratabound Deposits in Volcanosedimentary Sequences 53  
   5 Small Vein Deposits 53  
3.4.c Patterns in the Regional Distribution of Synvolcanic Mineralization and Alteration 54  
3.4.d The Effects of Metamorphism and Deformation 55
INTRODUCTION
4.1 General
4.1.b Previous Work

GEOLOGY OF THE BREDBO BLOCK
4.2 General
4.2.b Stratigraphy
4.2.c Structure and Metamorphism

THE BREDBO–BUNYAN STUDY AREA
4.3 General Nature, Distribution and Stratigraphic Position of the Rocks
4.3.b Metamorphic Zones
4.3.c Unit A: Metasedimentary Rocks
   1 Facies
   2 Geometry
   3 Type Area
   4 Contacts
   5 Distribution of Facies
   6 Description of Facies
      Metapelites (Am)
      Calc–Silicate Rocks (Ac)
      Metavolcanic Rocks (Av)
      Sericite–Rich Metavolcanic Rocks (As)
      Metalimestone (Al)
      Veins
   7 Interpretation of Unit A
4.3.d Unit B; Metavolcanic Rocks
   1 Facies
   2 Geometry
   3 Type Area
   4 Contacts
   5 Distribution of Facies
   6 Description of Facies
      Metavolcanic Rocks (Bv)
      Metapelites (Bm)
Crystal–Rich Metavolcanics, Meta–Arkose and Metapelite (Bf) 72
Sericite–Rich Metavolcanic Rocks (Bs) 72
Gossans (Bg) 73
Veins 73

7 Interpretation of Unit B

4.3.e Unit C; Bullanamang Porphyry
1 Facies 76
2 Previous work 76
3 Geometry 76
4 Type Area 76
5 Contacts 76
6 Distribution of Facies 76
7 Description of Facies 76

Coarse–Grained Metaporphry (Cp) 76
Medium–Grained Metavolcanic Rocks (Cv) 77
Metasedimentary Rocks (Cm) 77
Cream Metavolcanic Rocks (Ck) 78
Gossans (Cg) 78
Veins 78

8 Interpretation of Unit C

4.3.f Unit D; Metavolcanic Rocks
1 Facies 79
2 Geometry 79
3 Type area 79
4 Contacts 79
5 Distribution of facies 79
6 Description of facies 80

Massive, Hornblende–Bearing Metavolcanic Rocks (Dhv) 80
Lithic–Rich Metavolcanic Rocks (Dlr) 80
Cosgrove Porphyry (Dcp) 80
Massive, White, K–Feldspar–Rich Metavolcanic Rocks (Dk) 80
Mineralized, K–Feldspar–Rich Metavolcanic Rocks (Dkb) 81
Sericitic, Siliceous, Gossanous Metavolcanic Rocks (Ds) 81
Crystal–Rich Metavolcanic Rocks (Dx) 82
Dark–Green Metavolcanic Rocks (Dv) 82
Cherts (Dch) 82
Veins 83

7 Interpretation of Unit D 83
4.3.g Unit E; Metavolcanic and Metasedimentary Rocks

1 Facies
2 Geometry
3 Type Area
4 Contacts
5 Distribution of Facies
6 Description of Facies
   Massive, Hornblende-Bearing Metavolcanic Rocks (Ehv)
   Framework-Supported Metavolcanic Rocks (Ef)
   Interbedded Metavolcanic and Metasedimentary Rocks (Evs)
   Mineralized, Sericitic, Siliceous Metasedimentary and Metavolcanic Rocks (Es)
   Hematitic, Sericitic Metasedimentary Rocks (Ehs)
   Quartz Arenites (Eq)
   Metapelites (Em)
   Veins
7 Interpretation of Unit E

4.3.h Unit F; Metapelites with Minor Metavolcanic Rocks

1 Facies
2 Geometry
3 Type Area
4 Contacts
5 Distribution of Facies
6 Description of Facies
   Metapelites (Fm)
   Hornblende-Bearing Metavolcanic Rocks (Fhv)
   Metabasalt (Fb)
   Metalimestone (Fl)
   Chert (Fch)
7 Interpretation of Unit F

4.3.i Other Rocks in the Bredbo-Bunyan Study Area

1 The 500 Acre Granodiorite (I5)
2 Dolerite Dyke
3 Aplite Dykes (la)
4 Tertiary Basalt (Tb)
5 Ferruginous Gravel and Silcrete (Tg)
6 Ferricrete (Tf)
4.4 STRUCTURE OF THE BREDBO-BUNYAN STUDY AREA

4.4.a Bedding and Facing
4.4.b Folds
4.4.c Foliations and the Lineation
4.4.d Estimate of Elongation
4.4.e Faults
4.4.f The Style and Age of Intrusion of the Bullanamang Porphyry (Cp)

4.5 CONCLUSIONS AND INTERPRETATIONS

4.5.a Late Silurian Depositional History
4.5.b Late Silurian Intrusive History
4.5.c Metamorphic and Deformational History

Chapter 5 MINERALIZATION IN THE BREDBO-BUNYAN STUDY AREA

5.1 INTRODUCTION

5.2 MINERALIZATION IN UNIT A

5.2.a Gillans Prospect
1 Introduction
2 Exploration history
3 My work at the Gillans Prospect
4 Geology
5 Mineralization
   Disseminated Mineralization
   Vein and Stringer Mineralization
   Semi–massive Sulphide Bands
6 Other Information
7 Initial Interpretation of the Gillans Prospect

5.2.b Other Mineralization in Unit A
1 Gossans North of the Gillans Prospect
2 Gossans South of "Riversdale" Homestead
3 Initial Interpretation of the Other Mineralization in Unit A

5.3 MINERALIZATION IN UNIT B

5.3.a Picasso Prospect
1 Introduction
2 Exploration History
3 My Work at the Picasso Prospect 103
4 Surface Geology 103
   Metavolcanic Rocks (Bv) 103
   Gossans 104
   Pyritic Quartz Veins 104
5 Percussion-Drillholes 104
6 Mineralization 108
7 Initial Interpretation of the Picasso Prospect 112

5.3.b Gamma–Delta Prospect 115
   1 Introduction 115
   2 Previous Work 115
   3 My Work at the Gamma–Delta Prospect 115
   4 Geology 116
   5 Mineralization 116
   6 Gossan Geochemistry 116
   7 Initial Interpretation of the Gamma–Delta Prospect 119

5.3.c Other Mineralization in Unit B 119
   1 Harnett West Gossans 119
   2 Gossans South–Southeast of the Picasso Prospect 119
   3 Jasper Bands East of the Gamma–Delta Prospect 120
   4 The Riversdale Gossans 120
   5 Gossans North of "Riversdale" homestead 120
   6 Mount Oak Area 120
   7 Initial Interpretation of the Other Mineralization in Unit B 120

5.4 MINERALIZATION IN UNIT C 121
   5.4.a The Western Part of the Driscoll's Hill Prospect 121
      1 Description 121
      2 Initial Interpretation of the Western Part of the Driscoll's Hill Prospect 123

   5.4.b Other Mineralization in the Medium–Grained Metavolcanic Rocks (Cv) and the Metasedimentary Rocks (Cm) 123
      1 West of Cosgrove Hill 123
      2 The Cattle Yards Area 123
      3 Initial Interpretation of the Other Mineralization in the Medium–Grained Metavolcanic (Cv) and Metasedimentary Rocks (Cm) 123

   5.4.c Mineralization in the Coarse–Grained Metaporphyry (Cp) 124
      1 Hematitic Quartz Band 124
      2 Driscoll's Hill South Prospect 124
      3 Sheep Shelter Shed Area 124
      4 The Driscolls Hill Prospect 124
      5 Interpretation of the Other Mineralization in Facies Cp 124
5.5 MINERALIZATION IN UNIT D AND THE BASE OF UNIT E

5.5.a The Cosgrove Hill Area

1 Introduction 125
2 Exploration History 125
3 My Work in the Cosgrove Hill Area 125
4 Geology of the Cosgrove Hill Area 125
5 Small Zones of Interest 126
   The Northern Pyrophyllite, ±Kaolinite Outcrop 126
   K-Feldspar-Rich Rocks in Facies Dk 126
   Jaspers and Sericitic, Hematitic Rocks in Unit E 126
6 The Cosgrove Hill Prospect 127
7 Initial interpretation of the Cosgrove Hill Area 132

5.5.b Billilingra and Barite Prospects

1 Introduction 133
2 Previous Work 134
3 My Work at the Billilingra and Barite Prospects 134
4 Geology 134
   General Features 134
   Crystal-Rich Metavolcanic Rocks (Dx) 136
   Metapelites (Dm, Em) 137
   Mineralized, K-Feldspar-Rich Metavolcanic Rocks (Dkb) 137
   Hornblende-Bearing Metavolcanic Rocks (Ehv) 138
   Sericitic, Siliceous, Gossanous Metavolcanic Rocks (Ds) 138
   Magnetite-Rich Metavolcanic Rocks (Emt) 138
   Sericitic, Siliceous Metavolcanic Rocks (Ess) 139
   Metapelites (Fm) and Metabasalt (Fb) 139
5 Mineralization 139
6 Geochemistry 140
7 Initial Interpretation of the Billilingra and Barite Prospects 141

5.5.c Driscoll’s Hill Prospect

1 Introduction 145
2 Previous Work 145
3 My Work at Driscoll’s Hill Prospect 146
4 Geology 146
   General Features 146
   Sericitic, Siliceous, Gossanous Metavolcanic Rocks (Ds and Ess) 146
   K-Feldspar-Rich Metavolcanic Rocks (Dk) 146
   Minor Sedimentary Units in Unit E 146
   Hornblende-Bearing Metavolcanic Rocks (Ehv) 148
   Veins 148
5 Mineralization
6 Other Information
7 Initial Interpretation of the Driscoll's Hill Prospect
5.5.d Driscoll's Hill South Prospect
5.5.e Harnett Prospect
1 Introduction
2 Previous Work
3 My work at Harnett
4 Geology
   General Features
   Coarse-Grained Metaporphry (Cp)
   Dark-Green Metavolcanic Rocks, (Dv)
   Minor Units in Facies Dv
   Zone of Interest
   Hornblende-Bearing Metavolcanic Rocks (Ehv)
   Quartz Arenite (Eq)
   Interbedded Metavolcanic and Metasedimentary Rocks (Evs)
   Chert (Fch)
   Interbedded Metapelites (Fm) and Metavolcanics (Fv).
   Notes on the Distribution of Minerals in DDH–H3
5 Initial Interpretation of the Harnett Prospect
5.5.f Stonehenge Prospect
1 Introduction
2 Previous Work
3 My Work at Stonehenge Prospect
4 Geology
5 Initial Interpretation of Stonehenge Prospect
5.6 OTHER MINERALIZATION IN UNITS E AND F
5.6.a Jaspers Northeast of Cosgrove Hill
5.6.b Chert Unit at Harnett
Chapter 6 THE GEOLOGY OF THE PEAK VIEW PROSPECT

6.1 INTRODUCTION
6.1.a General
6.1.b Location
6.1.c Previous Work
6.1.d My Work at Peak View

6.2 REGIONAL GEOLOGY
6.2.a General
6.2.b Ordovician Metasedimentary Rocks (Om)

6.3 GEOLOGY OF THE PEAK VIEW OUTLIER
6.3.a General
6.3.b Footwall Sequence
   1 General
   2 Description of Facies
      Chloritic, Pyritic Metavolcanic Rocks, (Fc)
      K-Feldspar-Bearing Metavolcanic Rocks (Fk)
      Coarse-Grained Metavolcanic Unit (Fvo)
      Metasedimentary Rocks
   3 Footwall Mineralization
6.3.c Mineralized Horizon
   1 Definition
   2 Facies Present and Their Distribution
   3 Description of Facies
      Dark-Green, Fine-Grained, Chloritic Schists (Mc)
      Fine-Grained, Sericitic, Pyritic, Siliceous Schist (Ms)
      Metalimestone (MI)
      Limonitic, Sericitic, Siliceous Breccia (Mbx)
      The Sulphide Lens
      Semi-massive Sulphides
      Sericitic, Siliceous Metavolcanic Rocks (Mv)
6.3.d Hangingwall Sequence
   1 Introduction.
   2 General Features of the Hangingwall Metavolcanic Rocks
   3 Lithological Types in the Hangingwall Metavolcanic Rocks
   4 Distribution of the Facies
   5 Metasedimentary Rocks in the Hangingwall
6.4 STRUCTURE AND METAMORPHISM OF THE PEAK VIEW OUTLIER 188

6.5 INTERPRETATION OF THE PEAK VIEW PROSPECT 188
6.5.a General 188
6.5.b Footwall Rocks 189
6.5.c Mineralized Horizon 189
6.5.d Hangingwall Rocks 192
6.5.e Dolerite Dykes 194
6.5.f Summary of the Interpreted Depositional History 194
PART 4 Geochemical Studies

Chapter 7 GEOCHEMISTRY

7.1 INTRODUCTION

7.2 GEOCHEMISTRY OF THE METAVOLCANIC ROCKS

7.2.a Introduction
1 Processes Contributing to the Present Composition of the Metavolcanic Rocks
2 The Whole-Rock Geochemical Study
7.2.b The Samples
1 Samples from the Bredbo-Bunyan Area
2 Samples from the Peak View Area
7.2.c Results
1. Immobile Elements.
2 TiO₂ Variation Diagrams
3 P₂O₅ vs Zr Plot
7.2.d Discussion

7.3 RARE EARTH ELEMENT STUDY

7.3.a Introduction
1 Background
2 The Present Study
3 Samples
7.3.b Results
7.3.c Discussion
1 Factors Affecting the Distribution and Abundance of the REE in the Metavolcanic Rocks
2 The Primary Distribution of REE in the Rocks
3 The Effect of Metamorphism and Synvolcanic Alteration
4 Sample WDP 26
5 Other Points
6 Implications of the Primary Abundances
7.3.d Summary of Conclusions from the Rare-Earth Element Study

7.4 SULPHUR ISOTOPE STUDY

7.4.a Introduction
7.4.b Results
7.4.c Initial Discussion of Results
PART 5 Discussion

Chapter 8 DISCUSSION

8.1 THE PROBLEM OF METAMORPHIC VS ALTERATION MINERAL ASSEMBLAGES

8.2 THE PEAK VIEW DEPOSIT

8.2.a General

8.2.b The Origin of the Peak View Mineralization

1 Introduction

2 Environment of Deposition

3 Source of Components

4 The Plumbing System and Alteration

5 Deposition of the Sulphide Body

8.2.c The Effects of Metamorphism and Deformation

8.3 THE BREDBO-BUNYAN AREA

8.3.a General Geological Setting

8.3.b Initial Statement of Possible Models for the Formation of the Mineralization

8.3.c Subdivision of Mineralization and Alteration

8.3.d Timing of the Mineralization

8.3.e The Original Nature of the Mineralization and Alteration

1 The Main Mineralized Horizon

2 Mineralization Below the Main Mineralized Horizon

3 Mineralization Above the Main Mineralized Horizon

8.3.f Interpreted Depositional Environments and Timing of the Mineralization

8.3.g Flow Patterns in the System

8.3.h Hydrothermal Fluid Properties and Alteration

8.3.i Sources of Metals

8.3.j The Sulphur Isotope Results

1 Possible Sources for Sulphur in the Mineralizing Fluids and Their Isotopic Composition

2 Processes Which May Change the Isotopic Composition of the Mineralizing Fluid

3 Sulphur Species in the Fluids and Their Isotopic Composition

4 Interpretation of the Sulphur Isotopes in the Deep Footwall Zones

5 Interpretation of the Sulphur Isotopes from the Main Mineralized Horizon

6 The Source of Sulphur

8.3.k Source of the Hydrothermal Fluid
8.3.1 Precipitation of Sulphides, Barite and Gold 244
8.3.m Genetic Models 244
8.3.n Regional Implications 246

8.4 REGIONAL PATTERNS OF MINERALIZATION 247
8.4.a Mineralization and Palaeogeography 247
8.4.b The Deeper Parts of the Hydrothermal Systems 247

8.5 SUGGESTIONS FOR FUTURE WORK 249

References 250

Appendix 1 Features of the mineralization in the Canberra region 268
Appendix 2 The location of prospects from Chapter 3 which are not shown on the regional Metallogenic Sheets 279
Appendix 3 Locations of samples used for whole-rock geochemistry 280
Appendix 4 Geochemistry of the metavolcanic rocks 281
Appendix 5 Analytical techniques 287
Appendix 6 Details of the sulphur isotope samples 289

...
LIST OF FIGURES

Fig. 1.1 Location of the Study areas. page 5

Fig. 2.1 Schematic block diagram of the palaeogeography of southeastern Australia during the Late Ordovician. 7
Fig. 2.2 Scaled block diagram of the Early Silurian palaeogeography. 8
Fig. 2.3 Schematic block diagram of the palaeogeography of southeastern Australia during the Late Silurian and Early Devonian. 9
Fig. 2.4 Schematic block diagram of the palaeogeography of southeastern Australia during the Late Devonian and Early Carboniferous. 10
Fig. 2.5 Major structural blocks in the Canberra region. 11
Fig. 2.6.a Silurian facies and stratigraphy in the Canberra region. 15
Fig. 2.6.b Silurian stratigraphic units in the Canberra region. 16-18
Fig. 2.7 Schematic block diagram of the palaeogeography and inferred crustal structure of the Canberra region during the Ludlow. 25

Fig. 4.1 Simplified regional geological map showing the location of the two detailed study areas. 58
Fig. 4.2 Geology and structure of the Bredbo Block. 60
Fig. 4.3 Simplified geology of the Bredbo-Bunyan study area. 62
Fig. 4.4 Metamorphic zones in the Bredbo-Bunyan study area. 64

Fig. 5.1 Simplified geology and prospect locations in the Bredbo-Bunyan study area. 95
Fig. 5.2 Interpreted cross-sections through Gillans Prospect diamond-drillholes BRYG 001 and 002. 96-98
Fig. 5.3.a Interpreted cross-section through Picasso Prospect percussion-drillhole BRYP 101. 106
Fig. 5.3.b Estimated mineral distribution in Picasso Prospect percussion-drillhole BRYP 101. 107
Fig. 5.4.a Interpreted cross-section through Picasso Prospect percussion-drillhole BRYP 104. 109
Fig. 5.4.b Estimated mineral distribution in Picasso Prospect percussion-drillhole BRYP 101. 110
Fig. 5.5 Interpreted cross-section through Gamma–Delta Prospect percussion-drillhole BRYA 103. 117
Fig. 5.6 Interpreted cross-section through Driscoll's Hill Prospect percussion-drillhole BRAD 103. 122
Fig. 5.7 Geology of the Cosgrove Hill Prospect. 128-129
Fig. 5.8 Interpreted cross-section through Cosgrove Hill Prospect percussion-drillhole BRAC 101. 130
Fig. 5.9 Interpreted cross-section through Billilingra Prospect diamond-drillhole DDH-BL1. 135
Fig. 5.10 Interpreted cross-sections through Driscolls Hill Prospect percussion-drillholes BRAD 102 and 101. 147-148
Fig. 5.11.a Interpreted cross-section through Harnett Prospect diamond-drillholes DDH–H3, NP 43 and NP 41. 153-154
Fig. 5.11.b Estimated mineral distribution in Harnett Prospect diamond-drillhole DDH–H3. 155
Fig. 5.12 Interpreted cross-section through Stonehenge Prospect diamond-drillhole BRYZ 001. 166

Fig. 6.1 Mineralized horizon facies intersected in Peak View diamond-drillholes. 176-177

Legend for geochemical plots. 199
Fig. 7.1 Immobile element plots. 200-201
Fig. 7.2 TiO₂ variation diagrams. 203-213
Fig. 7.3 P₂O₅ vs Zr plot. 215
Fig. 7.4 Chondrite normalized REE plots. 220-224
Fig. 7.5 Sulphur isotope histograms for all samples and individual prospects. 229

Fig. 8.1 Schematic diagram showing the features of the hydrothermal system responsible for the mineralization in the Bredbo-Bunyan area. 245
Fig. 8.2 Inferred distribution of the mineralized horizon in the Bredbo Block. 248
LIST OF TABLES

<table>
<thead>
<tr>
<th>Table 2.1</th>
<th>Stratigraphic distribution and age range of selected Late Silurian fossils</th>
<th>page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 5.1</td>
<td>Picasso Prospect gossan geochemistry</td>
<td>105</td>
</tr>
<tr>
<td>Table 5.2</td>
<td>Gamma–Delta Prospect gossan geochemistry</td>
<td>118-119</td>
</tr>
<tr>
<td>Table 5.3</td>
<td>Cosgrove Hill area gossan geochemistry; northern pyrophyllite outcrop</td>
<td>126</td>
</tr>
<tr>
<td>Table 5.4</td>
<td>Geochemistry of the pyrophyllite-bearing outcrop at the Cosgrove Hill Prospect</td>
<td>127</td>
</tr>
<tr>
<td>Table 5.5</td>
<td>Geochemistry of Billilingra Prospect diamond–drillhole DDH-BL1</td>
<td>140</td>
</tr>
<tr>
<td>Table 5.6</td>
<td>Geochemistry of the gossanous barite bands at the Billilingra Prospect</td>
<td>142-143</td>
</tr>
<tr>
<td>Table 6.1</td>
<td>Geochemistry of the Peak View massive sulphide lens</td>
<td>183</td>
</tr>
</tbody>
</table>
# List of Plates

<table>
<thead>
<tr>
<th>Plate</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate 1</td>
<td>The $S_1$ foliation in the metavolcanic rocks (Bv) at the Picasso Prospect.</td>
<td>111</td>
</tr>
<tr>
<td>Plate 2</td>
<td>Chlorite-rich microlithon in the metavolcanic rock (Bv) at the Picasso Prospect.</td>
<td>111</td>
</tr>
<tr>
<td>Plate 3</td>
<td>A quartz-rich microlithon in the metavolcanic rock (Bv) at the Picasso Prospect.</td>
<td>113</td>
</tr>
<tr>
<td>Plate 4</td>
<td>A very coarse-grained microlithon in the metavolcanic rock at the Picasso Prospect.</td>
<td>113</td>
</tr>
<tr>
<td>Plate 5</td>
<td>Randomly oriented flakes in the sericite-rich rocks at the Cosgrove Hill Prospect.</td>
<td>131</td>
</tr>
<tr>
<td>Plate 6</td>
<td>Background rock at the Cosgrove Hill Prospect.</td>
<td>131</td>
</tr>
</tbody>
</table>
LIST OF MAPS

The maps are bound separately.

Map 4.1 Geology of the Bredbo-Bunyan study area

Map 5.1 Geology of Gillans and Picasso Prospects
Map 5.2 Interpreted geology of Gamma-Delta Prospect
Map 5.3 Interpreted geology of Billilingra and Barite Prospects
Map 5.4 Interpreted geology of Driscoll's Hill Prospect
Map 5.5 Geology of Harnett Prospect
Map 5.6 Interpreted and outcrop geology of the Stonehenge Prospect.

Map 6.1 Geology of the Peak View study area.
1.1 BACKGROUND

1.1.a The Canberra Region

The Silurian volcanosedimentary belts of the Canberra region contain numerous small deposits of base-metal sulphides, iron oxides, barite and gold. Many different styles of mineralization are present including: veins, stockworks, massive stratiform bodies, and stratabound veins and disseminations. In the past many of the deposits have produced small quantities of commodities including copper, lead, zinc, silver, gold, barite and iron. The largest deposit in the region is currently being exploited at the Woodlawn Mine. It consists of a massive sulphide body which originally contained 6.3 million tonnes of ore with 1.7% Cu, 5.5% Pb, 14.4% Zn, 89ppm Ag and an underlying stockwork with 3.7 million tonnes of ore with 1.9% Cu (McKay & Hazeldene, 1987).

The mineral deposits occur in meridionally trending belts composed of metamorphosed and deformed marine and subaerial volcanic rocks, with intercalated sedimentary rocks and minor granite bodies. Metamorphic grades vary up to greenschist grade and the rocks vary from being virtually undeformed to those with a very strong foliation.

1.1.b The Current Genetic Model

Mineralization such as the Woodlawn deposit is generally considered to have formed by the convective circulation of seawater through rocks below the sea floor (Solomon, 1976; Franklin et al., 1981). Heat to drive convection is thought to be derived from high-level intrusive bodies (Campbell et al., 1981). As the seawater descends in the cell it is heated, becomes reduced and leaches metals from the rocks. After passing through the hottest part of the system it rises through a zone of high permeability, such as a fault, and precipitates the ore minerals either below the seafloor as a stockwork and/or on the seafloor as a stratiform body. It follows that different alteration assemblages form in different parts of the convection cell and that different styles of mineralization and alteration will form due to temporal evolution of the system and variations in the environment of deposition.

1.1.c The Tasmanian Experience

Recent work on the alteration around the massive sulphide mineralization in the Cambrian Mt Read Volcanics of Tasmania has shown that it is possible to relate district-scale variations in alteration assemblages to the hydrothermal convection cell model (Eastoe et al., 1987). In the Murchison Gorge the distribution of assemblages is consistent with this area being a cross-section
This study is one of the first studies in an on-going research programme by the Australian National University and the Bureau of Mineral Resources in Canberra which is investigating the volcanic–associated mineralization in the Canberra region. The present study had two aims:

(i) to review the geology and mineralization in the Canberra region to find out the current level of knowledge and to determine the main problems;
(ii) to attempt to relate the sea water convection model to the numerous subeconimic mineral deposits in the Canberra region using the approach of the Tasmanian workers. This would involve:
   (1) defining the horizon(s) of exhalative mineralization,
   (2) defining zones of mineralization and alteration above and below the exhalative horizon(s),
   (3) defining the depth of seawater.

1.3 PROBLEMS

Two major problems were encountered during the study. First, recognising the effects of the regional metamorphism and deformation, and second, deciding which zones of mineralization and alteration could reasonably be related to the seawater convection model.

1.3.a Problems with Metamorphism and Deformation.

There are problems with the metamorphism and deformation on both the regional scale and the microscale. The Canberra region is structurally complex which makes it difficult to determine the relative stratigraphic position of different zones of mineralization and to define exhalative horizons. On a microscale, many of the rocks have a metamorphic foliation and greenschist facies mineral assemblages which leads to problems distinguishing minerals and textures produced during metamorphism from those which formed during the mineralizing event. Mineral assemblages produced during low-grade regional metamorphism are very similar to mineral assemblages produced during alteration in modern geothermal systems (Hedenquist & Reid, 1984).

Metamorphic and deformational fabrics are produced by a wide range of processes, however it is becoming clear that the foliation in low-grade metamorphic rocks is due to predominantly mass-transport processes associated with the metamorphic fluid (Etheridge et al., 1983).
Mass-transfer processes involve:

(i) dissolution of material from planar zones (Stephens et al., 1979; Fletcher & Pollard, 1981), commonly along grain boundaries which are subject to high normal stress (Durney, 1972),

(ii) transport of the material in a migrating metamorphic fluid phase (Etheridge et al. 1984),

(iii) precipitation of the material in sites such as metamorphic veins (Kerrich et al., 1977: Williams, 1972; Beach, 1974, 1979), pressure beards (Gray, 1978) and in dilational microfractures (Cox & Etheridge, 1983; in prep.),

(iv) development of mineral preferred orientations in dissolution sites due to either passive accumulation of insoluble minerals (Williams, 1972; Gray, 1978), or/and the oriented crystallization of new minerals (Knipe, 1981; Stephens et al., 1979),

(v) development of mineral preferred orientations in the precipitation sites due to oriented crystallization of new minerals (Cox & Etheridge, 1983; Winsor, 1983).

Much of the evidence for these processes has come from observing how relict primary microstructures in rocks have been modified during the production of domainal foliations. Premetamorphic minerals and structures commonly have random orientations and are truncated by dissolution and precipitation sites. Premetamorphic grains of platey minerals at high angles to the foliation may be deformed. For the metamorphosed and deformed rocks in the Canberra region this means that premetamorphic minerals and textures, including alteration features, may be preserved in the microlithons which are away from sites of dissolution or precipitation.

1.3.b Problems Recognising Mineralization Related to Seawater Circulation

The Canberra region has had a complex geological history and it is to be expected that the mineralization has formed by synvolcanic processes (epithermal as well as massive sulphide styles), metamorphic processes and pyrometasomatic processes related to granite intrusion. Each zone of mineralization has to be evaluated separately and this requires good descriptions of the deposits.

1.4 PROCEDURE

The study is divided into five parts:

(i) Part 1 is a review of the geology (Ch. 2) and mineralization (Ch. 3) in the Canberra region.

(ii) Part 2 is a detailed study of the geology (Ch. 4) and mineralization (Ch. 5) in the Bredbo-Bunyan study area. The Bredbo-Bunyan area was chosen because:

(1) initial indications were that it contained volcanic-associated, massive sulphide style mineralization,

(2) the mineralization occurs at a number of stratigraphic levels and so it was potentially a cross-section through a Silurian hydrothermal system.
(iii) Part 3 is a description of the Peak View massive sulphide deposit (Ch. 6). This deposit was chosen for detailed study because it contains a massive sulphide body; a style of mineralization not present in the Bredbo-Bunyan area.

(iv) Part 4 is a whole-rock geochemical study of both detailed study areas with rare earth element and sulphur isotope studies of the Bredbo-Bunyan area (Ch. 7).

(v) Part 5 is a discussion of the results (Ch. 8).

1.5 LOCATION AND ACCESS

The study areas are located in the southeastern part of the Lachlan Fold Belt (Packham, 1960), an area of metamorphosed and deformed volcanic, sedimentary and plutonic rocks of Palaeozoic age. The location of the study areas is given in Figure 1.1. The Canberra regional study area covers the Canberra 1:250 000 Metallogenic Sheet (Gilligan, 1974c) and adjoining parts of the Goulburn, Bega and Wagga Wagga sheets (Felton, 1974; Barnes & Herzberger, 1975; Degeling, 1977). The Monaro Highway passes through the middle of the Bredbo-Bunyan area and further access is provided by the numerous farm tracks in the area. The Peak View prospect is located around G.R. 132071 on the Cooma 1:100 000 Sheet. It is two kilometres northwest of the Peak View Post Office and is reached using farm access roads, fire trails and mineral exploration company tracks.

1.6 NOMENCLATURE

The nomenclature for referring to bedding, metamorphic foliations and lineations in the rocks is as follows:

(i) \( S_0 \) refers to lithological bedding,
(ii) \( S_0S \) refers to lithological bedding in Silurian rocks,
(iii) \( S_1S \) refers to the oldest recognised metamorphic surface in Silurian rocks,
(iv) \( S_1O \) refers to the oldest recognised metamorphic surface in Ordovician rocks,
(v) \( S_2O \) refers to a metamorphic surface in the Ordovician rocks which overprints an older metamorphic surface,
(vi) \( L_1O \) is the oldest lineation observed in Ordovician rocks,
(vii) \( F_2O \) refers to the second generation of folds in the Ordovician rocks,
(viii) \( D_1O \) refers to the first deformational event to affect the Ordovician rocks.
Fig. 1.1 Location of the study areas.
CHAPTER 2

THE GEOLOGY OF THE CANBERRA REGION

2.1 INTRODUCTION

The aim of this chapter is to present the geological history of the Canberra region. This will provide a basis for understanding how the mineralization in the Late Silurian rocks fits into the geological development of the region. The chapter consists of:

(i) an outline of the geological history of the Lachlan Fold Belt,
(ii) a description of the depositional history of the Canberra region, with an emphasis on the Late Silurian interval,
(iii) a description of the magmatic history of the region,
(iv) a discussion of the age and effects of the regional deformational and metamorphic events,
(v) a brief discussion of the tectonic setting during the Late Silurian.

2.2 THE GEOLOGICAL HISTORY OF THE LACHLAN FOLD BELT

The most recent reviews of the facies, distribution of facies, palaeogeography and tectonic development of the Lachlan fold Belt are presented by Cas (1983) and Powell (1984a,b,c). These authors review previous tectonic models and a discussion of these will not be given here. The following outline of the history of the Fold Belt is based on Cas (1983).

1 Cambrian

Cambrian rocks are restricted to the western part of the Fold Belt including western Victoria, northwestern New South Wales and western Tasmania. The rocks consist of mainly deepwater greenstones and flysch with minor shallow marine sequences, shallow-marine to terrestrial felsic and mafic volcanics, ultramafic rocks and lacustrine sediments. The Cambrian facies and their distribution suggest a mainly deepwater extensional rift tectonic regime with mafic volcanism developed along fractures in a thin Proterozoic basement. Shallow marine and terrestrial sedimentation occurred around the margins of the basin. The Late Cambrian Delamerian Orogeny transformed the mainly deep-water setting into a landmass.

2 Ordovician

Ordovician facies consist of quartzose turbidites (the dominant lithology in the Lachlan Fold Belt), mafic to intermediate volcanics, shelf carbonates and minor shallow-marine and terrestrial sequences. The palaeogeography (Fig. 2.1) was dominated by a deep marine setting with a mafic to intermediate volcanic arc. Along the western side of the Fold Belt a shoreline separated the
marine setting from the Delamerian landmass further west. To the south, in Tasmania, there was a broad carbonate shelf. The Canberra region was situated to the east of the arc in an area which Powell (1984a) interprets as a fore-arc basin.

LATE ORDOVICIAN

Fig. 2.1  Schematic block diagram of the palaeogeography of southeastern Australia during the Late Ordovician. (From Cas et al, 1980). C = Canberra.

3 Early and Middle Silurian

Early and Middle Silurian rocks are mainly deep-water successions with minor shallow-marine sequences. There are no volcanic rocks of Early Silurian age. This time interval includes the Benambran deformational event which involved intense folding and high-temperature, low-pressure style metamorphism of a central belt of Ordovician rocks to form the Wagga Metamorphic Belt. S-type granites were intruded into this Belt soon afterwards. According to Powell (1984b) the main elements in the Early Silurian palaeogeography (Fig. 2.2),
in the eastern side of the fold belt, included a Benambran landmass (which includes the Wagga Metamorphic Belt), a shallow-marine shelf, and a deep marine basin receiving flysch. The Canberra area lay along the marginal slope of the basin. During the Middle Silurian, in the area to the east of the Wagga Metamorphic Belt there was local uplift and erosion of the older sequences (the "Quidongan Orogeny" of Crook et al., 1973). Overall, the Early and Middle Silurian interval is considered to represent a transition from the Ordovician to the Late Silurian and Early Devonian palaeogeographic settings.

**EARLY SILURIAN**

![Scaled block diagram of the Early Silurian palaeogeography. (From Powell, 1984b).](image)

C= Canberra

4 Middle Silurian to Early Early Devonian

The Middle Silurian to early Early Devonian interval was a time of very diverse facies and complex facies patterns on a local and regional scale. Facies include deep/quiet water, flysch-like sequences, shallow-marine quartzite and conglomerate, terrestrial and submarine I- and S-type felsic volcanics, shallow-marine carbonates and epiclastic rocks, granites and terrestrial clastic sedimentary rocks. The facies distribution suggests an archipelago-type environment to the east of a continental mainland (Fig. 2.3) with deep marine basins separated by shallow-marine and
terrestrial areas. Volcanism occurred in all environments and granites were intruded during this time. The Canberra area lay in the archipelago-type environment.

**LATE SILURIAN-EARLY DEVONIAN**

![Schematic block diagram of the palaeogeography of southeastern Australia during the Late Silurian and Early Devonian. The brickwork pattern is limestone. (From Cas, 1983).](image)

5 Middle Early to Middle Devonian

The middle Early and Middle Devonian rocks consist of shallow-marine sequences, felsic volcanic rocks, granites and fluvial sequences. The period includes the Bowning Deformational Event during the earliest Devonian which was strongest in the Tumut Trough sequence. The Tabberabberan Deformational Event in the middle Devonian is associated with widespread unconformities in the eastern part of the Lachlan Fold Belt. The Early and Middle Devonian interval is considered to represent a period of transition from the mixed marine and terrestrial Middle Silurian to Early Devonian geography to the dominantly terrestrial Late Devonian to Early Carboniferous setting.

6 Late Devonian to Early Carboniferous

Late Devonian to Early Carboniferous rocks consist of mudstones and red beds with rare limestones, flysch, felsic and mafic volanics and lacustrine deposits. The palaeogeography (Fig. 2.4) is considered to have consisted of mainly terrestrial environments with local areas of
sedimentation and volcanism associated with rift grabens. The Kanimblan deformational event affected the Lachlan Fold Belt during the late Early Carboniferous.

LATE DEVONIAN-EARLY CARBONIFEROUS

Fig. 2.4 Schematic block diagram of the palaeogeography of southeastern Australia during the Late Devonian and Early Carboniferous. (From Cas, 1983). C = Canberra.

2.3 INTRODUCTION TO THE GEOLOGY OF THE CANBERRA REGION

2.3.a General

Accounts of the geological history of the Canberra region have been given by Strusz (1971) and Crook et al., (1973). This section builds on these earlier works by using the results of more recent studies. Powell (1983) presents a review of the development of the coastal area to the east of the present study area.

2.3.b The Structure of the Canberra Region

The rocks in the Canberra region are distributed in meridionally trending structural blocks (Fig. 2.5) which form a series of horsts and grabens bounded by steep faults (Strusz, 1971; Hayden, 1980; Gould, 1974). Each block represents a different former crustal level which has been brought to the present erosion surface (Owen & Wyborn, 1979). Silurian and Devonian rocks are common in the grabens and Ordovician rocks with granites are common in the horsts.
Fig. 2.5 Major structural blocks in the Canberra region. (Ba=Brindabella, Bb=Batemans Bay, Be=Breadalbane, Bu=Bungendore, Cf=Captains Flat, Je=Jerangle, Mi=Mitchello, Mo=Moruya, Wn=Woodlawn).
There has been a tendency in the past to interpret present structural grabens as discrete Palaeozoic sedimentary basins and present horsts as Palaeozoic geographic highs (e.g. Scheibner, 1973), however it is becoming clear that this interpretation is not generally correct and that the present structures mask the original palaeographic features (Cas, 1983; Powell, 1984b, p 310).

Before reconstructing the palaeogeography it is necessary to assess the strike-slip movement of the major meridional faults. In a review of the regional fault patterns Hayden (1980) showed that very little is known about the faults. Dip-slip movement can usually be demonstrated but strike-slip movement is difficult to assess. In a recent model for the development of the Lachlan Fold Belt, Packham (1985) argues that there has been large (mainly sinistral) movement on some of the major faults during the Early Silurian to Early Devonian period and in the Canberra region there was dextral movement on the Copperhannia-Lake George Fault. If this is the case then there was probably some movement on the Narongo and the Murrumbidgee Faults either or both of which may represent the southern extension of the Copperahannia-Lake George Fault. In the Bredbo-Bunyan detailed study area in the Bredbo Block, the metamorphic zones can be interpreted as part of the metamorphic zones produced by the Cooma Metamorphic Complex exposed in the Cotter Block to the west of the Murrumbidgee Fault (4.3.b). This suggests that there has not been any significant strike-slip movement on this fault. Hayden (1980) presents arguments which suggest a sinistral movement on the Narongo Fault in contrast to reports of dextral movement by earlier workers.

Although precise correlations between structural blocks are rare, there is a reasonably consistent distribution and sequence of facies in the blocks. This suggests that the rocks formed in an originally coherent setting and that there has been no significant strike-slip movement on the major faults.

2.3.c Sources of Information


2.3.d Basement

The oldest exposed rocks in the Canberra region are of Ordovician age. The nature of the basement to the Cambrian and Ordovician sequences in the Lachlan Fold Belt is controversial. Detailed reviews of the problem are given by Cas (1983) and Powell (1984a). One interpretation is that the widespread occurrence of Early Palaeozoic rocks which are characteristic of an oceanic setting such as flysch, andesites, mid ocean ridge type mafic rocks (Crawford & Keays, 1978),
boninites (Crawford & Cameron, 1980), and possible ophiolites (Crook & Felton, 1975) implies the presence of an oceanic crust at this time. A problem with this interpretation is that the Cambrian greenstones are intruded by S-type granites which strongly suggests the existence of a sedimentary layer in the crust in these areas (Cas, 1983). Crawford et al., (1984) reconcile this problem by suggesting that during the Benambran deformational event a large block of Precambrian crust was thrust beneath the Cambrian and Ordovician oceanic crust.

A second approach is based on the premise that the abundant Siluro-Devonian granites in the Fold Belt can be images of their source rocks and therefore give indications of the nature of lower crust. The granites can be divided into I-types, which are derived from igneous source rocks and S-types whose source rocks have been through a weathering cycle (White & Chappell, 1974; Chappell & White, 1984). The composition of the Ordovician sedimentary rocks (Wyborn & Chappell, 1983) makes them an unsuitable source for the S-type granites, except for rare plutons such as the Cooma Granodiorite which formed by in-situ melting of the Ordovician sedimentary rocks (Chappell, 1984). Nd and Sr isotope studies (Compston & Chappell, 1979; McCulloch & Chappell, 1982; McCulloch et al., 1983) indicate that the I-type granite source rocks were derived from the mantle over a long period from 400 Ma to 1600 Ma. These ages are consistent with zircon ages obtained from granites by I.S. Williams (Compston and Chappell, 1979). The source is unlikely to have been newly formed oceanic crust and White (1979) argued that because I-type batholiths are homogeneous on a very large scale they must have large, homogeneous sources. Such sources could have been produced by underplating during subduction. The S-type source components were removed from the mantle during the Proterozoic from ~1500 to 1800 Ma and were later weathered to form the S-type source. Overall, the granite geochemistry suggests that during the Silurian and Devonian much of the Lachlan Fold Belt was underlain by a sedimentary layer and a deeper igneous layer both probably of Proterozoic to Lower Palaeozoic age.

The position of the eastern margin of the source layer for the S-type granites, inferred from the western limit of S-type granites, is called the I-S line (White et al., 1976). Only I-type granites occur to the east of the line and both I-and S-types occur to the west of it. Shaw et al., (1982) considered that the Wologorong Batholith was S-type and that the I-S line passed to the east of it, however more recent work indicates that the batholith is I-type and that the I-S line passes to the west of it, probably along the Copperhannia Thrust which marks the western margin of the Hill End Trough sequence (B.W. Chappell, ANU, pers. comm., 1986). The I-S line passes through the middle of the regional study area (Fig. 2.5).

2.4 SILURIAN FACIES AND STRATIGRAPHY

2.4.a Facies

The Silurian sequences in the Canberra region are characterised by complex volcanic and sedimentary facies and facies relationships. The general sequence of facies for the ten structural blocks is shown in the stratigraphic columns in Figure 2.6.a and the formation names are given in
Figure 2.6.b. The sequences have been divided into nine facies:

(i) proximal flysch,
(ii) coarse sandstone (sometimes conglomeratic),
(iii) mudstone with minor calcareous units,
(iv) S-type volcanic rocks,
(v) I-type volcanic rocks,
(vi) limestone,
(vii) volcaniclastic and epiclastic rocks,
(viii) extrusive mafic volcanic rocks,
(ix) conglomerate.

2.4. b The Age of Units

1 Introduction

Precise age determinations for units are uncommon due to the lack of study and the wide-ranging nature of the macrofossil assemblages. Conodont and graptolite studies give the best ages, however very little work of this type has been done. Some isotopic age dates are available for the Goobarragandra Volcanics (Owen & Wyborn, 1979), Laidlaw Volcanics (Wyborn et al., 1982), Colinton Volcanics (D. Wyborn, BMR, pers. comm., 1986) and the Woodlawn Volcanics (Gulson, 1977). The stratigraphic distribution and age range of a potentially useful list of fossils is given in Table 2.1.

2 Goobarragandra Block

There is no internal evidence for the age of the Goobarragandra Volcanics. In one place they are conformably overlain by the Ludlovian Yarrongobilly Limestone. Isotope data suggest a Late Wenlockian age.

3 Tantangara Block

Palaeontological evidence for the age of the Cooleman Plains Group in the Tantangara Block is summarised by Pickett (1982) and Jell & Talent (undated). Conodonts in the Peppercorn Beds give a Late Llandoverian age. Conodont and macrofossil ages for the rest of the sequence give possibly late Wenlock, Ludlovian and Pridolian ages. Although Owen & Wyborn (1979) considered that deposition continued through the Wenlock this has yet to be demonstrated (Pickett, 1982). Faunas in the Tantangara Beds give Silurian ages, but stratigraphic relationships constrain the unit to the Early Llandovery. The S-type, Kellys Plain Volcanics were assigned a latest Silurian to Lower Devonian age since they appear to be unconformable on the Cooleman Plains Group (Owen & Wyborn, 1979). The age of this unit is currently under review, however, because recent isotopic dating has given Wenlockian ages (D. Wyborn, BMR, pers. comm., 1987). The volcanics are chemically identical to the Hawkins Suite which supports a Wenlockian age. Doone Wybom has suggested that the contact with the Cooleman Plains Group may in fact be a roughly
Fig. 2.6.a Silurian facies and stratigraphy in the Canberra region.

Sandstone and mudstone (proximal flysch)  
Coarse sandstone sometimes conglomeratic  
Mudstones with minor calcareous rocks.  
Limestone  
Conglomerate  
Fossil age  
Radiometric age  
Conglomerate  
Fault  
Nature of contact uncertain

SILURIAN  
DEVONIAN

COTTIER BLOCK  
CANBERRA BLOCK  
BREDGO BLOCK  
CULURRII BLOCK  
CAPTAINS FLAT BLOCK  
ROCKY RIDGE BLOCK  
BOOMBAY BLOCK

Conglomerate  
Fossil age  
Radiometric age  
Conglomerate  
Fault  
Nature of contact uncertain
Fig. 2.6.b  Silurian stratigraphic units in the Canberra region.
Fig. 2.6.b  Silurian stratigraphic units in the Canberra region. (Cont’d)
Fig. 2.6.b  Silurian stratigraphic units in the Canberra region. (Cont'd)
Table 2.1  Stratigraphic distribution and age range of selected Late Silurian fossils.

<table>
<thead>
<tr>
<th>STRUCTURAL BLOCK and HOST UNIT</th>
<th>FOSSIL with AGE RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phalacrites shearhyl</td>
</tr>
<tr>
<td>Canberra Block at Yass</td>
<td></td>
</tr>
<tr>
<td>Mundoonen Sandstone</td>
<td></td>
</tr>
<tr>
<td>Hawkins Volcanics</td>
<td></td>
</tr>
<tr>
<td>Yass Formation</td>
<td>O,G</td>
</tr>
<tr>
<td>Laidlaw Formation</td>
<td></td>
</tr>
<tr>
<td>Silverdale Formation</td>
<td>G</td>
</tr>
<tr>
<td>Booroo Ponds Group</td>
<td>K</td>
</tr>
<tr>
<td>Canberra Block at Canberra</td>
<td></td>
</tr>
<tr>
<td>Canberra Formation</td>
<td>I</td>
</tr>
<tr>
<td>Yarralumla Formation</td>
<td>I</td>
</tr>
<tr>
<td>Bredbo Block</td>
<td></td>
</tr>
<tr>
<td>Cappanana Formation</td>
<td>M,N</td>
</tr>
<tr>
<td>Colinton Volcanics</td>
<td>A</td>
</tr>
<tr>
<td>Captains Flat</td>
<td>Copper Creek Shale</td>
</tr>
<tr>
<td>De Drack Formation</td>
<td>U</td>
</tr>
<tr>
<td>Quidong</td>
<td>Quidong Limestone</td>
</tr>
<tr>
<td>Tantangara Block</td>
<td>Pepperorn Beds</td>
</tr>
<tr>
<td></td>
<td>Pocket Beds</td>
</tr>
<tr>
<td></td>
<td>Cooleman Limestone</td>
</tr>
<tr>
<td></td>
<td>Blue Waterhole Beds</td>
</tr>
</tbody>
</table>

References.

A. Browne (1944).
B. ANU Third Year Mapping Reports.
C. Glasson (1952).
D. Glasson (1957).
F. Hughes (1971).
H. Oldershaw (1965).
I. Pickett (1982).
K. Strusz (1980).
M. Veever (1951).
N. Veever (1953).
O. Brown (1941).
P. Harper (1909).
Q. Hill (1940).
S. Legg (1968).
cylindrical fault system due to Early Devonian subsidence. For the present review it will be assumed that the Kelly's Plain Volcanics are diachronous: partly Wenlockian and partly Early Devonian.

4 Nungar-Brindabella and Cotter Blocks

The age of the units in the Nungar-Brindabella and Cotter Blocks can only be inferred from lithological correlation. The Paddy’s River Volcanics are part of the Hawkins Volcanic Suite (Wyborn et al., 1981). Other units in the Hawkins Suite are probably of late Wenlock to earliest Ludlow age (see below). The Tidbinbilla Quartzite may correlate with either the Late Llandoverian Peppercorn Beds (Owen & Wyborn, 1979) or the basal parts of the latest Wenlockian to Late Silurian volcanosedimentary sequences in the region.

5 Canberra Block

The State Circle Shale has a Late Llandoverian age based on graptolites (Pickett, 1982). The age of the Black Mountain Sandstone is uncertain although it probably conformably overlies the State Circle Shale (Strusz & Jenkins, 1982; Pickett, 1982) and is therefore Late Llandoverian.

The age of the upper part of the sequence in the Yass area of the Canberra Block is well constrained (Pickett, 1982; Jenkins, 1982) however the ages of the Hawkins Volcanics and the Mundoonen Sandstone are not well confined. Faunas reported from thin sedimentary units within the Hawkins Volcanics by Hughes (1971) are wide-ranging. Most previous studies of the region have put the unit in the Wenlock on the basis that it is a thick volcanic unit which is older than the Ludlovian Yass Subgroup. The contact between the Hawkins Volcanics and the underlying Mundoonen Sandstone is in part conformable Browne (1954), Hughes (1971) and in the south is faulted (Holloway, 1972) or possibly unconformable (Topp, 1972). The coral *Rhizophyllum interpunctatum* from a thin fossil rich bed near the top of the unit (Hughes, 1971) has only been recorded from Ludlovian rocks (T. Munson, ANU, *pers. comm.*, 1986). Lithologically the Mundoonen Sandstone is very similar to Late Llandoverian proximal flysch units near Canberra (Black Mountain Sandstone and State Circle Shale) and in the Bredbo Block (Ryrie Formation). These problems may be resolved using the suggestion of Crook et al. (1973) that the Mundoonen Sandstone is diachronous. The fossil rich bed at the top of the unit may represent the base of the latest Wenlockian to Pridolian volcanosedimentary sequence and the rest of the Mundoonen Sandstone lies unconformably below it. If this is the case then the age of the lower part of the Mundoonen Sandstone can be inferred to be Late Llandoverian. This interpretation would constrain the Hawkins Volcanics to the earliest Ludlow and implies that, although the volcanics are thick (about 5 km in the type section; Hughes, 1971), they were deposited very rapidly.

In the Canberra area of the Canberra Block the age of the upper part of the sequence is well constrained by the Ludlovian faunas from the Yarralumla Formation (Pickett, 1982; Strusz, 1984). The age of the Hawkins Suite volcanics and the underlying Canberra Formation is not well defined. Rich faunas have been recovered from thin sedimentary units in the Walker Volcanics, however they do not give good age information (Chatterton & Campbell, 1980; Strusz, 1982,
The Canberra Formation is underlain unconformably by Late Llandoverian rocks. On stratigraphic grounds the unit is considered to be of Wenlockian age (Abell, 1982; Strusz, 1985). According to Jell & Talent (undated) the occurrence of the brachiopod *Rhipidium* in the base of the unit suggests a Late Wenlockian age. The Riverside "Member" contains corals including *Phaulactis shearsbyi*, *Mucophyllum crateroides* and *Rhizophyllum interpunctatum* (Table 2.1) which suggest a Ludlovian age. The Riverside "Member" also contains the trilobite *Onycopyge liversidgei* which is known from only two other localities, the well-constrained Ludlovian sequence at Quidong N.S.W. (Holloway & Campbell, 1974) and the Cappannana Formation. Graptolites from the "Member" indicate an earliest Ludlovian or younger age (Jell & Talent, undated). One solution to this problem might be that, because of the complex structure in the area, outcrops mapped as the Riverside "Member" may in fact be part of the Yarralumla Formation. Overall, the evidence for the age of the Canberra Formation is poor but it suggests that much of the Canberra Formation, and therefore the overlying Hawkins Suite volcanics, were deposited during the Late Wenlockian to Early Ludlovian.

6 Bredbo Block

The Ryrie Formation contains Late Llandoverian graptolites at its base (Richardson & Sherwin, 1975).

The age of the main sequence in the Bredbo Block is a problem. Recent work in the area (Beams, 1984a & b; Henderson, 1987; my work) indicates that the basal sedimentary sequence (Cappanana Formation) is overlain by mainly terrestrial volcanics (Colinton Volcanics) which are overlain by interbedded volcanic and sedimentary units (Rothlyn Formation). There is a transgressive sedimentary sequence at the base of the Rothlyn Formation. Recent isotope dating by Doone Wyborn (BMR, pers. comm., 1986) indicates a Late Silurian and possibly even earliest Devonian age for the volcanics. Although initial indications were that the Colinton Volcanics were possibly related to the S-type Laidlaw Suite near Canberra (Wyborn, 1984) recent work has shown that they are I-type (Bain et al., 1987). The volcanics of the Rothlyn Formation are also I-type. These units may be related to the I-type volcanic suites which are common in the blocks east of the Bredbo Block. The Colinton Volcanics and the underlying Cappanana Formation contain Ludlovian corals and the trilobite *Onycopyge liversidgei* occurs in the Cappanana Formation (Table 2.1). Overall, these observations suggest that the main sequence in the Bredbo Block is no older than Ludlovian and in terms of the regional stratigraphy:

(i) the Cappanana Formation may correlate with the Yarralumla Formation and the Yass Subgroup,

(ii) the Colinton Volcanics may be coeval with the Laidlaw Volcanics,

(iii) the transgressive sequence at the base of the Rothlyn Formation may correlate with the lower parts of the Silverdale Formation near Yass.
7 Captains Flat, Rocky Pic and Cullarin Blocks

The ages of the sequences in the Captains Flat, Rocky Pic and Cullarin Blocks are generally poorly constrained and can only be based on lithological correlation with the better defined areas. A whole rock U-Pb and Rb-Sr study of the sequence near Woodlawn by Gulson (1977) gave Late Silurian ages. The corals reported from the Captains Flat and Woodlawn areas (Table 2.1) suggest a Ludlovian or younger age however the identifications need to be confirmed. Plant fragments from the Covan Creek Formation indicate an Early Devonian age (Sherwin, 1973) or possibly Silurian age (D. Wyborn, BMR, pers. comm., 1986).

8 Bombay Block

The age of the De Drack Formation in the Bombay Block is Ludlovian and possibly Pridolian based on conodont assemblages (Wyborn & Owen, 1986).

2.5 DEPOSITIONAL HISTORY OF THE CANBERRA REGION

2.5.a Ordovician

Ordovician rocks in the Canberra region consist of proximal and distal flysch sequences with minor mafic volcanic rocks. Distal flysch is exposed on most of the structural blocks. It was deposited on the outer margins of a large submarine fan, supplied with sediment from the south (Cas et al., 1980). Basaltic lavas and volcaniclastic rocks with minor chert occur in the Tantangara Block. These rocks are part of the Molong Volcanic Arc which formed during the Late Darriwilian to Gisbornian. Deposition of distal flysch continued during and after the volcanism. Proximal flysch of late Estonian to Early Bolindian age occurs on the Cotter and Nungar-Brindabella Blocks. The change to the deposition of proximal flysch may have been due to either progradation of the fan or to the emergence of a local source by early movements of the Benambran deformational event.

2.5.b Benambran Deformational Event

Unconformities below Llandovery proximal flysch units in the Nungar-Brindabella Block (Tantangara Formation), Tantangara Block (Tantangara Formation), Canberra Block (State Circle Shale and Mundoonen Sandstone) and Bredbo Block (Ryrie Formation) indicate a period of uplift, erosion and tilting during the latest Ordovician to Early Llandovery. This event is considered to be part of the Benambran deformational and metamorphic event which produced the Wagga Metamorphic Belt to the west at this time.

2.5.c Early Llandovery

During the Early Llandovery, proximal flysch was deposited in the Tantangara and Nungar-Brindabella Blocks (Tantangara Formation). It is considered to have formed in a series of fans in a small trough with sediment supplied from the uplifted Wagga Metamorphic Belt to the west. The flysch sequence is unconformably overlain by Late Llandoveryian rocks. The
unconformity is considered to be due to the continued influence of the Benambran deformational event.

2.5.d Late Llandovery

During the Late Llandovery a transgressive, shallow-marine sequence was deposited on the Tantangara Block (Peppercorn Beds) and possibly further east in the Cotter Block (Tidbinbilla Quartzite). In the Canberra and Bredbo Blocks, proximal flysch sequences were deposited (State Circle Shale, Black Mountain Sandstone and Mundoonen Sandstone [lower part only?!]). In the Blocks further to the east no rocks of Llandoverian age have been reported however Crook et al., (1973) suggest that distal flysch may have been deposited in these areas during this time and that the deposits have not yet been distinguished from the Ordovician sequences. The proximal flysch unit reported from the Kybeyan area of the Cullarin Block (O'Grady, 1980) may be of this age.

The proximal flysch was deposited in a series of submarine fans supplied with sediment from a landmass to the west (Crook et al., 1973) which probably become emergent due to uplift during the Benambran deformational event. Owen & Wyborn (1979) suggest that the landmass was separated from the deep basin by a shallow-marine shelf.

2.5.e Quidongan Deformational Event

Unconformities above the Llandovery proximal flysch sequences and below the latest Wenlockian and Ludlovian sequences in the Canberra and Bredbo Blocks are attributed to the Quidongan deformational event (Crook et al., 1973). It is not clear whether the event affected the rocks in the other structural blocks. To the west in the Tantangara Block, Owen & Wyborn (1979) consider that deposition of the shallow marine sequence (Cooleman Plains Group) continued during this time however this is yet to be confirmed using palaeontological evidence (Pickett, 1982). If the Kelly's Plain Volcanics are partly Wenlockian then the unconformity with the underlying Tantangara Formation would be restricted to the Late Llandovery to Early (and Middle?) Wenlockian. This may be evidence for a Quidongan deformational event in this area. In the blocks to the east of the Canberra Block the boundary between the Ordovician and Late Silurian units is usually a fault although it is an unconformity in the Woodlawn area. In the Bombay Block the Ordovician and Silurian sequences are disconformable (D.Wyborn, BMR, pers. comm., 1986) despite the large time break.

The Quidongan Orogeny is generally considered to have transformed the deep marine setting into a landmass.

2.5.f Latest Wenlock and Late Silurian

During the latest Wenlock, subaerial S-type volcanics were deposited throughout much of the western part of the region. In the Canberra area the Hawkins Suite volcanics were preceeded by a shallow-marine sedimentary sequence (Canberra Formation). In the Cotter and Nungar-Brindabella Blocks Hawkins Suite volcanics were deposited directly onto the Ordovician rocks. Further west in the Tantangara Block there are a few small volcaniclastic units low in the
Pocket Beds and at least part of the S-type, Kellys Plain Volcanics may be of this age. The S-type Goobarragandra Volcanics were deposited at around this time.

During the Ludlow, shallow-marine sequences were deposited throughout much of the region: in the Tantangara Block (Cooleman Plains Group), Canberra Block (Yarralumla Formation and Yass Subgroup), Bredbo Block (Cappanana Formation), the Captains Flat Block (Copper Creek Shale), the Rocky Pic Block (de Drack Formation) and in the Bombay Block (de Drack Formation). In the Canberra and Bredbo Blocks the shallow marine conditions were interrupted by the deposition of subaerial volcanics (S-type Laidlaw Volcanics; I-type Colinton Volcanics) but these were followed by shallow-marine environments (Silverdale Formation and Booroo Ponds Group; Rothlyn Formation). In all of the Blocks east of the Bredbo Block the transgressive shallow-marine sequence is followed by I-type volcanics.

The volcanic sequences in the southeastern part of the Bredbo Block (Rothlyn Formation), the Captains Flat Block (Kohinoor Volcanics) and Rocky Pic Block (Woodlawn Volcanics) all have a similar association of facies. They are composed of dacitic to rhyolitic pyroclastic and extrusive rocks with interfingering and interbedded volcanioclastic and epiclastic sedimentary rocks. Welded ignimbrites occur near the base of the volcanics in the Woodlawn area of the Rocky Pic Block. Small basalt and/or andesite units occur in the volcanioclastic facies rocks in the Captains Flat and Bredbo Blocks and a thick unit of partly pillowed basalt occurs at the top of the volcanic sequence in the Woodlawn area of the Rocky Pic Block. The Captains Flat and Rocky Pic Block sequences have only very rare, small limestone units. There is a thick limestone unit (Cloyne Limestone Member; Henderson, 1987) close to the top of the sequence in the Bredbo Block.

Further east in the Bombay Block the basal sedimentary sequence is succeeded by a thick sequence of subaerial volcanics (Long Flat Volcanics) with only minor sedimentary rocks.

The environment in the area of the Cotter and Nungar-Brindabella Blocks during the Late Silurian is not clear mainly because the Silurian sequence in these areas is very small. Feary (1984) suggested that there was a subaerial volcanic hinterland to the west of the Boambolo area, south of Yass in the Canberra Block, during this time.

Overall, the distribution of facies suggests that during the latest Wenlock the region was mainly terrestrial with local shallow-marine areas. During the Ludlow the region subsided and the palaeogeography (Fig. 2.7) consisted of a roughly meridionally trending deep-marine trough (Rocky Pic and Captains Flat Blocks and southeastern part of the Bredbo Block) bounded on its western side by a broad shallow marine shelf with local subaerial areas (all Blocks west of the Bredbo Block). The eastern side of the trough was a shallow-marine shelf initially and later a belt of subaerial volcanics. A similar model has been developed by Bain et al. (1987) who called the trough the Ngungawal Basin.

The volcanosedimentary sequences are conformably and unconformably overlain by latest Silurian and earliest Devonian proximal flysch units in the Canberra Block (Barrambogie Group), Captains Flat Block (Carwoola Beds), Rocky Pic Block (Covan Creek Formation) and Bombay Block (Palerang Formation). In the Yass area of the Canberra Block sediment was supplied from volcanic and Ordovician sedimentary source rocks to the southwest and west. In the Woodlawn
area of the Rocky Pic Block sediment was supplied from a similar source to the south (Henry, 1978). The change to proximal flysch deposition was probably related to local uplift due to the onset of the Bowning deformational event.
2.5.g Bowning Deformational Event
Unconformities below Lower Devonian units in the Tantangara, Nungar-Brindabella, Canberra and Rocky Pic Blocks are attributed to the Bowning deformational event. The event involved uplift, erosion, folding and probably metamorphism (2.7).

2.5.h Early Devonian
In the Tantangara and Nungar-Brindabella Blocks part of the subaerial, S-type, Kellys Plain Volcanics may have been erupted during the Early Devonian. After a period of erosion subaerial I-type volcansics (Mountain Creek Volcanics) were erupted. These rocks and the surrounding pre-Devonian sequences were partly eroded to form fluviatile deposits which were succeeded in the late Early Devonian by shallow-marine limestones and clastic sedimentary rocks (Murrumbidgee Group).

In the Currawang area of the Rocky Pic Block terrestrial sandstones and conglomerates followed by shallow-marine sedimentary rocks (Mulwaree Group) were deposited during the Early Devonian. To the east in the Bombay Block shallow-marine sediments (Fernleigh Group) were being deposited at this time.

2.5.i Tabberabberan Deformational Event
A period of uplift and erosion in the sequence on the Nungar-Brindabella Block at the end of the Early Devonian is attributed to the Tabberabberan deformational event.

2.5.j Middle and Late Devonian
In the Nungar-Brindabella Block a thick sequence of fluvial sedimentary rocks (Hatchery Creek Conglomerate) was deposited during the Middle Devonian. In the Bombay Block a sequence of A-type rhyolites, with minor basalt and shale (Comerong Volcanics) were deposited during the late Middle Devonian to early Late Devonian. These were followed by a unit of interbedded sandstones and shales with a basal conglomerate during the Late Devonian (Minuma Range and Merrimbla Groups).

2.5.k Kanimblan Deformational Event
Folding of the Middle and Late Devonian sequences is attributed to the early Carboniferous Kanimblan deformational event which is considered to be the event which ends deposition in the Lachlan Fold Belt.

2.5.l Mesozoic and Cainozoic
The Myalla Road Syenite, south of Cooma was intruded during the Jurassic. During the Tertiary, plateau basalts were extruded and there was fluvial and lacustrine (eg. Taylor & Walker, 1986a&b) sedimentation. Two stages of uplift occurred with movement along the major meridional faults. Colluvial deposits formed during the Pleistocene ice age and since then alluvial deposits have accumulated along many watercourses.
2.6 INTRUSIVE HISTORY OF THE CANBERRA REGION

Many large granite bodies with smaller mafic and ultramafic bodies were emplaced during the interval from Late Silurian to Middle Devonian and they tend to occur in the present horsts. The granites are considered to be comagmatic with the volcanic rocks (Wyborn et al., 1981; Wyborn, 1984; Wyborn & Owen, 1986; Wyborn & Chappell, 1986).

In the western part of the study area in the Goobarragandra, Nungar-Brindabella, Tantangara and Cotter Blocks granites of the mostly S-type Young, Gingera and Murrumbidgee Batholiths were intruded during the Late Silurian. I-types are slightly younger than the S-types. The Micalong Swamp Basic Igneous Complex, which is composed of stocks and sheeted dykes of gabbro, dolerite and diorite, was intruded into the Goobarragandra Block at this time. The Hawkins Suite volcanics are considered to be comagmatic with the rocks of the Murrumbidgee Batholith and the Berridale Batholith further south. The Laidlaw Suite volcanics are possibly comagmatic with the Shannons Flat Adamellite. In the Early Devonian a number of small I-type plutons of the Boggy Plain Suite were emplaced which are considered to be comagmatic with the Early Devonian Mountain Creek Volcanics.

The isotopic dating of the Cooma Complex was reviewed by Reid (1980). He concluded that the Cooma Granodiorite formed at 416 ±5.4 Ma, which corresponds to the Late Silurian. Intrusive relationships suggest that this pluton must either predate, or be synchronous with, the Murrumbidgee Batholith.

In the central part of the study area, in the Canberra and Cullarin Blocks and the northern part of the Rocky Pic blocks the ages of the intrusives are poorly constrained, partly due to the resetting of isotopic systems during metamorphism. The most reliable dates are 410 Ma for the Sutton Adamellite (Abell, 1981), ~419 Ma for the Koolambah Granodiorite (Hayden, 1980) and 417 Ma for the Federal Golf Course Tonalite (Abell, 1981) which is thought to be part of the Michelago Igneous Complex (Abell, 1981). These dates suggest a Late Silurian age for these plutons. Further north the Wologorong Batholith has a "reconnaissance" Rb-Sr whole rock isochron of 405 ±11 Ma (Shaw et al., 1982) which suggests a latest Silurian to earliest Devonian age.

Most of the granites in the eastern part of the study area, in the southern part of the Rocky Pic Block and the Bombay Block are part of the Early Devonian Bega Batholith. The Lockhart Basic Igneous Complex occurs along the western side of the Bega Batholith and is intruded by it. Some of the units in the Long Flat Volcanics are comagmatic with the Bega Batholith. Along the eastern side of the Bombay Block there are a number of small mafic bodies and A-type granites of late Middle to early Late Devonian age. They are considered to be comagmatic with the A-type Comerong volcanics.

Overall, the results suggest that in the western part of the study area S-type and minor I-type granites were emplaced during the Late Silurian. I-type granites were emplaced throughout the region in the Early Devonian. A-type granites were intruded in the late Middle to early Late Devonian. Mafic bodies were emplaced with the granites.
2.7 METAMORPHIC AND STRUCTURAL HISTORY

2.7.a General

The structural and metamorphic history of the Canberra region is poorly understood due to the lack of age control on events and the problems of correlating structures between different structural blocks. In particular there is the problem that folding events of different ages may produce coaxial folds. Duff (1985) has recently summarised much of the structural information for part of the region and has examined important areas.

2.7.b Metamorphism

Metamorphic grades in the region are in the very low- and low-grades of Winkler (1979) except for the following areas:

(i) in granite contact aureoles where biotite with cordierite or andalusite may be developed.

(ii) in parts of the Ordovician rocks of the Cullarin Block where there are meridional zones of chlorite-, biotite- and andalusite-grade assemblages (Hayden, 1980; Olley, 1984). Similar zones have been recognised in Ordovician rocks south of the study area (McQueen et al., 1986).

(iii) in the Cooma area of the Cotter Block at the Cooma metamorphic complex (Joplin, 1942; Hopwood, 1976; Granath, 1980; Vernon & Hobbs, undated; Vernon, 1981). The central Cooma Granodiorite is surrounded by a zone of migmatites followed by a high-grade metamorphic zone characterised by orthoclase and cordierite, followed by low-grade zones of andalusite, then biotite, and finally chlorite.

2.7.c Folds and Foliations

1 Ordovician

Early Folds

Recumbent isoclinal folds either with no axial-plane cleavage or, a segregation or slatey axial-plane cleavage have been recognised in parts of the Cullarin Block (Stauffer & Rickard, 1966; Abell, 1981) and in the Rocky Pic Block (Duff, 1985; Abell, 1981). On the Cotter Block there are areas in which the main folds are upward- and downward-facing. The folds have an axial-plane cleavage which crenulates an earlier fine slatey cleavage. These observations imply the existence of earlier recumbent folds (Duff, 1985). Reid (1980) has also reported a foliation which predates the main foliation in the Ordovician rocks on the Cotter Block.
Main Folds

The dominant structural feature in the Ordovician rocks are upright, variably plunging, open to tight, meridionally trending folds with an axial-plane slatey cleavage or crenulation cleavage (Duff, 1985).

Later Folds

Later folds are mostly conjugate kinks (Duff, 1985). In the Rocky Pic Block and the eastern parts of the Bombay Block the kink folds are associated with a crenulation cleavage developed on an earlier foliation. This event also crenulates cordierite porphyroblasts in the granite contact aureoles in the Bombay Block. In the northern Rocky Pic Block, east of Lake George, early isoclinal folds are refolded to form more open style, second generation folds with an axial-plane crenulation cleavage (Horsley, 1972).

Other Features

Hopwood (1976), Granath (1980) and Vernon (1981) have made detailed studies of the structure and metmorphism in the Cooma Metamorphic Complex and this is summarised by Vernon & Hobbs (undated). In the low-grade zones, bedding (S₀) is folded to form isoclinal, meridionally trending folds (F₁) with a steeply dipping axial-plane slatey cleavage or schistosity (S₁). In places bedding is transposed to form a layering (S) which is parallel to S₁ and is folded to form steeply plunging folds (F₁'). F₁ and F₁' folds have the same axial-plane surface (S₁) and are called Group 1 folds. Group 2 folds overprint Group 1 folds. F₂ folds have a differentiated crenulation cleavage (S₂) in their axial-plane and F₂' folds have a kink-like axial-plane crenulation cleavage (S₂'). Late kinks (F₃,S₃) affect all the older surfaces. Porphyroblasts of andalusite have inclusion trails indicating that they grew during F₁ and F₂ which indicates that it was a prograde sequence (Vernon & Hobbs, undated). Structures similar to S₀, S₁ and S₂ have been recognised in the high-grade zones.

Crook (1978, and in Cas et al., 1980) reports latitudinally trending folds in the metamorphic aureole of the Sutton Granite in the Cullarin Block northeast of Canberra. These folds may be due to the intrusion of the granite or they may represent pregranite folds which are preserved from the later intense deformation which produced the main, meridionally trending folds.

2 Middle and Late Silurian

First Folds

The intensity and effects of the first folding event are variable. In much of the Goobarragandra, Canberra and Bombay Blocks folds are upright and open with little or no cleavage development. In the Tantangara, Bredbo, Captains Flat and Rocky Pic Blocks the folds are generally upright, open to isoclinal and have a strong axial-plane slatey cleavage.
Later Folds

Later folds are mainly kinks. The main foliation is crenulated by a later foliation in parts of the Bredbo Block (Ch. 4), in the Peak View area of the Rocky Pic Block (Ch. 6), in the Captains Flat Block (D. Wyborn, BMR, pers. comm., 1986) and in the northern part of the Rocky Pic Block, north of Lake George (P. Stuart-Smith, BMR, pers. comm., 1986). In parts of the Bredbo Block the second foliation (S2S) is accentuated by the coarse recrystallization of biotite parallel to S2S.

3 Devonian

Folding in the Devonian rocks is variable. The Early Devonian volcanics in the southern part of the Nungar-Brindabella and Tantangara Blocks are only tilted (Owen & Wyborn, 1979). Elsewhere in the region the Devonian sequences have generally been folded to form meridional folds with variable degrees of development of an axial-plane cleavage.

4 Other Features

The margins of some of the plutons of the Bega Batholith and the Ellenden granite are mildly foliated (Felton, 1977; Wyborn & Owen, 1986). Powell (1983) has recognised megakinks (trending NE and SW) in the coastal region to the east of the study area. Megakinks have also been reported from the Captains Flat Block by Olley (1984).

2.7.d Faults

The regional fault pattern was reviewed by Hayden (1980). The pattern is dominated by the major meridional faults with minor northwest- and northeast-trending faults curving away from the meridional faults. The meridional faults clearly have dip-slip movements since they often juxtapose Ordovician rocks with Silurian and Devonian rocks, and/or juxtapose rocks with low metamorphic grades with higher grade rocks. Movement is usually west block up. As explained in Section 2.3 strike-slip movement is difficult to assess. The northwest-trending faults commonly have sinistral offsets, and the northeast-trending faults commonly have dextral offsets.

2.7.e The Age of Folding, Metamorphism and Faulting

1 Observations

Depositional lacunas which may be associated with deformational events occurred during the latest Ordovician to earliest Llandoverian, the middle Llandoverian, the Wenlock, the latest Silurian to earliest Devonian, the latest Early Devonian and the latest Devonian.

According to Owen & Wyborn (1979) the Ordovician volcanic and sedimentary rocks of the Tantangara Block were metamorphosed to upper greenschist facies before the Late Llandoverian. This was probably part of the Benambran deformational event which produced the Wagga Metamorphic Belt at this time.
Stauffer & Rickard (1966) considered that the recumbent structures in the Ordovician rocks were produced in the early part of a single deformational event which also folded the Silurian rocks. Reinspection of important outcrops has cast doubt on this interpretation and it is likely that the recumbent folding involved only Ordovician rocks (M.J. Rickard, ANU, pers. comm., 1986). Structures similar to the Ordovician recumbent structures have not been found in the Middle and Late Silurian rocks. This constrains the age of recumbent folding to the interval from Bolindian to Wenlockian.

In the Tantangara Block the significance of the unconformity beneath the Kelly's Plain Volcanics cannot be determined until the age of the volcanics is confirmed. If the volcanics are Wenlockian then the unconformity can be attributed to a deformational event in the period from Late Llandoverian to Early (and Middle?) Wenlockian. This would be consistent with the Quidongan Event. If the volcanics are Early Devonian and are unconformable on the Cooleman Plains Group then this would indicate a latest Silurian to earliest Devonian deformational event. This would be consistent with the Bowning Event.

In the Nungar-Brindabella Block, Late Silurian granites have a well-developed secondary foliation which is parallel to the foliation in the enclosing Ordovician and Early Silurian rocks. These rocks are overlain virtually undeformed Lower Devonian volcanics which suggests that in this area the foliation was produced during the latest Silurian to earliest Devonian.

In the Cotter Block the main foliation in the Ordovician rocks is continuous with the foliation in the Late Silurian granites (Reid, 1980). The structures in the Cooma Metamorphic Complex were produced in the large aureole around the central Cooma Granodiorite which has an age of 416 ±11 Ma (Reid, 1980). These observations suggests that the main deformation event in the Cotter Block occurred in the latest Silurian to early Devonian. K/Ar ages and estimated mineral blocking temperatures suggest that the Cooma Granodiorite and the surrounding high-grade metamorphic rocks took 20 my to cool from 600 to 175°C (Tetley, 1979; Vernon 1981).

The Bowning Unconformity (Browne, 1954) which separates the earliest Devonian Elmside Formation from the slightly younger Sharpeningstone Conglomerate has been used to suggest a regional-scale orogeny, however the significance of the structure has been questioned. Crook & Powell (1976) suggest that it may be due to soft sediment movement due to loading by the conglomerate. Powell (1984b) considers that, although the contact is erosional, the apparent discordance may be due to parasitic folding in the mudstone. The rocks are not foliated.

Hayden (1980) dated the Koolambah Granodiorite in the Cullarin Block at about \( \approx 419 \) Ma (early Ludlow) using the K/Ar technique on biotite and hornblende. He argued that since the pluton is undeformed, does not have sheared margins and truncates \( F_2O \) structures it must postdate the \( F_2O \) event. There are some problems with this interpretation:

(i) He states (p104) that sedimentary structures such as bedding and ripple cross lamination are "well preserved and often enhanced" within the contact aureole whereas the "\( S_2 (=S_2O) \) slaty cleavage has typically been destroyed by recrystallization". An alternative explanation is that the rocks were unfoliated prior to granite emplacement.
Further north in the Cullarin Block the Urialla Granite (D. Wyborn, BMR, *pers. comm.*, 1986) and the Tinderry Granite (Hill, 1975) predate the main deformation.

(ii) Felsic dykes in the Cullarin Block which are considered to be related to the Silurian volcanics have \(F_2O\) structures. His interpretation implies that the \(D_2O\) event, and therefore the volcanics, are Wenlockian or older. This age is too old because the volcanics in the surrounding structural blocks are probably Ludlovian.

(iii) The dips of the Ordovician metasediments are shallower around the pluton and Hayden interpreted this as being due to the pluton opening out the limbs of a pre-existing tight fold during intrusion. An alternative interpretation is that the aureole has preserved early dips and the rocks away from the aureole have been tightly folded during later deformation.

More work needs to be done to confirm the absolute age of the Koolambah granite and its age relative to structures in the surrounding rocks. The measured age may be too old or the granite may have been emplaced before the main deformation and during the deformation it was not deformed.

Doone Wyborn (BMR, *pers. comm.*, 1986) reports that metamorphic biotite and muscovite from the Captains Flat Block give Middle Devonian ages which suggests that the metamorphism and folding in this Block were part of the Tabberrabberan deformational event.

Recent work in the Rocky Pie Block, to the north of Lake George, by Peter Stuart-Smith (BMR, *pers. comm.*, 1986) shows that the main folding event folded both the Ordovician and Silurian rocks and postdates the intrusion of the Wollogorong Batholith. This is consistent with the observation by Gould (1974) that dips in the aureole around the Wollogorong Granite are atypically low.

According to Duff (1985) and Powell (1983) the major folding event \(D_2O, D_1S\) to affect the Silurian and Ordovician rocks in the Bombay Block can be constrained to the latest Silurian to Early Devonian because:

(i) \(F_2O\) structures are truncated by Emsian (late Early Devonian) granites and the \(F_2O\) fabric has been partly overgrown in the contact aureoles.

(ii) The \(F_2O\) folds also fold the Late Silurian sequence in the Wyanbene-Bendethera region producing \(F_1S\) folds.

The foliation in the margins of the Bega Batholith granites in the Bombay Block must be post Early Devonian.

According to Felton (1977) the Late Devonian Comerong Volcanics and Merrimbula Group in the Bombay Block lie with marked unconformity on folded and foliated Ordovician rocks. She notes that the Early Devonian Mulwaree Group is in marked unconformity with the Silurian rocks but it is not clear whether the Silurian rocks were simply tilted or folded before deposition of the early Devonian sequence.

Owen & Wyborn (1979) consider that the Kiandra Fault (which has been strongly disrupted by later events) was operative during the Benambran deformation event. Some granites of the Bega Batholith are foliated where they are cut by the Mulwaree Fault suggesting that this fault must
post-date the granites and therefore probably D₁ (D. Wyborn, BMR, *pers. comm.*, 1986) Hayden (1980) considers that the regional fault pattern developed after the main deformation.

2 Summary

The observations suggest the following structural history:

(i) Ordovician rocks in the very western part of the study area were metamorphosed in the earliest Silurian as part of the Benambran deformational event and the Kiandra Fault was operative at this time.

(ii) The earliest deformation (D₁O) of the Ordovician rocks produced recumbent folds. These are thought to have formed by soft-sediment, gravity sliding (Powell, 1983) and their age is constrained to the interval from Bolindian to Wenlockian.

(iii) The main regional deformation of Ordovician and Silurian rocks occurred during the latest Silurian and Early Devonian. The observations in the Cooma area and my own work in the Bredbo area (Ch. 4) suggest that the both the early folds (F₁₀ and F₁S) and the second folds (F₂O and F₂S) were produced during a single, long-lasting metamorphic and deformational event. The two foliations may have been produced due to rotation of the strain ellipsoid during deformation (Granath, 1980).

(iv) Late kinks in the Silurian and Ordovician rocks may have a variety of ages and origins. They may have formed in the later part of the main deformation event, during granite intrusion, or during faulting but many are likely to be related to the event(s) which deformed the Devonian rocks.

(v) The age of the folding of the Early Devonian sequences is not clear. The folding could have been due to the Middle Devonian Tabberrabberan deformational event which affected other parts of the Lachlan Fold Belt or it could have been due to the Early Carboniferous Kanimblan deformation event.

(vi) The Early Carboniferous Kanimblan deformation event affected the Late Devonian sequences.

2.8 THE LATE SILURIAN TECTONIC SETTING

2.8.a Constraints

The geology of the Canberra region imposes certain constraints on any tectonic model for the Late Silurian:

(i) the model for the Late Silurian should fit into a sequence of events which included deposition in a deep marine setting in the Late Ordovician; local folding and metamorphism in the earliest Silurian; deep-marine, shallow-marine and terrestrial environments during the Early Silurian; uplift during the Middle Silurian; volcanism and sedimentation in a marine trough during the Late Silurian; intense regional deformation during the earliest Devonian; terrestrial volcanism and shallow marine sedimentation during the Devonian; and a major folding event in the Early
Carboniferous. Overall there has been a change from a deep-marine setting to a terrestrial setting.

(ii) There must be lower crustal layers which are suitable sources for the I- and S-type magmatism. Rickard & Ward (1981) used the spacing of plutons and volcanoes in an attempt to determine the structure of the Palaeozoic crust and they inferred that there was oceanic crust to the east of the sedimentary layer which was the source for the S-type magmas. Below these there was a diorite layer formed by underplating (White, 1979).

(iii) Wybom (1977) notes that many of the mafic intrusive rocks in the region occur in meridionally elongate bodies including meridional dyke swarms. He considered that these features indicate that the crust was undergoing extension at the time of intrusion.

(iv) The formation of the deep trough suggests a tensional regime during the Late Silurian. The location of the trough to the east of the I-S line suggests that the margin of the S-type source layer influenced the formation of the basin.

(v) Mafic volcanics in the Canberra region are confined to the blocks which developed in the Late Silurian trough. This suggests that the trough was developed over deep crustal structures capable of tapping mantle magmas.

2.8.b Tectonic Models

Previous tectonic models for the Lachlan Fold Belt during the Silurian are reviewed by Powell (1983, 1984b) and Cas (1983). Powell uses plate tectonic concepts to produce a model for the development of the Lachian Fold Belt and he suggests that during the Middle Silurian to early Devonian period the region was in a dextral transtensional regime with no subduction. An easterly migrating subcrustal heat source produced the magmatism. Cas (1983) concluded that a broad, ensialic rift setting best explains the pattern of facies and magmatism. This is clearly consistent with the Late Silurian of the Canberra region.
CHAPTER 3

A REVIEW OF THE MINERALIZATION IN THE SILURIAN BELTS OF THE CANBERRA REGION

3.1 INTRODUCTION

3.1.a Aims

This chapter is a review of the copper, lead, zinc, iron, gold and barite mineralization in the Silurian rocks of the Canberra regional study area (Fig. 1.1). The aims of the study were:

(i) to determine what styles of mineralization and alteration are present in the region,
(ii) to determine the effects of regional metamorphism on the zones of mineralization and alteration,
(iii) to distinguish zones of mineralization and alteration which may have formed by synvolcanic convective circulation of seawater,
(iv) to delineate exhalative horizons and zones of mineralization and alteration above and below this horizon.

3.1.b Procedure

The study is based on exploration company reports, published material, theses and my own work in the Cooma area. For each deposit I have attempted to obtain information about the host rocks; the effects of metamorphism and deformation; the style of the mineralization; the ore and gangue minerals and the nature of any alteration in the host rocks. This information and the references are summarised in Appendix 1. Most of the deposits are shown on the following 1:250 000 Metallogenic sheets: Canberra (Gilligan, 1974c), Goulburn (Felton, 1974), Wagga Wagga (Degeling, 1977) and Bega (Herzberger & Barnes, 1975). Details of the location of deposits which are not shown on these sheets are given in Appendix 2. Many of the deposits are shown on the 1:100 000 geological sheets of the region particularly: Brindabella (Owen and Wyborn, 1979), Tantangara (Owen and Wyborn, 1979), Canberra (Abell, 1982), Michelago (Richardson, 1979) and Braidwood (Felton & Huleatt, 1977). Some of the deposits in the Bredbo Block are shown on the map by Henderson (1979). Unnamed deposits are referred to using their Metallogenic sheet number with a prefix, "G" for Goulburn sheet, "C" for Canberra sheet and "B" for Bega sheet.

The main part of this chapter is a description of the geology and mineral deposits in each of the structural blocks in the Canberra region. The structural blocks are shown in Figure 2.5 and stratigraphic columns for the blocks are given in Figure 2.6. Information about the geology of the blocks was obtained from the same sources which were used in Chapter 2 (2.3.c). The locations of villages, towns and cities, mentioned in the text, are given in Figures 1.1 and 2.5.
3.1.c Limits
This review does not include Mo, W, Sn or Bi mineralization in or close to granites and mineralization in Ordovician and Devonian rocks.

3.1.d Previous Reviews
Some of the larger deposits in the study area are included in regional studies by McClatchie (1970), Felton et al., (1972) and Gilligan (1974 a & b). This study is a more detailed investigation of a smaller area than these previous studies.

3.1.e Specialist Studies
A number of specialist studies have been done on some of the deposits in the region. Most have concentrated on the Woodlawn deposit, including studies of metal zoning (McKay and Hazeldene, 1987), sulphur isotopes (Ayres et al., 1979), surface geochemistry and biogeochemistry (Ryall & Nicholas, 1979) and lead isotopes (Gulson, 1977, 1979). McLeod & Stanton (1984) investigated the chemistry of the phyllosilicate minerals associated with the Woodlawn, Googong and Breadalbane deposits. Andrew & Binns (1984) investigated the geochemistry and sulphur isotopes at the Currawang East deposit. M. Vaasjoki (CSIRO Division of Mineralogy, Sydney, pers. comm., 1984) has investigated lead isotopes at the Harnett prospect. Burns & Smith (1976) investigated the sulphur isotopes at Currawang. Ostic et al. (1967) did a lead isotope study of the Captains Flat deposit. Bird (1984) included oxygen, hydrogen and lead isotope studies in his work on the Briars Mine. Sulphur isotopes have been measured on the Captains Flat deposit by Stanton & Rafter (1966).

3.2 MINERALIZATION

3.2.a Goobarragandra Block

1 Geology
The Goobarragandra Block is composed of the Goobarragandra Volcanics, a sequence of subaerially deposited felsic volcanic rocks with rare small epiclastic sedimentary units.

2 Mineralization

Stockwork Copper Deposits
At the Glen Copper and the Nottingham Copper prospects, north-northwest of Brindabella, chalcopyrite and hematite with minor magnetite, bornite, wittichenite (Cu₂BiS₃) and pyrite occur in veins associated with silicification and chlorite alteration of the volcanics.
Gold, ±Copper Veins

The Murphys Reef, Stokes Reef, Broken Cart Gold Mine and Wyora Copper Mine were developed on veins of quartz with gold, ±pyrite, ±chalcopyrite.

3 Notes on Genesis

McClatchie (1970) considered that the stockwork copper deposits formed due to pyrometasomatism associated with the emplacement of the Late Silurian Young Granodiorite. The gold, ±copper mineralization is probably also related to the nearby Young Granodiorite which contains numerous gold-bearing, quartz veins.

3.2.b Tantangara Block

1 Geology

Early Llandoverian proximal flysch deposits (Tantangara Formation) are unconformably overlain by a shallow-marine sedimentary sequence composed of siltstone, shale, limestone, chert and arenite (Cooleman Plains Group). Part of the S-type, Kelly's Plain Volcanics in this block are probably of Wenlockian age.

2 Mineralization

Mineralization in the Tantangara Block is dominated by the Mount Black Mine and the smaller Hancoxs Mine, located 27 km south-southwest of Brindabella. At these deposits lead-zinc mineralization occurs in the matrix of breccias in joints at the top of the Ludlovian Cooleman Limestone. Mineralization at the Mount Black Mine consists of quartz, sphalerite and galena with minor chalcopyrite, pyrite, marcasite, tetrahedrite and sericite with traces of covellite, mackinawite, arsenopyrite, calcite, leucoxene, sphene and zircon.

In the Kelly's Plain Volcanics at Smith's Range there is a prospect developed on pyritic quartz veins (C 243). Elsewhere in the block there is goethite, magnetite and quartz occur in the Mount Black Fault.

3 Notes on Genesis

Ashley & Creelman (1975) suggested that the Mount Black and Hancoxs deposits are similar to Mississippi Valley type deposits and formed by the interaction of the limestones with connate brines expelled during diagenesis. They note, however, that the presence of quartz in the gangue, the lack of dolomitisation and the lack of barite and fluorite are features which are atypical of this type of mineralization. Owen & Wyborn (1979) pointed out that granites occur within a few hundred metres of the deposits and suggested that the deposits may have been hydrothermally modified during intrusion of the granite. Another possibility is that the deposits are of intrusive related, metasomatic replacement origin.

Owen & Wyborn (1979) have suggested that the mineralization on the Mt Black fault may be related to the intrusion of Early Devonian granites.
3.2.c Nungar-Brindabella Block
There is no relevant mineralization in this block.

3.2.d Cotter Block
The Congwarra Copper Lode and the Paddys River Iron Prospect are located at the northern end of the Cotter Block, 18 km west-southwest of Canberra. They occur in limestone lenses within the Paddys River Volcanics at their contact with the Late Silurian, Shannons Flat Adamellite. The deposits are composed of magnetite with minor pyrite, chalcopyrite, ±galena, ±sphalerite, ±arsenopyrite, ±gold. Owen & Wyborn (1979) consider that the mineralization formed by metasomatic replacement of the limestone by fluids derived from the granite.

3.2.e Canberra Block

1 Geology
Llandoverian proximal flysch deposits (State Circle Shale, Black Mountain Sandstone, Mundoonen Sandstone [lower part only?] ) are unconformably overlain by a latest Wenlockian and Late Silurian volcanosedimentary sequence. The base of the sequence consists of transgressive shallow marine sedimentary rocks (Canberra Formation, and the upper part of the Mundoonen Sandstone?). These are followed by two subaerially deposited, S-type, volcanic suites (Hawkins Suite and Laidlaw Suite) which are separated by thin, shallow-marine and fluvial sedimentary rocks (Yarralumla Formation, Yass Subgroup). In the Yass area the volcanics are overlain by shallow-marine shale, limestone and sandstone (Yass Basin sequence: Silverdale Formation, Booroo Ponds Group and Barrambogie Group).

2 Mineralization.

Pyrrhotite Deposits in the Canberra Formation
The Glenesk, Westmead Park, Westmead Park Grid, Murrumbateman Creek, Esso Location B11, Hardwicke, Bedulluck, Oak Hill, Kingfisher and Deacon Prospects occur in sedimentary rocks of the Canberra Formation just north of Canberra. This area is marked as B7L16 on the Canberra 1:250 000 Metallogenic Sheet (Gilligan, 1974c). The mineralization is composed of pyrrhotite with minor pyrite and a trace of chalcopyrite, sphalerite and galena in a quartz, chlorite and carbonate gangue. It occurs as veins and disseminations, and in the matrix to breccias. Host rocks include shale, sandstone and volcanic units. The Oak Hill and Kingfisher deposits are associated with calc-silicate minerals including epidote and actinolite and there is a large intrusive porphyry near the Oak Hill deposit.

Base-Metal Veins in the Hawkins Volcanics
There are numerous base-metal vein-type deposits in the Hawkins Volcanics. The largest deposit is at the Kangiara Mine which occurs in the centre of a group of mines known as the
Kangiara Field, 30 km northwest of Yass. The Kangiara Mine exploited veins developed in two joints in the volcanics. Mineralization consisted of pyrite, chalcopyrite, galena and sphalerite with minor bismuthinite, marcasite, tetrahedrite, bismuth, silver, electrum, chalcocite, covellite and digenite in a gangue of quartz, barite and the host volcanic. Silicification and chlorite-epidote alteration occur in the host rocks. Other deposits in the Kangiara Field consist of veinlets of galena, ± sphalerite, ± chalcopyrite, ± pyrite, ± quartz. Felton (1977) has suggested that the abundant fragmental textures in the host rocks of the Kangiara Field may indicate proximity to a volcanic centre.

Elsewhere in the Hawkins Volcanics there are numerous small prospects developed on veins of pyrite, chalcopyrite and quartz; some with minor galena and/or sphalerite (Spion Kop, G 167, G 168, Bachelors Reef, Mayfield, G 171, Everton Silver Mine, Rays, Wallah Wallah, G 151, Marie Corelli, Old Kangiara, Mammoth Lode, G 156, White Flag, Clan McKenenzie Mine, Democrat Mine, Triangle Mine, Kangiara Copper Mine, G 162, Langs Creek Mine, Eclipse Mine and The Victory.

**Base-Metal Veins in the Laidlaw Volcanics and the Yass Basin Sequence**

In the Laidlaw Volcanics there are a few veins of quartz and pyrite, ± galena, ± chalcopyrite at the C 95 and C 10 prospects and the Belconon (sic) Gold and McDonalds Mines. A few veins of quartz and galena occur in limestones at the base of the Yass Basin sequence (in the Silverdale Formation?) just above the Laidlaw Volcanics, (Beder Vale, G 231, G 232, Belle Vale Silver and Humewood Base-metal prospects).

**Red Hill Skarn**

At the Red Hill Copper Mine, 19 km north of Yass, disseminated pyrite and chalcopyrite occur in a siliceous matrix in rocks composed of talc and magnetite with minor chlorite and carbonate. The mineralised rocks occur around limestones in a sequence of volcanics near a lamprophyre intrusion.

**Gold-Bearing Quartz Veins**

Between Canberra and Yass there are several gold deposits in the Mundoonen Sandstone, the volcanics and the Canberra Formation (Nanima Creek Gold Workings, Remington and Jordans Claim, Crocker and Butts Claim, Gooda Creek Gold, G 239, G 240, Hall Copper, Gold Creek Gold, Murrumbateman Creek, Caledon and Edith May prospects). The mineralization consists of veins of quartz with minor gold and some deposits have minor base-metal sulphides or bismuthinite.

**Base-Metal Sulphide, Fluorite Deposits**

There are base-metal sulphide, fluorite, ± barite, ± carbonate veins in the Hawkins Volcanics at Wyelba, 18 km south of Yass.
3 Notes on Genesis
The association of calc-silicate minerals and an intrusive porphyry with the pyrrhotite deposits in
the Canberra Formation suggests that they are of pyrometasomatic origin. The base-metal veins in
the volcanics are considered to have formed by synvolcanic hydrothermal activity (Felton et al.,
1972) and Roberts (1976) interpreted the Kangiara deposit as Kuroko-type. The Red Hill Skarn is
clearly of pyrometasomatic origin. The gold-bearing quartz veins are similar to mineralization
which occurs in Ordovician rocks to the east of these deposits and Felton (1977) considers that the
veins are related to high-level intrusive porphyries. The base-metal sulphide, fluorite deposits are
probably genetically related to similar mineralization which occurs in the Lower Devonian,
Mountain Creek Volcanics elsewhere in the region (Felton, 1977).

3.2.f Bredbo Block

1 Geology
The geology of the Bredbo Block is described in detail in Section 4.2 (Fig. 4.2). Llandoverian proximal flysch units (Ryrie Formation) are unconformably overlain by a Late Silurian sequence consisting of three components (Henderson, 1987):

(i) the Cappanana Formation composed of mainly mudstones with minor limestone lenses. Sandstones are common at the base, small volcanic units occur near the top of the unit and calc-silicate rocks occur in places.

(ii) the Colinton Volcanics composed of dacitic volcanics with minor lenses of shale and limestone. The general lack of interbedded sedimentary rocks suggests that the volcanics were deposited in a subaerial environment.

(iii) the Rothlyn Formation composed of generally massive and poorly foliated dacites interbedded with thick shale units and minor units of sandstone, limestone and basalt/andesite. Thick shales, limestone and feldspathic sandstones are the dominant lithologies at the top of the unit.

Coarse-grained intrusive porphyry bodies occur along the western side of the block and small basic dykes occur in places. The block appears to have a synclinal structure in places and the western side of the block is strongly foliated (the Bransby Shear Zone of Henderson, 1987).

2 Mineralization

Mineralization in the Cappanana Formation
The most common style of mineralization in the basal sedimentary sequence consists of gossans developed in and around calcareous sedimentary rocks and limestones (Glenfergus, Woolshed, Cappawidgee [=Bransby Silver Mine] and Ingala prospects; London Bridge, Burra Silver-Lead and Colinton Silver Mines). The primary mineralization consists of galena, ±sphalerite, ±chalcopyrite, ±pyrite, ±pyrrhotite in quartz veins and in disseminations in the host
rock. At the London Bridge Mine there is also a zone of magnetite and pyrrhotite mineralization in a chlorite and tremolite skarn.

At the Michelago Iron Quarries the primary mineralization probably consists of magnetite with minor iron and base-metal sulphides occurring as disseminations in sedimentary units. The sequence is strongly foliated.

The largest deposit in the Cappanana Formation is at the Gurubang prospect, 16 km east-southeast of Cooma, where large bodies of massive to semi-massive sulphides occur in limestones immediately above the contact with the Ordovician rocks. There were several drill intersections of up to 10 m of sulphides and one 55 m intersection. The bodies are composed of pyrrhotite with minor pyrite and a trace of chalcopyrite, sphalerite and galena in a chert gangue. It is not clear whether the sulphide bodies are stratiform or not, and it is possible that they occur in fault zones.

At the Gillans prospect disseminations, veins and thin (<10 cm) massive bodies of pyrrhotite with minor pyrite and a trace of chalcopyrite occur in a metapelite unit close to the Murrumbidgee Fault. The mineralization will be described more fully in Section 5.2.a.

Mineralization Along the Eastern Margin of the Bredbo Block

Gossans are common along the faults along the eastern margin of the Bredbo Block near Michelago (C 165, C 166, C 167, C 168, Yarradon Iron Quarries and part of the Michelago Iron Quarries). Where the deposits have been drilled the mineralization consists of pyrite, ±pyrrhotite, ±sphalerite, ±galena, ±chalcopyrite in veins, disseminations, massive to semi-massive zones and in fault breccias. The most common gangue mineral is quartz.

Mineralization in the Colinton Volcanics

Southwest of Bredbo, there is a sequence of the Colinton Volcanics, in the western limb of the inferred regional syncline and in the Bransby Shear Zone. Along the top of the sequence there is a well-defined, mineralized horizon marked by sericitic, siliceous, pyritic, ±K-feldspar-rich rocks which includes the Cosgrove Hill, Billilingra, Barite, Driscolls Hill, Harnett and Stonehenge prospects and probably extends south to the Bushy Hill prospects east of Cooma. Mineralization consists of disseminations and veins of pyrite, ±galena, ±sphalerite, ±chalcopyrite, ±barite, ±orpiment?, ±gold. The gangue consists of quartz, ±sericite, ±K-feldspar ±carbonate, ±chlorite, ±hematite, with local zones of pyrophyllite, ±kaolinite, ±alunite. At the Billilingra, Barite and Harnett prospects barite forms large veins. In the volcanics below the Cosgrove Hill-Stonehenge horizon there are numerous small zones of mineralization (Riversdale, Mt Oak, Picasso and Gamma-Delta prospects). The mineralization consists of numerous thin bands of gossan (after disseminated pyrite, ±chalcopyrite, ±sphalerite, ±galena), usually associated with sericitic, ±siliceous zones in the volcanics. These prospects will be described more fully in Chapter 5.

The Colinton Volcanics east and northeast of Bredbo, on the eastern limb of the inferred regional syncline, are much thicker than in the western limb. The lower part of the sequence consists of mixed volcanics and sediments and these are overlain by a thick sequence of subaerially...
deposited volcanics. At the southern end of this belt the Birchams prospect, Baczynski's hematitic barite unit, Colinton Silver prospect and the Colinton North prospect all occur just above the last sedimentary horizon in the sequence. Mineralization consists of disseminations and/or veins and/or stockworks composed of pyrite, ±chalcopyrite, ±sphalerite, ±galena, ±barite, ±hematite with a gangue of quartz, ±sericite, ±chlorite, ±carbonate.

There are also numerous old workings and gossans (Baczynski, 1970; Beams, 1984b) along or below the Birchams-Colinton North horizon. At the Reed and Party, and Baalgammon prospects quartz, chalcopyrite, ±galena veins are developed in limestones. At the Bredbo Barite deposit, barite and quartz occur in a fault. Pyrolusite occurs at deposit C 252.

Further north, in the Michelago area, zones of mineralization occur in thin chloritic shale units in the lower part of the Colinton Volcanics at the Ponderose prospect and in the western part of the Michelago Copper prospect. Disseminations, veins and minor massive sections of pyrite, ±magnetite, ±chalcopyrite occur with a gangue of quartz, chlorite, sericite and carbonate. It is possible that these two deposits represent the northern continuation of the Bircham's-Colinton North mineralized horizon.

At the Googong prospect, 6 km south of Queanbeyan, disseminations and veins of pyrite and pyrrhotite with minor base-metal sulphides occur in a limestone body and at the contacts of the limestone with the enclosing siltstone. The host rocks are part of a thin sedimentary unit in a thick sequence of biotite-bearing volcanics. Calc-silicate rocks associated with an intrusive porphyry occur nearby (Abell, 1982).

Veins of quartz, gold, ±pyrite, ±hematite, ±base-metal sulphides form in rhyolitic volcanics close to the top of the Colinton Volcanics at Ryries Gold prospect, deposit C 247 and the Collington Gold Mine. At the Michelago Gold prospect gold occurs in a quartz stockwork in the Livingstone Porphyry.

Mineralization in the Rothlyn Formation

To the east of Cooma there are a number of deposits in the Middle Flat area which occur at about the same stratigraphic level on both limbs of the Rock Flat Syncline. Stratabound disseminations and veins of pyrite, ±sphalerite, ±galena, ±chalcopyrite, ±barite, ±arsenopyrite occur in volcanic units at the Skidmore prospect and similar mineralization occurs in shales at the Dartmoor and Dartmoor East Mines. Tetrahedrite and gold are also reported from the Dartmoor Mine. A quartz, gold and pyrite vein occurs at deposit B25 which is along strike from the Dartmoor deposits.

Elsewhere in the Rothlyn Formation there is a siliceous, sericitic zone with veins and disseminations of pyrite at the Square Range prospect, 14 km southeast of Cooma. Barite occurs in a vein parallel to the foliation in the host volcanic unit at the Black Rock Barite deposit. Gossans occur in the shales at the Bunyan and Coornatha prospects and in the volcanics at the Caves and Alpha prospects.

In the upper part of the Rothlyn Formation in the mainly sedimentary rocks there are the Gate and Rock Flat prospects, however there is very little information about them.
3 Notes on Genesis

It is likely that the calcareous rocks in the Cappanana Formation have been sites of preferred deposition of components from hydrothermal solutions. These solutions may have been related to synvolcanic processes, and/or metamorphism and/or granite intrusion. The skarn zone at the London Bridge Mine is clearly of a pyrometasomatic origin. The nature of the mineralization at the Michelago Iron Quarries is not clear but it is possible that it was formed initially by a synvolcanic process and has subsequently been deformed. Very little is known about the Gurubang mineralization and the genesis of the mineralization will only become clear with more work.

Initial impressions of the Gillans mineralization are that it may have formed either during metamorphism as metamorphic veins precipitated in extensional sites from components dissolved out of the host rocks; or, it may represent metamorphosed synvolcanic mineralization, possibly deposited deep in the footwall below an "ore horizon".

The origin of the mineralization in the faults along the margins of the Bredbo Block is not clear. If the faults were active during the Late Silurian then it is possible that the faults were feeder zones for the synvolcanic mineralization. This appears unlikely, however, because according to Hayden (1980) the faults probably formed during the latest Silurian to earliest Devonian Bowning Orogeny. The mineralization usually occurs in places where the faults cut the Colinton Volcanics and the Colinton Volcanics contain most of the apparently syngenetic mineralization in the Silurian sequence. Hence it is possible that metamorphic fluids have dissolved material from the Colinton Volcanics and subsequently precipitated it in the fault zones. In this case the mineralization would be of latest Silurian to Early Devonian age (2.7 e.).

Much of the mineralization in the Colinton Volcanics and the Rothlyn Formation probably represents synvolcanic mineralization which has been metamorphosed and deformed. The mineralized horizons in the Colinton Volcanics are at about the same stratigraphic level and probably represent parts of a single horizon which has been disrupted during deformation. The presence of pyrophyllite, K-feldspar, alunite suggests an epithermal style of mineralization. The zones of disseminated and vein-style mineralization in the volcanics below the Cosgrove Hill-Stonehenge (-Bushy Hill?) horizon probably represent metamorphosed and deformed synvolcanic, epigenetic mineralization.

McLeod & Stanton (1984) have included the Googong prospect in a study of stratiform sulphide deposits which are inferred to be of exhalative origin. They give no description of, or reference to a description of the deposit. The presence of calc-silicate rocks near the deposit and the distribution of sulphides around the margins of the limestone body suggest that it may be of pyrometasomatic origin.

The gold mineralization in the Colinton Volcanics may have formed due to synvolcanic hydrothermal processes, and/or during metamorphism and/or it may be related to the intrusion of the Livingstone Porphyry.

The Skidmore, Dartmoor and Dartmoor East deposits, and possibly the Square Range deposit, appear to be part of a synvolcanic, epigenetic-style mineralized horizon at a high stratigraphic level in the Bredbo Block sequence.
3.2.1 Cullarin Block

There is a small area of volcanic and sedimentary rocks in the Cullarin Block, 30 km south-east of Cooma and west of the settlement of Kybeyan. The rocks are considered to be of Silurian age (Tolliday, 1978; O'Grady, 1980; Duncan, 1980). At the Two Eagles prospect disseminations and veins of pyrite, sphalerite and galena occur in a sericitic volcanic unit. Some veins have a chlorite gangue. At the Caves Gossan mineralization consists of quartz and galena in veins associated with silicification and chlorite development in the host volcanic unit. The mineralization at these two prospects is likely to be of synvolcanic origin.

3.2.2 Southern Rocky Pic Block

There are a number of small areas of volcanosedimentary rocks, probably of Silurian age, along the Narongo Fault south of the Captains Flat Block. The Narongo Fault forms the western margin of the Rocky Pic Block in this area. The most important mineral deposit is the small, stratiform, massive sulphide body at Peak View (Ch. 6), 20 km south of Jerangle. The lens is composed of pyrite, sphalerite, galena and chalcopyrite in a gangue of sericite, chlorite and quartz. The footwall volcanic unit contains albite phenocrysts in a matrix of quartz and chlorite with minor biotite, pyrite. The hanging-wall volcanics show varying degrees of sericite development with associated feldspar destruction. The sequence has a strong foliation. The mineralization is probably of volcanic exhalative origin.

The Narongo, Anembo and Calabash Gossans are developed above sulphides associated with carbonate units. At the Jerangle Barite deposit, barite and quartz occur at the contact of the volcanics with the Wangrah Adamellite. A pyrometasomatic origin for this deposit is likely.

3.2.3 Captains Flat Block

1 Geology

The stratigraphic sequence in the Captains Flat Block is composed of four parts:

(i) a lower sedimentary sequence in which a basal quartzite and conglomerate (Rutledge Quartzite) is succeeded by shales and mudstones with minor limestone lenses (Copper Creek Shale),

(ii) the volcanic sequence with a few thin shale units (Kohinoor Volcanics),

(iii) a sequence of volcanoclastic sedimentary rocks and minor volcanic units which interfinger with, and overlie, the volcanic sequence (Captains Flat Formation).

(iv) a sequence of turbiditic sediments (Carwoola Beds).

2 Mineralization

Mineralization in the Captains Flat Block is dominated by the Lake George Mine at Captains Flat. From 1937 till 1962 Lake George Mines Pty Ltd processed in excess of 4 million tonnes of ore with average grades of 10% Zn, 6% Pb, 0.67% Cu, 56 ppm Ag and 1.7 ppm Au. The ore
occurs as three contiguous massive sulphide ore shoots in a shale unit close to the top of the Kohinoor Volcanics. The ore bodies are composed of, in order of decreasing abundance, pyrite, sphalerite, galena, chalcopyrite, tennantite-tetrahedrite, arsenopyrite, gold, pyrrhotite and stannite. Gangue minerals are quartz with minor carbonate, chlorite and sericite. The sulphide lenses are zoned with a zone of massive to semimassive pyrite which has some chalcopyrite-rich patches at the base followed by a zone of banded pyrite and sphalerite which has a galena and sphalerite rich top. The whole sequence has a strong penetrative foliation which is parallel to bedding. The ore horizon changes to a chert-dolomite rock or a ferruginous chert around the margins of the ore bodies.

Alteration at the Lake George Mine is not well documented. Stratigraphically below the ore lenses there is a 75 to 90 m thick zone of volcanics which have abundant chlorite, sericite and pyrite and only rare primary feldspar. The zone extends 1200 m along strike to the south and 500 m to the north of the ore lenses to a total of about 3 km. Above the ore lenses the volcanics are apparently unaltered except for a few zones of silicification.

In the district around Captains Flat the mineralized horizon is represented by cherty exhalites (J. Bain, BMR, pers. comm., 1985). In the Primrose Valley area cherty exhalites occur in the volcanic rocks (Olley, 1984). Minor disseminated pyrite and chalcopyrite occurs in the Kohinoor Volcanics close to the Lake George Mine at the Federal Mine.

Veins of pyrite, ±galena, ±sphalerite, ±chalcopyrite are common in the Copper Creek Shale stratigraphically below the Lake George Mine (Glasson & Paine, 1965). Elsewhere in the Block similar veins occur at the Foxlow Gossans and at the Bollards prospect.

In the volcanosedimentary sequences above the Kohinoor Volcanics there are vein-type gold deposits at the Woodlands and Foxlow prospects. At the Briars Mine, 24 km north-northwest of Captains Flat, veins and disseminations of pyrite, sphalerite, galena and chalcopyrite occur in a mafic agglomerate near a banded, pyritic chert. At the Clare prospect in the Captains Flat Formation pyrite and pyrrhotite occur in a gangue of garnet and actinolite, close to felsic porphyry intrusives.

3 Notes on Genesis

Glasson & Paine (1965) considered that the mineralization at the Lake George Mine formed by hydrothermal replacement of pyritic shale beds, however Davis (1974) proposed a volcanic exhalative origin for the deposit. He considered that the chert units along strike from the sulphide bodies and the alteration and disseminated mineralization in the footwall were formed at the same time. Bird (1984) concluded that the Briars Mine mineralization formed during metamorphism. The presence of sulphidic cherty exhalites close to the mine, however, suggests a metamorphosed synvolcanic origin for the mineralization. The Clare prospect is clearly of pyrometasomatic origin. The origin of the vein-type gold deposits is not clear; they may be either synvolcanic or metamorphic.
3.2.j Northern Rocky Pic Block

1 Geology
The Silurian volcanosedimentary sequence in the northern part of the Rocky Pic Block consists of:

(i) a basal shallow marine sedimentary sequence (DeDrack Formation, in part and Clare Vale Beds, in part),
(ii) volcanic and volcaniclastic rocks (Woodlawn Volcanics and Coopers. Creek Dacite), with volcaniclastic sedimentary rocks laterally equivalent to the volcanics (DeDrack Formation, in part, Clare Vale Beds, in part),
(iii) a sequence of pillowed basalts (Currawang Basalt), overlying and interfingering with the volcanics,
(iv) a thick unit of proximal flysch (Covan Creek Formation).

2 Mineralization

Mineralization in the Sedimentary Sequence Below and Laterally Equivalent to the Volcanics

Barite bodies. At the Clare Vale prospect, 15 km north-northwest of Woodlawn, there are large lenticular bodies of barite, with up to 20% pyrite, arsenopyrite, tetrahedrite and sphalerite, as well as minor pods and veins of barite. The mineralization occurs in mudstones at the top of the Clare Vale Beds. The bodies are parallel to bedding which is also parallel to the strong penetrative foliation in the rocks. The host mudstones are rich in sericite and quartz.

Stratabound zones of barite and/or base-metal sulphide mineralization. The Gurrunda barite and base-metal prospects, 12 km north of Breadalbane, occur along a chloritic, mineralized horizon in a sequence of mudstones and volcaniclastic rocks with minor limestone and black shale of the Clare Vale Beds. The horizon is parallel to bedding which is also subparallel to the foliation. The mineralized horizon is composed of chloritic sedimentary rocks which contain abundant disseminated pyrite, with minor chalcopyrite, sphalerite, pyrrhotite and traces of tetrahedrite and arsenopyrite. Large barite lenses in the horizon contain minor pyrite.

At the Lucky Hit Mine, southeast of Gurrunda, mineralization occurs in two strongly foliated stratabound zones in a sequence of chloritic sandstones and mudstones of the Clare Vale Beds. The two zones are composed of chloritic phyllite with disseminations and thin bands of chalcopyrite with minor pyrite, pyrrhotite and sphalerite. Quartz, barite and carbonate occur as gangue minerals in places. Similar mineralization occurs to the northwest at the Merilla Copper Mine and to the southwest at the Chisholms Freehold and Tauntons prospects. The foliation is parallel to bedding in the area around these prospects.

The Hannan's Flat mineralization, 4 km west-northwest of Breadalbane, occurs within a calcareous and chloritic horizon of the Clare Vale Beds. Disseminated sulphides (<30%) are concentrated toward the top of the horizon. Pyrite, sphalerite and minor galena occur in calcareous units; pyrrhotite and pyrite with minor chalcopyrite occur in chloritic units. The hangingwall
sequence of clastic sedimentary rocks contains only traces of sulphides in metamorphic veins. The mineralized horizon and the host sequence have a strong foliation which is subparallel to bedding.

**Other mineralization.** There are a number of deposits composed of veins and disseminations of base-metal sulphides in the Mulloon area, 14 km east of Bungendore. It is not clear whether the mineralization is in the DeDrack Formation or the Ordovician rocks. In the DeDrack Formation at Tarago there is a barite vein and at the Mount Fairy Dolomite Quarry there is some copper mineralization.

*Mineralization in the Volcanics*

The Woodlawn massive sulphide deposit occurs at a very low stratigraphic position in the Woodlawn Volcanics. It occurs in a sequence of tuffaceous shale, sericitic shale and rhyolite which are considered to be the lateral equivalents of extrusive volcanic rocks further to the south. The massive sulphide lens is fine-grained and banded and composed of pyrite, sphalerite, galena and chalcopyrite with minor tennantite-tetrahedrite, arsenopyrite, pyrrhotite and stannite in a gangue of talc, chlorite and quartz with minor barite and tuffaceous shale. The lens is underlain by a zone of pyrite and chalcopyrite in chlorite schist and a stockwork zone composed of quartz, chlorite, pyrite, chalcopyrite and sphalerite veinlets. A number of small sulphide lenses occur in the hangingwall.

The alteration assemblages and zonation at Woodlawn have been documented by Peterson & Lambert (1979):

(i) Zone I occurs in the immediate vicinity of the ore lens and includes the footwall mineralization. It extends deep into the footwall to the south of the ore lens and consists of chlorite schist and minor bedded chert. No primary ferromagnesian minerals or feldspars are present. The zone extends to small synvolcanic faults to the south of the ore bodies (McKay & Hazeldene, 1987).

(ii) Zone II surrounds Zone I and is characterised by quartz, sericite, chlorite with minor sulphides. Almost no primary ferromagnesian minerals and feldspar are present in this zone.

(iii) Zone III includes the central volcanic pile to the south of the ore bodies and is characterised by quartz, sericite, albite, chlorite and pyrite. There are patchy zones of more intense chlorite alteration with disseminations and stringers of sulphides.

(iv) Zone IV envelopes zones II and III and consists of the least altered rocks.

Peterson & Lambert (1979) suggest that Zone I represents the alteration in the feeder pipe for fluids which formed the ore. Zone II represents less-pervasive alteration by metal-poor fluids during and after the formation of the ore. Zone IV has no hydrothermal effects, only changes due to burial diagenetic effects and subaerial exposure. Zone III is much the same as Zone IV except it has local small areas of hydrothermal alteration.

At the Breadalbane No I and II prospects, west of Breadalbane, mineralization occurs in a strongly foliated sequence of interbedded siltstones, fine sandstones, sericitic shales and coarse tuffaceous rocks at about the middle of the Coopers. Creek Dacite. The Breadalbane No I deposit
occurs on the western limb of the Breadalbane Syncline and the Breadalbane No II deposit occurs at about the same stratigraphic level on the eastern limb. At both deposits mineralization occurs in two stratiform bodies composed of chlorite and magnetite with minor pyrite, pyrrhotite, chalcopyrite, hematite, sphalerite, carbonate, actinolite, talc and quartz. At the Breadalbane No II deposit the volcanic unit which forms the footwall to the lower mineralized horizon is carbonate-altered and deeper in the footwall calcareous sediments have local zones of chlorite alteration with pyrite, chalcopyrite and pyrrhotite mineralization. The Currawang Fault passes through the Breadalbane No II deposit.

Mineralization in the Currawang Basalt

At the Currawang Mine, 10 km northwest of Woodlawn, mineralization consists of massive pods and disseminations of sulphides in a sericitic, chloritic, cherty slate. The sulphides include pyrite and sphalerite with minor galena, chalcopyrite, arsenopyrite, pyrrhotite and tetrahedrite. The mineralization and the host slate are intensely sheared and the sulphides commonly show banding parallel to the cleavage. The host slate is enclosed in weakly deformed and virtually undeformed spilites. It is not clear whether the host slate is a metamorphosed clastic sedimentary rock or an altered and deformed basalt.

The Currawang East deposit is a lobate, pipe-like body of massive pyrite, galena, pyrrhotite, chalcopyrite and sphalerite (containing 3/4 to 1 million tonnes of sulphides at 1.8% Cu, 3% Pb and 13% Zn) in spilites. The gangue minerals are chlorite, talc and quartz. Banding in the sulphides due to deformation is common. The body is rich in pyrite and galena at the top and chalcopyrite and pyrrhotite at the base. It is surrounded by three alteration zones:

(i) a zone of chlorite and talc alteration with disseminated sulphides which forms an envelope around the sulphide body,

(ii) a transition zone in which albite in the basalt is altered to K-feldspar and the basalt has biotite veins,

(iii) an outer envelope of intense veining by quartz, sulphides, epidote and carbonate with sericite alteration of the basalt. The intensely veined rock contains deformed, elliptical spilite fragments and may be either a hydrothermal breccia (G. de Ross, St Joe Pty Ltd, *pers. comm.*, 1984) or a primary fragmental rock (Gould, 1974).

Greg de Ross (St Joe Pty Ltd, *pers. comm.*, 1984) considers that although the deposit may originally have been a stratiform body it is more likely to have been a discordant breccia pipe.

Mineralization in the Covan Creek Formation

Gould (1974) states that minor pyrite bodies occur at the base of the Covan Creek Formation, however he gives no information about them.
Other Prospects

At the Glen prospect, drilling intersected base-metal sulphides in veins and small massive sections, however I have no further information about the prospect. Very little information is available on the Mountain Ash Gold Mine and the Sweetwood Lea prospect.

3 Notes on Genesis

Gould (1974) concluded that the mineralization at the Breadalbane I and II, Currawang Copper Mine, Hannan's Flat, Lucky Hit, Clare Vale Barite and Gurrunda Barite deposits formed by submarine exhalative processes. He was unable to define the relative stratigraphic position of the deposits but considered that:

(i) the Currawang Mine and Breadalbane I and II deposits were at a similar position, high in the sequence,

(ii) the Clare Vale, Gurrunda, Hannan's Flat, Lucky Hit and Woodlawn deposits are all low in the sequence.

Gould (1974) considered that the variations in composition of the deposits was due to the temporal evolution of the composition of the hydrothermal fluid and variations in the environment of deposition. In particular the barite and magnetite-chalcopyrite deposits reflected more oxidising conditions in the discharge site. Recent exploration work in the region, including the Breadalbane area, suggests that some of the mineralization may be of epithermal style (I. Gordon, Electrolytic Zinc Company of Australia Pty Ltd, pers. comm., 1987). The Clare Vale Barite deposit is reported to be stratiform, however my experience with the Billilingra and Barite prospects (5.5.b) suggests that it is possible that the mineralization may be in veins parallel to the foliation and bedding.

The Woodlawn deposit is generally agreed to be of the volcanic exhalative origin (Petersen & Lambert, 1979; Malone, 1979; Ayres, 1979; McKay & Hazeldene, 1987).

3.2. Bombay Block

1 Geology

The Silurian sequence in the Bombay Block consists of a basal sedimentary sequence (De Drack Formation) overlain by a sequence of subaerial volcanics (Bombay and Long Flat Volcanics), overlain by proximal flysch (Palerang Formation).

2 Mineralization

Contact-Aureole Deposits in the DeDrack Formation

At the Boro Silver-Lead Mine and the Glenrossal, Hanging Rock, Ennisclare, Limekilns, Wyanbene, C60 and Mayfield prospects, north-northwest of Braidwood, mineralization occurs in calc-silicate units within a sequence of clastic sedimentary rocks close to Lower Devonian granites. The mineralization consists of disseminations, veins and minor massive sections of pyrite, sphalerite, galena, chalcopyrite and magnetite with minor pyrrhotite, ±bismuth minerals,
±arsenopyrite, ±cassiterite. Gangue minerals include garnet, tremolite, actinolite, chlorite, quartz and carbonates.

**Barite Veins in the Volcanics**

Veins of barite with galena occur in the volcanics at the Reedy Creek, Little Bombay and Bombay prospects west of Braidwood.

**Other Prospects**

Disseminated pyrite, chalcopyrite, galena and sphalerite occur in a chloritic gangue in a fault zone in the volcanics at the Krawaree prospect, 34 km south-southwest of Braidwood. The Gundillions Reef prospect was developed on a vein of quartz and gold.

3 Notes on Genesis

The contact aureole deposits in the DeDrack Formation are clearly of pyrometasomatic origin. The barite veins in the volcanics may be genetically related to the granites of the Early Devonian Bega Batholith which contain barite, ±galena veins in places. The origin of the Krawaree prospect mineralization is not clear; it may represent synvolcanic mineralization which has been faulted although it may be much younger and possibly related to either metamorphism or granite intrusion.

3.3 METAMORPHISM AND DEFORMATION

There have been a few detailed studies which give some information about the effects of metamorphism and deformation on the mineralization.

1 Woodlawn

The rocks in the Woodlawn region have a metamorphic foliation (Gilligan *et al.*, 1979). Around the orebody, Peterson & Lambert (1979) found it difficult to distinguish primary textures in the rocks due to the metamorphic foliation and associated recrystallization. Pressure beards are common around pyrite grains and sometimes occur around quartz and feldspar grains and lithic fragments. The present mineral composition of the alteration zones is due to the metamorphic reconstruction of original alteration phases such as clays and zeolites.

Textures in the orebody, such as the fine-scale primary layering and the fine grainsize of the orebody, led Ayres (1979) to conclude that the greenschist facies metamorphism had not significantly affected the original fabric. Textures in the orebody produced by metamorphism and deformation include:

(i) folds and faults,
(ii) a strong schistosity in the chlorite, talc, muscovite gangue,
(iii) beard textures around pyrite euhedra and pyrite aggregates,
(iv) brecciated pyrite, with the fractures commonly filled with galena,
(v) cross-cutting veins of finer grained, recrystallized sulphides,
(vi) pyrite augen, fringed by sphalerite or chalcopyrite in silicate-rich zones,
(vii) grains with adjusted boundaries,
(viii) cross-cutting veinlets of galena or chalcopyrite.

2 Deposits in the Northern Rocky Pic Block

Gould (1974), in a study of the Breadalbane I and II, Hannan's Flat, Gurrunda, Currawang Copper, Lucky Hit and Clare Vale Barite deposits, noted that although almost all of the rocks in the region have a metamorphic foliation the intensity of deformation increases in the areas of mineralization. The fact that the foliation is parallel to bedding in these areas made it particularly difficult to distinguish metamorphic banding from bedding. The zones of mineralization show a number of features which were interpreted to be due to metamorphism and deformation:

(i) breccia textures,
(ii) growth of fibrous chlorite and amphibole,
(iii) recrystallization of minerals (especially sphalerite, galena and chalcopyrite) to form annealed mosaic textures. Individual grains are equant with grainboundaries commonly meeting at 120°. Annealing or growth twins are common.
(iv) pyrite and magnetite grains have fractured in a brittle fashion,
(v) changes to mineral compositions with pyrrhotite partly pseudomorphed by pyrite and hematite partly pseudomorphed by magnetite,
(vi) the flow or migration of chalcopyrite into cleavages, fractures in grains and fold hinges,
(vii) gross thinning of orebodies along fold hinges and thickening in fold hinges.

3 Captains Flat

The strong deformational fabric in the rocks at Captains Flat commonly obliterates the primary textures (Davis, 1974). The intensity of the metamorphic textures in the orebody led Glasson & Paine (1965) to consider that it had formed due to structurally controlled replacement of a possibly pyritic shale. A number of textures in the orebodies described by Glasson & Paine (1965) can readily be interpreted as being due to metamorphism:

(i) intensely brecciated pyrite,
(ii) drag folding associated with shears,
(iii) shears filled with carbonate,
(iv) galena in fractures in pyrite.

Davis (1974) considered that the small-scale banding in the orebody was due to primary chemical sedimentary stratification rather than either metamorphic processes or hydrothermal selective replacement.
4 Currawang East

Andrew & Binns (1984) report that during metamorphism and deformation at the Currawang East deposit caused:

(i) recrystallized microstructures with pyrite and pyrrhotite in textural equilibrium,
(ii) banding in the orebody.

5 Other Work

In a study of the phyllosilicates and related minerals at the Woodlawn, Captains Flat, Breadalbane and Googong deposits McLeod & Stanton (1984) show that the bands in the deposits have retained their compositional integrity, acting as closed systems during metamorphism. They consider that the minerals at the deposits were essentially formed at the time of mineralization and during early diagenesis and that metamorphism has done no more than impose a foliation and increase the grainsize of the minerals.

3.4 DISCUSSION OF THE REGIONAL MINERALIZATION

3.4.a Previous Work

Very little detailed work has been done on the mineralization in the region except for the Woodlawn deposit. Although a significant amount of information is available for the Captains Flat, Mount Black, Briars, Breadalbane I and II, Hannan's Flat, Lucky Hit, Gurrunda, Clare Vale, Currawang and Currawang East deposits more work is needed.

3.4.b Classification of Deposits

The mineralization in the region can be divided into the following groups:

1 Mineralization in Carbonates and Associated with Calc-Silicate Minerals and/or Intrusive Bodies

This group includes the Congwarra, Paddys River Iron, Glenesk, Westmead Park, Westmead Park Grid, Murrumbateman Creek, Esso Location B11, Hardwicke, Bedulluck, Oak Hill, Kingfisher, Deacon, Red Hill Skarn, London Bridge (in part), Clare, Boro Silver-Lead Mine, Glenrossal, Hanging Rock, Ennisclare, Limekilns, Wyanbene, C 60 and Mayfield deposits. The Mount Black, Hancox's and Googong deposits may also belong in this group. These deposits probably have a pyrometasomatic origin.

2 Other Mineralization in Carbonates

Mineralization at prospects and mines including Mount Black, Hancoxs, Beder Vale, G231, G232, Belle Vale Silver, Humewood Base-metal, Glenfergus, Woolshed, Cappawidgee, Ingalar, London Bridge Mine, Colinton Silver Mine, Gurubang, Googong, Narongo, Anembo, and Calabash occurs within and around carbonate units. These deposits probably formed by a
variety of processes including basin dewatering (Mississippi Valley deposit model), synvolcanic hydrothermal processes, pyrometasomatism and metamorphism. In all cases the limestone probably acted as a suitable environment for deposition.

3 Mineralization on Faults.

The Yarradon Iron Quarries, C 165, C 166, C 167, C 168, Michelago Copper (in part) and the Jerangle Barite prospects are located on major meridional faults and the Bredbo Barite, Dam Shaft, Krawaree and the Mount Black Fault deposits occur on smaller faults within the structural blocks. These deposits may represent zones of mineralization which have been cut by the later faulting. Alternatively, the deposits may have formed in the faults presumably because the faults have acted as efficient paths for fluids. In this case the fluids may have been produced by synvolcanic processes, or during deformation and metamorphism, or during granite intrusion.

4 Stratiform and Stratabound Deposits in Volcanosedimentary Sequences

This group has a number of classes:

(i) stratiform massive sulphide deposits (Woodlawn, Captains Flat and Peak View),
(ii) stratabound magnetite deposits (Breadalbane I and II and possibly the western part of the Michelago Copper prospect),
(iii) massive sulphide bodies in the Currawang Basalt (Currawang Mine and Currawang East),
(iv) stratabound disseminations and veins of sulphides, ±barite in the volcanics (Cosgrove Hill, Billilingra, Barite, Driscolls Hill, Harnett, Stonehenge, Bushy Hill, Gillans, Picasso, Gamma-Delta, Riversdale, Birachs, Reed and Party, Baalgammon, Colinton Silver, Colinton, Baczynski's gossans, Ponderose, Michelago Copper [in part], Michelago Iron Quarries, Skidmore, Dartmoor, Dartmoor East, Square Range, Two Eagles, Cave Gossan, Federal Mine, Briars Mine, Gurrunda, Hannan's Flat, Lucky Hit, Merilla, Chisholms Freehold, Tauntons and possibly the Clare Vale Barite, Mulloon and Googong prospects).
(v) stratiform barite (Clare Vale Barite deposit?).

The mineralization in this group probably represents mineralization formed initially by synvolcanic processes which has subsequently been deformed and metamorphosed. For many deposits it is not clear whether the mineralization is of epithermal style or of volcanic-associated massive sulphide style.

5 Small Vein Deposits

This is a diverse group which includes the following classes:

(i) base-metal veins in volcanics (Glen, Nottingham, Spion Kop, G 167, G 168, Bachelors Reef, Mayfield, G 171, Everton Silver Mine, Rays, Wallah Wallah, G 151, Marie Corelli, Old Kangiara, Mammoth Lode, G156, White Flag, Clan McKenzie Mine, Democrat Mine, Triangle Mine, Kangiara Copper Mine, G 162, Langs Creek
Mine, Eclipse Mine, The Victory, C 10, Belconnon Gold, McDonalds and C 95). These deposits probably have a variety of origins and may have formed by:

1. 
2. 
3. 

(1) synvolcanic hydrothermal processes,
(2) during metamorphism,
(3) during the intrusion of granites. Felton (1977) considers that the Wallah Wallah and Frank Winters prospects are probably related to Early Devonian intrusive porphyries.

(ii) base-metal, \( \pm \) barite veins in the sedimentary rocks (Black Rock Barite, Foxlow Gossans, Bollards, Mount Fairy Dolomite Quarry vein and Tarago Barite prospects). The origin of these deposits is probably similar to the previous class.

(iii) base-metal and fluorite veins (Wyleba base-metal and Wyleba fluorite deposits). Felton (1977) considered that these deposits were probably related to similar deposits in Lower Devonian volcanics in the region.

(iv) gold in veins in the volcanics (Murrumbateman Creek, Gooda Creek, G 239, G 240, Hall Copper, Gold Creek, Caledon, Edith May, Foxlow Gold, Woodlands, Gundillions Reef, B 25, Collington, C 247 and Ryries deposits). The origin of the mineralization is not clear, however it is possible that the last three deposits are related to the Livingstone Porphyry which is host to the Michelago Gold prospect.

(v) barite veins in the volcanics (Bombay, Little Bombay and Reedy Creek deposits). These veins are probably genetically related to the Early Devonian granites of the Bega Batholith which host similar mineralization.

(vi) gold in veins in intrusive porphyries (Michelago Gold prospect).

3.4.c Patterns in the Regional Distribution of Synvolcanic Mineralization and Alteration

The distribution of mineralization, inferred to be of synvolcanic origin, has a number of patterns:

(i) the Goobarragandra and Bombay Blocks (and the Tantangara Block?) have large areas of subaerially deposited felsic volcanics which appear to be virtually devoid of synvolcanic mineralization,

(ii) the Cotter Block has no synvolcanic mineralization,

(iii) the Canberra Block has many small vein-style deposits of base-metal sulphides associated with chloritisation and silicification which occur in a thick sequence of subaerially deposited volcanics. The largest veins appear to be associated with a volcanic centre around Kangiara.

(iv) the Northern Rocky Pic, Captains Flat, Southern Rocky Pic and Cullarin Blocks have a dominantly submarine volcanosedimentary sequence which contains stratiform and stratabound base-metal sulphide mineralization and some magnetite and barite mineralization. In the Captains Flat Block the mineralized horizon can be traced around the regional syncline by following chert beds whereas in the Northern Rocky Pic
Block no mineralized horizon has been defined. Many of the deposits have conformable footwall alteration zones characterised by chloritic assemblages and variable feldspar destruction. The Woodlawn deposit has a pipe-like zone of intense chlorite alteration in the footwall. Footwall alteration and mineralization are well-developed below Lake George Mine, and a similar zone may have been intersected at the Federal Mine, 2 km to the east. At the Breadalbane No II deposit there are small zones of intense chlorite alteration below the main alteration zone. Woodlawn appears to be the only deposit with significant hangingwall alteration although there are sericitic zones at Peak View. The alteration at the Currawang Mine is more siliceous and sericitic than the other deposits in the northern Rocky Pic Block (Gould, 1974).

(v) initial impressions of the Bredbo Block mineralization are:

(1) there are many zones of stratabound alteration and mineralization but no stratiform deposits,

(2) the most significant mineralization occurs in the mainly subaerially deposited, Colinton Volcanics. It forms a well-defined horizon in the Cosgrove Hill–Stonehenge (-Bushy Hill?) area and this same horizon may continue to the horizon defined by the Bircham's-Colinton North (-Ponderose-Michelago Copper?) prospects. Smaller zones of mineralization below the main horizon may represent deep footwall zones in the hydrothermal system. At least part of the mineralization appears to be of epithermal style.

(3) there is a smaller mineralized horizon in the marine Rothlyn Volcanics.

3.4.d The Effects of Metamorphism and Deformation

The Canberra region is structurally complex. At the present level of understanding of the geology and structure of the blocks it is usually difficult or impossible to determine the relative stratigraphic position of zones of mineralization and to define mineralized horizons. Correlation of rock units and mineralized horizons between blocks is speculative.

Intense penetrative fabrics are widespread and are even more strongly developed in mineralized areas in the Canberra Block (Felton, 1977) and the northern Rocky Pic block (Gould, 1974). It is possible that mineralization in these deformed zones (sometimes referred to as "shear zones") is genetically related to the metamorphism and deformation, although it could be argued that zones of syngenetic mineralization and alteration are more susceptible to deformation. In the latter case there is the problem of distinguishing primary minerals and textures from those formed during the mineralizing event from those formed during metamorphism. This problem is exacerbated by the fact that the main foliation is commonly subparallel to bedding.

The detailed studies suggest that orebodies consist of primary fabrics, such as bedding, and metamorphic and deformational textures produced by processes including:

(i) growth of new minerals, due to conversion of phases (eg. pyrrhotite to pyrite) and destruction of original alteration phases such as zeolites,
(ii) recrystallization,
(iii) brittle fracuring of minerals such as pyrite and magnetite,
(iv) plastic deformation of minerals such as galena, sphalerite and chalcopyrite,
(v) foliation development in silicate-rich areas,
(vi) folding and faulting,
(vii) development of metamorphic veins.
CHAPTER 4

THE GEOLOGY OF THE BREDBO-BUNYAN STUDY AREA

4.1 INTRODUCTION

4.1.a General

This chapter presents the results of a detailed study of the Bredbo-Bunyan area. The aims were to:

(i) define the stratigraphy and structure of the area,
(ii) determine the mode and environment of deposition of the metavolcanic and metasedimentary units,
(iii) determine the effects of metamorphism and deformation,
(iv) define the stratigraphic position of the mineralization,
(v) distinguish the effects of any synvolcanic alteration on the rocks.

This will provide a basis for describing and understanding the mineralization in the area (Ch. 5).

4.1.b Previous Work

Parts of the study area were included in larger regional studies by Browne (1914, 1944), Joplin (1943). These workers considered that Units A, B, C (in part) and D (4.3.a) were Ordovician, Units E and F to be Silurian and part of Unit C to be a Silurian intrusive. Joplin called these "Ordovician" units the Bransby Beds and described the metamorphic history of the region. Hancock (1963) and Richardson (1977) also mapped parts of the area. Richardson considered that the Bransby Beds probably represented more strongly sheared parts of the Silurian sequence. The area has been included in regional mapping by Cominco Exploration Pty Ltd (Young, 1974) and Esso Exploration Production Inc. (Beams, 1984a&b). Simon Beams' work outlined the nature, distribution and gross structure of the main geological units in the central part of the Bredbo Block between Bredbo and Cooma. Parts of the study area and/or adjacent areas were included in theses by Baczynski (1970) and Pillans (1974), and a number of undergraduate mapping reports including those of Horner (1972, 1973), Kosseris (1980), Lorenz (1979), Lamont (1980) and Girdler (1980). Henderson (1987) has recently revised the stratigraphy of the Bredbo Block based on regional mapping.

4.2 GEOLOGY OF THE BREDBO BLOCK

4.2.a General

The Bredbo-Bunyan study area is located in the Bredbo Block (Figs 2.5, 4.1) which is defined for the present work as the the belt of mainly Silurian rocks south of the Royalla Fault
Fig. 4.1  Simplified regional geological map showing the location of the two detailed study areas. (After Brunker et al., 1970.)
(Henderson, 1987) and east of the Murrumbidgee Fault. The eastern margin is the contact with Ordovician rocks of the Cullarin Block. This contact is faulted in places (the Queanbeyan, Burra, Collingwood and Umeralla Faults), and east of Cooma and Bredbo it is an unconformity (Richardson, 1979; Henderson, 1987). (Strictly speaking the boundary of a structural block should be a fault and so perhaps the Bredbo Block should be considered as the western part of the Cullarin Block). To the south the Silurian rocks disappear beneath extensive Tertiary basalts.

The stratigraphy and structure of the Bredbo Block (Fig. 4.2) is not well understood because of the poorly bedded nature of the metavolcanic rocks, the lack of good facing evidence and the local intense foliation which masks bedding in all lithologies (Richardson, 1979). The structure is complicated by the possible presence of numerous, roughly meridional faults (Henderson, 1987).

The following description of the geology of the Bredbo Block is based on the work of Richardson (1979), Henderson (1987) and my own work in the Bredbo-Bunyan area. It uses the revised stratigraphy of Henderson (1987). The most important revisions were:

(i) the subdivision of the Colinton Volcanics of previous workers into the Colinton Volcanics and the Rothlyn Formation.

(ii) the inclusion of the Williamsdale Volcanics and most of the Bransby Beds into the Colinton Volcanics.

4.2.b Stratigraphy

The oldest rocks in the Bredbo Block are the Llandoverian proximal flysch units of the Ryrie Formation which occur in two small areas near Colinton. These are unconformably overlain by a Late Silurian (2.4.b) sequence consisting of three components:

(i) Cappanana Formation. The Cappanana Formation is composed of mainly mudstones with minor limestone lenses. Sandstones are common at the base, small volcanic units occur near the top of the unit and calc-silicate rocks occur in places.

(ii) Colinton Volcanics. The Colinton Volcanics are a sequence of dacitic to rhyolitic volcanics with minor lenses of shale and limestone. Rhyolitic units become common toward the top of the sequence. The volcanics are thickest in the northern part of the block and south of Bredbo it appears that only the stratigraphically low, dacitic units occur. The general lack of interbedded sedimentary rocks suggests that the volcanics were deposited in a predominantly subaerial environment. The volcanics commonly have a well-developed foliation and ferromagnesian minerals, (mainly biotite with minor amphibole and ?pyroxene), are usually altered.

(iii) Rothlyn Formation. The Rothlyn Formation is composed of interbedded volcanic and sedimentary rocks. The volcanic rocks are mainly massive and poorly foliated dacites with minor basalt. The sedimentary units are mainly shale with minor sandstone and limestone. The upper part of the formation is composed of mainly shales and interbedded feldspathic sandstone and shale, with a thick limestone unit and minor dacites and basalt.
LEGEND

LATE SILURIAN

- **Sn**
  - Rothlyn Formation
  - Sandstone and shale
- **Ss**
  - Sedimentary and volcanic rocks

- **Sc**
  - Colinton Volcanics
- **Sb**
  - Colinton Volcanics (Bransby Shear Zone)
- **Sa**
  - Cappanana Formation

LLANOVERY

- **Sr**
  - Ryrie Formation

- **s**
  - Shear Zone

- **- -**
  - Fault

- **--**
  - Geological boundary

- **× ×**
  - Syncline

0 10 20km

Scale 1 : 500 000

Fig. 4.2 Geology and structure of the Bredbo Block (after Henderson, 1987). The very northern part of the block is not shown.
Coarse-grained intrusive porphyry bodies (Bullanamang Porphyry and Livingstone Porphyry) occur in the western part of the block and small basic dykes occur in places. East and south of Cooma there are areas of Tertiary basalt. Sand, clay, volcanogenic sediments, gravels and diatomite along the larger river valleys between Cooma and Bredbo are part of the Tertiary Lake Bunyan (Taylor & Walker, 1986a&b).

4.2.c Structure and Metamorphism

The Colinton Volcanics are thickest in the northern part of the Bredbo Block and thin to the south. The Rothlyn Formation occurs mainly in the southern part of the Block where it overlaps the Colinton Volcanics or lies directly on the Cappanana Formation. The overall structure of the Bredbo Block between Bredbo and Cooma appears to be synclinal (Beams, 1984a&b; Baczynski, 1970). The inferred syncline appears to plunge gently to the south, and north of Bredbo most of the western limb is faulted out. The Rothlyn Formation narrows considerably to the north of Bredbo, probably due to faulting and the plunge of the inferred regional syncline.

Henderson (1987) recognised broad "shear zones" in the Bredbo Block which are characterised by the occurrence of a strong foliation in the rocks. The Bransby Shear Zone, which occurs along the western side of much of the block, includes most of the Bransby beds of earlier workers. The rocks in the Bredbo-Bunyan study area show varying degrees of development of a metamorphic foliation and metamorphic mineral assemblages vary up to greenschist facies. Mesoscopic folds are most obvious in the small metasedimentary units and kinks occur in all foliated units. Bedding is rare in the metavolcanic units and any folding is difficult to recognise.

4.3 THE BREDBO-BUNYAN STUDY AREA

4.3.a General Nature, Distribution and Stratigraphic Position of the Rocks

The Bredbo-Bunyan study area is located in the south west part of the Bredbo Block on the western limb of the inferred regional syncline. It is bound on its western side by the Murrumbidgee Fault which separates the 500 Acre Granodiorite of the Murrumbidgee Batholith from the Silurian sequence.

The Silurian sequence is divided into six mapping units which occur in meridionally trending strips (Map 4.1, Fig. 4.3). The sequence has a roughly meridional strike and faces east (4.4.a). The original thickness of the mapping units is not clear because:

(i) parts of Units A and B have been faulted out by the Murrumbidgee Fault,
(ii) the amount of shortening during metamorphism has not been determined,
(iii) it is possible that the contacts of Unit C are faults and/or intrusive contacts (4.3.e),
(iv) the effects of folding have not been determined.

The position of the Bredbo-Bunyan study area in the Bredbo Block stratigraphic sequence is not well defined because my units A, B, C, D and part of E occur in the Bransby Shear Zone (Henderson, 1987) which was formerly called the Bransby Beds (Richardson, 1979). The
Fig. 4.3. Simplified geology of the Bredbo-Bunyan study area.
stratigraphic position of the rocks in the Bransby Shear Zone is an old problem but present indications are that:

(i) Unit A may correlate with the Cappanana Formation,
(ii) Units B and D correlate with the lower parts of the Colinton Volcanics,
(iii) Units E and F correlate with the lower part of the Rothlyn Formation,

This correlation would require that the Colinton Volcanics are much thinner in the study area than further north in the Bredbo Block. It is possible that the higher stratigraphic units of the Colinton Volcanics were either never deposited or were eroded from the southern area. The unlikely possibility of a major strike-slip fault between Units D and E is discussed below in Section 4.4.e.

4.3.b Metamorphic Zones

Five metamorphic zones have been recognised in the Bredbo-Bunyan area based on the metamorphic minerals in the matrix of the metavolcanic rocks. They have a roughly meridional trend (Fig. 4.4). The zones are:

(i) blue-green amphibole zone,
(ii) brown biotite with minor chlorite and sericite zone,
(iii) green biotite, sericite and chlorite zone,
(iv) chlorite and sericite zone,
(v) chlorite and/or prehnite zone.

The blue-green amphibole zones was only seen in the Gillans Prospect drill-holes adjacent to the Murrumbidgee Fault. The assemblages suggest a progressive decrease in metamorphic grade from west to east. Some of the rocks with green biotite are inferred to have been altered prior to metamorphism and so the occurrence of this mineral may reflect primary compositional variation rather than a change in metamorphic grade.

It is possible that the metamorphic zones are related to the low-grade zones which partly surround the Cooma Metamorphic Complex (Vernon, 1981; Vernon & Hobbs, undated) which occurs on the western side of the Murrumbidgee Fault immediately south the study area. In both areas the metamorphic grade increases toward the Murrumbidgee Fault.

4.3.c Unit A; Metasedimentary Rocks

1 Facies

Unit A is composed of metapelites (Am) with minor calcsilicate rocks (Ac), metavolcanic rocks (Av), sericite-rich metavolcanic rocks (As) and metalimestone (Al).

2 Geometry

Unit A is exposed in a meridional strip to the east of the Murrumbidgee Fault in the southwestern part of the study area. The unit generally has subvertical dips and crops out over distances of up to 700 m across strike.
Fig. 4.4. Metamorphic zones in the Bredbo-Bunyan study area.
3 Type area

The best exposures of Unit A occur in the Monaro Highway roadcut at G.R. 92800150 and nearby around Pearmans Hill (G.R. 92630205). Limited structural information and the stratigraphic relationships suggest that the rocks in this area form a meridionally trending anticline. The western limb of the inferred anticline was intersected in the two drill-holes (BRYG 001 and BRYG 002) at the Gillans Prospect (5.2.a, Map 5.1). Most of my information on the nature of Unit A comes from these drill-holes.

4 Contacts

The stratigraphic base of Unit A (presumably an unconformity with Lower Silurian and/or Ordovician rocks) is not exposed and has probably been removed by the Murrumbidgee Fault. The contact between Unit A and Unit B is conformable and is taken as the base of the first thick volcanic unit above which the metasedimentary units comprise only a small part of the sequence.

5 Distribution of Facies

In the Pearmans Hill area the inferred lower part of Unit A is composed of mainly metapelites, the middle part is composed of interbedded metapelites, calc-silicate rocks and minor metalimestone lenses, and the upper part is composed of interbedded metapelites and metavolcanic rocks.

6 Description of Facies

Metapelites (Am)

The metapelites are composed of quartz, plagioclase, and chlorite, ±biotite, ±sericite, with minor amounts of ilmenite, pyrrhotite, sphene, rutile and carbonate. There are three textural types:

(i) Fine-grained metapelites. These rocks are very fine-grained and have a pale-brown, cream or black colour in the drill-core. They are composed of silt- to clay-size grains of quartz and plagioclase with minor chlorite and/or biotite and opaques. Hand samples of the rocks appear to be massive and only poorly bedded however in thin section they are finely bedded due to small changes in grain size. Some beds are well-sorted, framework-supported and graded. Other beds are poorly sorted and have unevenly distributed coarse-silt-size grains of quartz and plagioclase in a finer silt-size matrix. The rocks are either unfoliated or have a poor foliation based on the preferred orientation of the phyllosilicates. Some of the rocks have a very fine-grained, granoblastic texture.

(ii) Medium-grained metapelites. These rocks have a dark-green to black colour and compared to the fine-grained metapelites they have a coarser grained granoblastic texture with better foliation(s) and are slightly richer in phyllosilicates (mostly biotite with lesser chlorite and sericite). Most of the rocks have a subequigranular grain size and a single foliation (S1) which is a continuous slaty cleavage defined by the preferred
orientation of the phyllosilicates, quartz and plagioclase. Sericite forms lenticular aggregates parallel to the foliation. In places the $S_1$ foliation is weakly crenulated and a crenulation cleavage ($S_2$) is developed. The phyllosilicates in the $S_2$ cleavage-defining domains are slightly coarser grained than in the intervening quartz-rich microlithons and in places they are oriented at a consistent, low angle to the $S_2$ cleavage. Some of the medium-grained metapelites have a strongly dominal texture with domains of different grainsizes. The coarse-grained domains have a well-developed granoblastic texture with grains of unstrained, subhedral biotite. These biotite grains may show a preferred orientation parallel to either of the foliations, or be randomly oriented. Fine-grained domains show one or both of the foliations. In places the medium-grained metapelites have a few, very-large plagioclase grains and lenticular quartz grains. Some of the rocks are bedded, based on slight variations in the size of the matrix grains.

(iii) Sericite-rich metapelites. These rocks have abundant phyllosilicate grains, especially sericite, and always have a well-developed continuous foliation ($S_1$). These rocks are bedded and some are graded from poorly foliated bases composed of silt-size quartz and feldspar to well-foliated, phyllosilicate-rich tops.

The three textural types of metapelite grade into each other and the fine-grained metapelites occur as small domains and as thin bands in the other types. Each type dominates broad intervals in drill-hole BRYG 001 but BRYG 002 is dominated by the medium-grained metapelites and has only small intervals of the sericite-rich metapelites.

Calc-Silicate Rocks (Ac)

The calc-silicate rocks in the western limb of the inferred anticline (in the Gillans drill-holes) are composed of amphibole and epidote with minor amounts of biotite, chlorite, quartz, plagioclase, and opaques. Bedding is well-developed and is based on variations in the proportions of different minerals. Interbedded thin metapelite units are common. The calc-silicate units have a continuous foliation which is parallel to bedding. In one rock there is a bed of quartz and amphibole which has amphibole-rich bands cutting it at an angle to define a crenulation cleavage ($S_2$). In some rocks bedding is isoclinally microfolded and the $S_1$ foliation is axial-planar to these folds.

Surface samples of calc-silicates from the eastern limb of the inferred anticline are composed of epidote, ±tremolite, ±calcite, ±diopside, ±garnet, ±quartz, ±?wollastonite. These rocks have a granoblastic texture, sometimes with a weak foliation defined by the preferred orientation of tremolite.

Metavolcanic Rocks (Av)

The metavolcanic rocks are petrographically the same as those in facies Bv which are described below in Section 4.3.d. A feature of the facies Av rocks is that they have abundant, brown, metamorphic biotite in the matrix.
Sericite-Rich Metavolcanic Rocks (As)

The sericite-rich metavolcanic rocks form small zones, parallel to strike, in the metavolcanic rocks (Av) near the top of Unit A. The rocks are not shown on Map 4.1 but their distribution at the Gillans and Picasso Prospects is shown on Map 5.1. They are composed of metavolcanic phenocrysts of quartz and plagioclase in a very-strongly foliated matrix of quartz and sericite. The outcrops are always associated with gossanous material and the textures suggest that the rocks originally had abundant disseminated pyrite.

Metalimestone (Al)

The small metalimestone lenses are composed of calcite and diopside with minor tremolite. They have a granoblastic texture. The large grains of calcite are intensely twinned and the twins are often bent.

Veins

Unit A rocks contain a number of different types of veins apart from the mineralized veins at the Gillans Prospect which will be described in section 5.2.a. Types of veins include:

(i) very thin (<<1 mm) veins composed of brown carbonate (?siderite) which are usually developed parallel to the $S_1$ foliation.

(ii) thick veins (up to several centimeters wide), parallel to bedding and the $S_1$ foliation, composed of coarse-grained, polygonal carbonate with minor biotite, amphibole, and pyrrhotite. These veins have gradational contacts with the host-rock and contain abundant inclusions of the foliated host-rock. They are particularly common in parts of the drill-core which have calc-silicate units. The carbonate forms aggregates of polygonal grains which are strongly twinned and the twins are commonly bent. In some veins there is a stylolitic foliation which is parallel to the crenulation cleavage ($S_2$) in the host.

(iii) quartz, ±amphibole veins cutting the $S_1$ foliation and folded by it.

(iv) veins of undeformed laumontite, ±carbonate which cut both the $S_1$ foliation and other types of veins.

(v) veins of chlorite and brown carbonate (?siderite) with fibrous microstructures in extensional mesofractures across the $S_1$ foliation.

(vi) rare veins parallel to the $S_1$ foliation composed of fibrous carbonate.

7 Interpretation of Unit A

(i) The coarse-grained granoblastic textures with unstrained biotite and quartz grains indicate that the rocks have been recrystallized during the metamorphism. Recrystallization has probably occurred at all stages of metamorphism and the presence of coarse-grained, randomly oriented and unstrained biotite grains indicates that it continued after the $S_2$ cleavage-forming event.
(ii) The bedding and graded bedding in the metapelites (Am) suggests that these rocks probably represent metamorphosed siltstones and shales, deposited at least in part as turbidites.

(iii) The difference between the fine- and medium-grained metapelites can be accounted for, in part, by the effects of recrystallization. Where there are domains of the fine-grained metapelites in the medium-grained metapelites it appears that the fine-grained metapelites have been recrystallized to form the medium-grained metapelites during metamorphism. Where the two metapelite types are interbanded, however, it appears that they reflect primary grainsize and/or compositional differences.

(iv) The fine and medium-grained metapelites have a low phyllosilicate content and Beams (1984b) has suggested that these rocks represent silicified biotite siltstones. An alternative interpretation is that the composition is an original feature due to a volcanic provenance. The composition and textures of the medium-grained metapelites are very similar to the matrix of the metavolcanic rocks (Av) and in some places the rocks contain large grains of quartz and plagioclase which are probably relict volcanic phenocrysts. The lenticular grains of sericite in the metapelites may be altered vitriclasts. This volcanic material may have been derived from:

1. the earliest volcanic rocks of the Colinton Volcanics,
2. erosion of older (Wenlockian) volcanic rocks, possibly to the west of the area.

(v) The sericite-rich metapelites (As) may have formed:

1. by metamorphism of rocks which were originally very rich in volcanic glass. Potassium is concentrated in the matrix of the metavolcanic rocks in the study area and this might produce sericite during metamorphism.

2. during metamorphism, possibly in zones of intense retrogression. Granath (1976) describes very sericite-rich rocks in retrograde zones in the Ordovician metasedimentary rocks, to the west of the study area in the Cotter Block, near Cooma.

3. by metamorphism of zones of synvolcanic alteration.

(vi) The calc-silicate rocks probably originally consisted of carbonate units interbedded with volcanic siltstones.

(vii) The association of facies in Unit A is consistent with a shallow-marine environment in a volcanic terrain.

(viii) The microstructures suggest a three stage metamorphic and deformational history:

Stage 1; D_1 deformation and metamorphism at biotite grade with the development of S_1,

Stage 2; D_2 deformation, still at biotite grade, with low-strain crenulation folding and production of S_2,

Stage 3; recrystallization at biotite grade during the later part of D_2 and after D_2.
(ix) Most of the veins probably formed during metamorphism. The textures in the thick carbonate veins suggest that they formed in dilational sites parallel to the S1 foliation and were subsequently deformed during the later parts of D1 and during D2. Many of the other veins probably formed during D1. Veins with laumontite are the youngest and may have formed during the late stages of the main metamorphic event or at some later stage.

4.3.d Unit B; Metavolcanic rocks

1 Facies

Unit B is composed of metavolcanic rocks (Bv) with minor metapelites (Bm), bedded, sorted, metavolcanic sandstones (Bf), sericite-rich metavolcanic rocks (Bs) and gossans (Bg).

2 Geometry

Unit B occurs in a ≈600 to 1200 m wide strip which runs for the whole length of the study area (22 km). The western side (base) of it is faulted out by the Murrumbidgee Fault in the central and northern part of the area. Much of Unit B is obscured by Tertiary sediments of Lake Bunyan (Taylor & Walker, 1986a&b) along the Numeralla and Murrumbidgee Rivers.

3 Type area

Good exposures of Unit B occur along the southern side of the Murrumbidgee Gorge west of Bredbo (around G.R. 91801770), along gullies at the Picasso Prospect and upstream from G.R. 93200160.

4 Contacts

Unit B is conformable on Unit A.

5 Distribution of Facies

The central and northern parts of Unit B in the study area are mainly metavolcanic rocks (Bv) with rare metapelite units (Bm). In the southern part of the study area there are many metapelite and metavolcanic sandstone units (Bf) in the eastern part of Unit B. The gossans (Bg) and sericite-rich metavolcanic units (Bs) occur close to the base of the unit in its central and southern parts. Unit B appears to become thinner to the south.

6 Description of Facies

Metavolcanic Rocks (Bv)

These metavolcanic rocks are composed of relict volcanic phenocrysts and phyllosilicate-rich lenticles supported in a matrix of quartz, feldspar, phyllosilicates, epidote,
sphene and magnetite. The rocks have a good foliation ($S_1$) which is defined by the preferred orientation of the phyllosilicate-rich lenticles and the minerals in the rocks.

The rocks do not show any obvious bedding even along the gullies in and around the Picasso Prospect which have almost continuous outcrop. Close inspection of samples from the percussion-drillholes (BYP 101 and BYP 104) at the Picasso Prospect revealed no variation in the size and the abundance of the relict phenocrysts of quartz and feldspar which might indicate bedding. Differences in the intensity of the foliation between outcrops suggests that the rocks were originally heterogeneous, possibly due to bedding but this has yet to be confirmed. The strike of the metavolcanic rocks is inferred to be meridional from the strike of the interbedded metasedimentary units.

**Relict phenocrysts.** Relict phenocrysts in the metavolcanic rocks vary in size up to about 4 mm and comprise from 10 to 60% of the rocks. They are poorly sorted and unevenly distributed in the rocks. Relict phenocrysts of quartz, in less-deformed rocks, have embayments and commonly appear to be broken fragments of larger subhedral grains. The quartz grains have undulose extinction, deformation bands and minor deformation lamellae. In more deformed rocks the grains are fractured or microboudinaged and some consist of lenticular, polycrystalline aggregates of small subgrains. The space between microboudinaged fragments is filled with carbonate, quartz and tiny phyllosilicate grains. Tiny phyllosilicate grains occur along the subgrain boundaries in some places.

Relict phenocrysts of feldspar commonly appear to be broken fragments of larger subhedral grains although in some rocks near the base of Unit B many have a prismatic, subhedral shape. The grains show varying degrees of alteration to sericite, ±epidote, ±chlorite, ±biotite. The degree of alteration varies from incipient phyllosilicate development along the cleavages to almost complete replacement. The altered grains generally retain a prismatic shape except in a few cases where grains, almost completely altered to sericite, have a lenticular shape parallel to the foliation.

Relict phenocrysts of plagioclase commonly show no sign of deformation, however some grains are fractured and microboudinaged. The gaps between fragments are filled with quartz, ±carbonate, ±epidote. In rare cases plagioclase grains show zones of subgrain development.

Most of the plagioclase is albite however in the biotite metamorphic zone grains of oligoclase and andesine are present and some grains show complex compositional zoning. The zoning is enhanced by the preferential alteration of only some zones. Relict phenocrysts of plagioclase in the blue-green amphibole zone and parts of the biotite zone commonly have thin rims of clear unaltered ?albite which contain small inclusions of matrix minerals and have diffuse contacts with the matrix. The quality of albite twinning in the relict plagioclase phenocrysts is poorer in more altered grains and in grains composed of albite.

Some relatively uncommon feldspar grains which do not show albite twinning may be relict K-feldspar phenocrysts.

Relics of mafic phenocrysts are a minor component of the rocks. They have a prismatic shape and are composed of aggregates of sphene, ±phyllosilicates, ±opaque, ±epidote. The sphene
and/or opaque grains are usually arranged in parallel bands. In rare cases the grains contain coarse flakes of biotite which suggest that these grains are altered biotite phenocrysts. In some rocks the opaque bands are microfolded. In places the grains are microboudinaged and in some highly deformed rocks the grains occur as lenticular aggregates parallel to the foliation. In one sample there were relict phenocrysts of amphibole.

**Phyllosilicate-rich lenticles.** The phyllosilicate-rich lenticles are of two types:

(i) biotite/chlorite-rich lenticles. These are composed of biotite and/or chlorite with minor amounts of epidote, sericite, sphene, magnetite and tourmaline. They are generally <0.5 mm wide and up to 9 mm long. Where chlorite is dominant it has a poor preferred orientation parallel to the foliation in the rock but it also forms radiating aggregates of grains. In biotite-rich lenticles biotite forms decussate, coarse-grained aggregates with a good preferred orientation.

(ii) sericite-rich lenticles. These are composed of fine-grained sericite which has a very good preferred orientation. The lenticles vary in size from tiny aggregates of a few grains up to large 10 x 30 mm masses which anastomose around relict phenocrysts and small matrix domains. Phenocrysts sometimes have scalloped margins where they are in contact with these lenticles. The thicker lenticles always have a few grains of unstrained sericite which are at high angles to the foliation and in some rocks the lenticles are crenulated. Sericite-rich lenticles sometimes cut across the biotite/chlorite lenticles.

**Matrix.** The matrix of the metavolcanic rocks is composed of quartz, plagioclase, chlorite, sericite and epidote, ±biotite, ±magnetite, ±carbonate, ±sphene with ubiquitous accessory apatite and zircon. It usually has a granoblastic texture with the phyllosilicates aligned to define a continuous foliation (S₁), however there are always some phyllosilicate grains at an angle to the foliation. In rare cases there are small, coarse, granoblastic domains in which there is a very weak foliation (S₂) at an angle to the S₁ foliation in the rest of the rock.

In some rocks there are small domains in the matrix composed of micro-cryptocrystalline quartz, ±feldspar, phyllosilicates and opaques. Where grain boundaries are visible they have a sutured appearance. Some of these domains contain tiny, acicular, subhedral feldspar grains.

Epidote occurs as aggregates of tiny grains and as single, large crystals up to 3 mm long. In the brown-biotite metamorphic zone the larger epidote grains are sub-euhedral and zoned with brown cores and yellow rims. Some of the epidote grains have a radiating fibrous texture.

Magnetite grains are subhedral to euhedral and sometimes have rims of brown ?martite/?sphene. Magnetite has an irregular distribution in the rocks and is commonly concentrated in small, round domains or long bands in the rocks. Apatite grains are anhedral to subhedral and in rare cases the larger grains are intergrown with epidote. Some of the larger grains of magnetite and apatite are fractured and microboudinaged.

**Other features.** Phyllosilicate-rich microlithons in the rocks are often weakly crenulated and a very weak crenulation cleavage (S₂) is produced. This cleavage is not continuous through the rock.
In areas around the mineralization at the Picasso and Gamma-Delta Prospects the metavolcanic rocks contain coarse-grained aggregates of randomly oriented muscovite and lenticular carbonate grains. The muscovite grains at high angles to the foliation are bent and/or kinked. In some of these rocks plagioclase is being replaced by sericite.

The Unit B metavolcanics intersected in the upper parts of the Gillans Prospect diamond-drillholes, close to the Murrumbidgee Fault, have some additional textures. Most of the rocks have blue-green amphibole which occurs as large framework grains and as small matrix grains. In one rock the S₁ foliation is defined by bands of small blue-green amphibole grains. Most of the large grains have numerous inclusions of matrix mineral grains and have the same pleochroic scheme as the small matrix grains (α=pale yellow, β=γ=blue-green). However, some of the large grains do not have inclusions of matrix minerals and are zoned from cores with α=pale yellow, β=γ=brown-green to rims of the blue-green amphibole described above. In one rock there is a cumulophyric aggregate of brown-green amphibole grains. Another rock contains large grains of strained biotite and a few cumulophyric biotite grains. The biotite is optically identical to the matrix biotite.

In some places in the brown-biotite metamorphic zone the biotite in the recrystallized domains and in fractures in the relict phenocrysts of plagioclase is a green colour whereas the biotite in the lenticles is a brown colour.

A few rocks from the Gamma-Delta Prospect contain lenticular grains which are composed of radiating coarse albite blades and opaque grains.

*Metapelites (Bm)*

Metapelite lenses, up to a few metres thick and a few tens of metres long, occur at various levels in the volcanics. The units are always strongly foliated and bedding is difficult to discern.

*Crystal-Rich Metavolcanic Rocks, Meta-arkose and Metapelite (Bf)*

In the southeastern part of Unit B there are beds of crystal-rich, framework-supported metavolcanic rocks and meta-arkoses in lenses up to 30 metres thick and tens to hundreds of metres long. They are sometimes plane-laminated and a single bed may be from a few centimeters to several meters thick. Graded bedding is rare.

In the gully at G.R. 93200160 there is a small lens of plane-laminated, fine meta-arkoses and metapelites. The rocks are composed of minor phenocrysts of quartz supported in a well-foliated matrix of epidote and quartz with minor chlorite. Around G.R. 94009990 the rocks are composed of quartz and altered plagioclase phenocrysts supported in a matrix of well-foliated sericite and carbonate with minor chlorite and epidote. Magnetite is concentrated in parallel planes through the rock at an angle to the foliation suggesting original, thin, iron-rich zones.

*Sericite-Rich Metavolcanic Rocks (Bs)*

These rocks are composed of relict phenocrysts of quartz and porphyroblasts of pyrite (now pseudomorphed by limonite) supported in a matrix of strongly foliated sericite and quartz. These
rocks will be described more fully in Chapter 5 in the descriptions of the Gamma-Delta, Picasso, Riversdale and Mt Oak prospects.

**Gossans (Bg)**

The gossans in Unit B form bands and lenses which are always parallel to the foliation in the host metavolcanics. They are composed of strongly foliated bands of iron oxides and hydroxides which envelope, and interfinger with, small lenses of strongly foliated metavolcanic rock. In the gossan bands, limonite pseudomorphs after pyrite and limonitic boxworks are abundant. The gossans will be discussed more fully in Chapter 5 in the sections on the Gamma-Delta, Picasso, Riversdale and Mt Oak Prospects.

**Veins**

The most common veins in Unit B are composed of quartz, chlorite, ± epidote, ± pyrite. They are usually parallel to the $S_1$ foliation but in places veins cut the $S_1$ foliation or are disrupted by it. In a few places there are veins up to 20 cm wide and <2 m long composed of quartz and pyrite. At the Picasso Prospect two small prospecting pits are developed on such veins.

7 Interpretation of Unit B

(i) The large grains of quartz and feldspar in the metavolcanic rocks represent relict volcanic phenocrysts which have been modified by metamorphism and deformation. The embayments in quartz phenocrysts are primary features produced by magmatic resorption. The plagioclase phenocrysts were originally zoned with compositions ranging up to at least andesine. In most rocks the phenocrysts appear to have been broken fragments of grains although some rocks in the lower parts of the unit have a high proportion of unbroken, subhedral grains.

(ii) The large grains composed of sphene, ± phyllosilicates, ± opaques, ± epidote represent relict mafic phenocrysts including biotite and possibly amphibole and pyroxene. The parallel bands of opaques and/or sphene probably represent a crystallographic direction in the original grains. In the Gillans Prospect drill-holes the large brown-green amphibole grains and the large biotite grains may also be relict phenocrysts.

(iii) Interpreting the history of the relict phenocrysts is difficult, however:

1. the albitisation of feldspar in the chlorite metamorphic zone and only partial albitisation in the biotite metamorphic zones is probably due to metamorphism.
2. the partial alteration of the plagioclase phenocrysts to epidote and/or phyllosilicates may be due to either metamorphism or synvolcanic alteration.
3. the formation of ? albite overgrowths on plagioclase phenocrysts in the brown-biotite metamorphic zone is probably due to metamorphism.
4. alteration of mafic minerals (biotite and/or ? amphibole and/or ? pyroxene) to form aggregates of sphene, ± phyllosilicates, ± opaques, ± epidote may be due to original magmatic processes, or synvolcanic alteration or metamorphism.
(5) the relict phenocrysts were deformed during metamorphism. Plagioclase has deformed in a brittle fashion usually, although rarely, some grains show plastic strain. Quartz has deformed in both a plastic and a brittle fashion. The mafic relics have mostly behaved as rigid bodies although in places they were fractured. The spaces between microboudinage fragments have been filled with metamorphic minerals including quartz, carbonate, phyllosilicates and epidote.

(6) corrosion of quartz phenocrysts where they were in contact with sericite lenticles is a metamorphic feature related to pressure solution.

(iv) The biotite/chlorite lenticles have recrystallized during metamorphism to their coarse grain size. The amphibole-rich folia in the Gillans Prospect rocks probably represent similar structures. It is possible that the smaller, thinner lenticles represent phyllosilicate-rich domains produced by pressure solution processes. the larger lenticles are discontinuous and thick which suggests that they represent original compositional domains such as vitriclasts, xenoliths, mafic lithic fragments, or zones (veins) of hydrothermal alteration in the volcanics. The presence of tourmaline in some of the lenticles supports the last interpretation.

(v) The sericite-rich lenticles probably have two origins. Those which are in contact with, and appear to corrode relict phenocrysts, and/or cut across the biotite/chlorite lenticles and/or have a more continuous, anastomosing texture probably formed during metamorphism due to pressure solution processes and represent the incipient development of a domainal, differentiated foliation. The more discontinuous, discrete lenticles, however, probably represent primary compositional domains in the rocks, such as vitriclasts. If this is the case then the lenticles may have defined a primary foliation but this is yet to be confirmed.

(vi) The matrix has crystallized new minerals and been recrystallized during metamorphism. The very fine-grained domains apparently represent areas of only weakly metamorphosed matrix material. The observation that the fine-grained domains are relatively rich in opaques and poor in phyllosilicates compared to the coarser areas suggests that the phyllosilicates in the coarse domains have formed at the expense of the opaques in the fine-grained domains.

(vii) The tiny, acicular feldspar grains in some of the fine-grained domains represent relict primary grains. The radiating, fibrous epidote grains in the rocks in the biotite zone and the lenticular grains composed of radiating blades of albite with opaques may represent filled vesicles. The albite may have replaced earlier zeolites.

(viii) Magnetite, apatite (and zircon?) were probably originally present in the rocks as volcanic microphenocrysts and have grown during the metamorphism to form sub-euhedral grains.

(ix) The rocks which have a relatively carbonate-rich matrix may represent rocks with originally more carbonate (perhaps due to synvolcanic alteration) or rocks which have been exposed to carbonate rich metamorphic fluids.
(x) The coarse grains of muscovite in the rocks around the mineralized areas clearly predate the main deformational event since they are deformed by it. They probably represent altered feldspars since the relict plagioclase grains have inclusions of coarse muscovite in them.

(xi) The lack of bedding in the rocks and the phenocryst textures suggest that most of the rocks were originally deposited as pyroclastic mass-flows and lavas. The rocks with a high proportion of broken phenocrysts may have been deposited as pyroclastic mass-flows. The rocks with relatively few broken phenocrysts, and/or small acicular feldspar grains in the matrix, and/or vesicles were probably deposited as lavas.

(xii) The observations suggest that the metamorphic and deformational history of the rocks involved a single, long, metamorphic event with shorter deformational events. The history can be divided into three stages:
   Stage 1 was at biotite grade and the \( S_1 \) foliation formed,
   Stage 2 involved crenulation of the rocks and it is possible that the recrystallized domains which have a weak foliation at an angle to the main foliation formed at this time,
   Stage 3 involved the continuation of the metamorphic event, with no strain, to recrystallize parts of the rock to produce coarse, strain-free grains including phyllosilicates at angles to the main foliation.

(xiii) Structures and minerals in the rocks which could represent metamorphosed synvolcanic alteration effects (although this is not the only interpretation) include:
   (1) coarse muscovite grains (after feldspar?),
   (2) lenticles of chlorite, epidote, magnetite, sphene and tourmaline representing disrupted alteration veins,
   (3) rocks with abundant carbonate in the matrix.
   (4) altered plagioclase and mafic phenocrysts.

(xiv) The metapelite beds (Bm) may represent metamorphosed epiclastic mudstones and/or metamorphosed vitriclastic units.

(xv) The crystal-rich metavolcanic rocks, meta-arkoses and metapelites (Bf) may represent metamorphosed epiclastic mass-flow deposits, and/or pyroclastic-fall deposits.

(xvi) The sericite-rich metavolcanic rocks (Bs) are similar to the sericite-rich rocks of facies As. The sericite-rich zones may represent originally potassium rich beds such as vitriclastic units, and/or zones of synvolcanic alteration, and/or zones of intense metamorphic retrogression.

(xvii) The gossans (Bg) may have developed on metamorphosed synvolcanic mineralization and/or zones of mineralization formed during metamorphism and/or metamorphic veins developed in zones of synvolcanic mineralization and alteration.

(xviii) Most of the veins formed during metamorphism in dilational sites parallel to the \( S_1 \) foliation. Some of the veins which cut the \( S_1 \) foliation clearly post-date the peak of \( D_1 \). The age of the quartz-pyrite veins is not clear.
4.3.e Unit C; Bullanamang Porphyry

1 Facies

Unit C is composed of coarse-grained metaporphyry (Cp), medium-grained metavolcanic rocks (Cv), metasedimentary rocks (Cm), cream metavolcanic rocks (Ck) and rare gossans (Cg).

2 Previous Work

Part of Unit C was mapped and described as granite porphyry by Browne (1944). Joplin (1943) called the unit a quartz diorite porphyrite. Henderson (1987) refers to it as the Bullanamang Porphyry.

3 Geometry

Unit C varies from 200 to 1500 m wide and extends for the whole length of the mapping area (22 km).

4 Type Area

Good exposures of Unit C occur in road cuts along the Monaro Highway particularly at G.R. 92931380 and around the Monaro Highway Rest Area at G.R. 94300522.

5 Contacts

The nature of the contacts of Unit C with Unit B and Unit D is not clear. In the northern part of the area the contact with Unit D has been interpreted by Pillans (1974) as a fault (Billilingra Fault) based mainly on a topographic depression along the contact although he did not note the change in lithology across the contact. Within Unit C the small areas of medium-grained metavolcanic rocks (Cv) and metasedimentary rocks (Cm) commonly have complex interfingering contacts with the metaporphyry (Cp).

6 Distribution of Facies

The dominant lithology in Unit C is the coarse-grained metaporphyry (Cp). The medium-grained metavolcanic rocks (Cv) and the metasedimentary rocks (Cm) form meridionally trending, narrow zones within the metaporphyry. The cream metavolcanic rock (Ck) forms an irregularly shaped area to the west of Cosgrove Hill.

7 Description of Facies

**Coarse-Grained Metaporphyry (Cp)**

The coarse-grained metaporphyry generally forms low, very weathered outcrops composed of large (<10 mm) relict quartz phenocrysts in a well-foliated, phyllosilicate-rich matrix. In weakly foliated areas the rocks are fresher and composed of relict phenocrysts of quartz, plagioclase, K-feldspar and an altered mafic mineral, supported in a matrix of quartz, partly
altered feldspar and sericite, ±chlorite, ±biotite, ±epidote, ±carbonate. Accessory minerals include apatite and zircon.

**Relict phenocrysts.** Relict phenocrysts of quartz are subhedral to euhedral bipyramids with deep embayments. All have undulose extinction and subgrain development is common. Relict phenocrysts of plagioclase occur as subhedral grains up to 8 mm long which show varying degrees of alteration to sericite with minor epidote. Relict phenocrysts of K-feldspar are rare but occur as large (<15 mm), pink, subhedral grains.

Prism-shaped aggregates of coarse-grained chlorite, epidote and sphene, usually with the sphene grains arranged in parallel planes, probably represent altered mafic minerals (including biotite?). Browne (1944) reports biotite and hornblende phenocrysts in the unit however these were not seen in this study.

**Lenticular bodies.** Large lenticular bodies, up to 4 x 10 cm, composed of chlorite, epidote, sphene, opaques, ±biotite are a minor constituent of the rock. Some have relict biotite grains which are partly replaced by chlorite.

**Matrix.** The matrix shows varying development of a continuous to incipiently domainal cleavage (S₁). Incipient phyllosilicate-rich folia are composed of sericite and/or biotite and/or epidote. The rest of the matrix has a subequigranular texture and phyllosilicate grains may be randomly oriented or show variable degrees of preferred orientation parallel to the phyllosilicate-rich folia. Pressure shadows around relict phenocrysts are filled with quartz, carbonate and phyllosilicates.

**Other features.** In places the rocks have numerous microfractures which cut the matrix and relict phenocrysts at a high angle to the S₁ foliation. The microfractures are filled with fibrous quartz and phyllosilicates.

The metaporphyry contains small aplitic zones and coarse-grained pegmatitic zones. The pegmatitic zones are composed of very large (<3 cm) grains of K-feldspar and quartz with only minor matrix material and have gradational contacts with the enclosing rock.

**Medium-Grained Metavolcanic Rocks (Cv)**

Most of facies Cv is composed of well-foliated, medium-grained metavolcanic rocks which are similar to the rocks of Unit B and Unit D. In the roadcut at G.R. 92861508 the rock has relict phenocrysts of unaltered amphibole. The metavolcanics contain a few meta-aplitic dykes which generally strike parallel to the foliation. The dykes have a creamy-pink colour with a mylonitic fabric and are composed of quartz, K-feldspar and albite with a trace of opaques, zircon, apatite, sericite, chloride and biotite.

**Metasedimentary Rocks (Cm)**

There is a metasedimentary sequence composed of metapelites, quartz arenite, metalimestone and jasper south of the Chakola Road around G.R. 93640186. Parts of the metalimestone are rich in hematite. The units strike approximately north-south.
Cream Metavolcanic Rocks (Ck)

The cream metavolcanic rocks are composed of quartz crystals supported in a very fine-grained matrix of quartz, K-feldspar and minor sericite with iron oxide pseudomorphs after pyrite. The rocks are usually massive but in places they have a strong foliation. The rocks are very similar to the massive, white, K-feldspar rich rocks of facies Dk.

Gossans (Cg)

The gossans are described in section 5.4. The main gossans in the metaporphyry are at the Driscoll's Hill and Driscoll's Hill South Prospects. The gossans are composed of relict phenocrysts in a phyllosilicate-rich (sericite and ?chlorite) matrix which contains disseminated pyrite. In places there are vein-like zones parallel to the foliation, up to a few metres wide and tens of metres long, in which the matrix of the rock is very siliceous and has minor disseminated pyrite.

West of Cosgrove Hill there is a zone of gossan in the metavolcanic rocks (Cv). It is composed of gossanous bands interbanded with sericitic metavolcanic rocks.

Veins

Small veins, <10 cm wide and <5 m long, composed of banded jasper and parallel to the S�foliation are common in places.

8 Interpretation of Unit C

(i) Before metamorphism the metaporphyry (Cp) was composed of well-formed phenocrysts of embayed quartz, plagioclase, K-feldspar and mafic minerals supported in a relatively coarse-grained quartzofeldspathic matrix.

(ii) The phyllosilicate minerals, epidote and carbonate in the matrix have a metamorphic texture and probably formed during metamorphism.

(iii) The coarse-grained metaporphyry (Cp) is interpreted as an intrusive porphyry dyke or sill rather than an extrusive volcanic unit because of the coarse grain size of the relict phenocrysts and the matrix. The large lenticular aggregates of chlorite, epidote and sphene probably represent altered mafic xenoliths. The pegmatitic and aplitic zones represent some minor phases associated with the intrusive porphyry.

(iv) The medium-grained metavolcanic rocks (Cv), the metasedimentary rocks (Cm) and the cream metavolcanic rocks (Ck) probably represent large slices of Unit B and Unit D rocks which were enveloped by the coarse-grained porphyry (Cp) during intrusion. In particular, it appears that the cream metavolcanic rock (Ck) is part of the massive, white, K-feldspar-rich metavolcanic facies (Dk) which occurs immediately to the east around Cosgrove Hill.

(v) The jasper veins are probably of metamorphic origin.

(vi) The gossanous zones (Cg) in Facies Cp may have a number of origins:

1. they may represent zones of high fluid flow during metamorphism which has replaced the matrix of the rocks with quartz and minor pyrite,
(2) they may have formed when the porphyry was intruded,
(3) the zones may be related to the synvolcanic hydrothermal systems which produced the mineralization and alteration in the overlying Unit D rocks. This would require that the porphyry was intruded during volcanism or that it was in fact an extrusive unit deposited after Unit B.

4.3.f Unit D; Metavolcanic rocks

1 Facies

Unit D consists of a complex group of rocks with numerous zones of mineralization including the Cosgrove Hill, Billilingra, Driscoll's Hill, Harnett and Stonehenge prospects. It is divided into the massive, hornblende-bearing metavolcanic rocks (Dhv); lithic-rich metavolcanic rocks (Dlr); the Cosgrove "Porphyry" (Dcp); massive, white, K-feldspar-rich metavolcanic rocks (Dk); sericitic, siliceous, gossanous metavolcanic rocks (Ds); mineralized, K-feldspar-rich metavolcanic rocks (Dkb); crystal-rich metavolcanic rocks (Dx); dark-green metavolcanic rocks (Dv) and cherts (Dch). Unit D contains very few metasedimentary rocks.

2 Geometry

Unit D extends for the entire length of the study area (22 km) and the width of the unit varies from <100 to 1200 m. Outcrop width thins to the south.

3 Type Area

Reasonably good exposures of Unit D occur along farm tracks east of "Billilingra" homestead (east of G.R. 93761250 and G.R. 93941132). An almost complete section through Unit D was intersected in Harnett diamond-drillhole DDH-H3 (0-288 m, see 5.5.e).

4 Contacts

Unit D appears to be conformably and/or disconformably overlain by Unit E.

5 Distribution of Facies

The distribution of facies is complex but note:

(i) the massive, white, K-feldspar-rich metavolcanic rocks (Dk) occur along strike to the north and south of the Cosgrove Porphyry (Dcp),
(ii) the mineralized, K-feldspar-rich metavolcanic rocks (Dkb) occur along the eastern side of the Billilingra Prospect,
(iii) sericitic, siliceous, gossanous metavolcanic rocks (Ds) occur for most of the length of Unit D,
(iv) the crystal-rich metavolcanic units (Dx) occur along the western side of Unit D in the area of the Billilingra, Driscoll's Hill, Driscoll's Hill South and Harnett prospects,
(v) the dark-green metavolcanic rocks (Dv) form a narrow strip from the Harnett Prospect to the Stonehenge Prospect,
(vi) the cherts (Dch) form thin units in the sericitic, siliceous, gossanous metavolcanic rocks (Ds) in the area of the Stonehenge prospect.

6 Description of Facies
Detailed descriptions of parts of Unit D are given in the descriptions of the Cosgrove Hill, Billilingra, Barite, Driscoll's Hill, Harnett and Stonehenge Prospects (Ch. 5).

**Massive, Hornblende-Bearing Metavolcanic Rocks (Dhv)**
Massive, hornblende-bearing metavolcanic rocks occur in a small area to the south of the junction of the Bredbo and Murrumbidgee Rivers. They have subhedral phenocrysts of bipyramidal, embayed quartz, sericite-altered feldspar, fresh amphibole, altered biotite, and microphenocrysts of magnetite supported in a matrix composed of cryptocrystalline quartz and K-feldspar with minor chlorite, carbonate and ?epidote. The matrix has pink, K-feldspar-rich zones in places and elsewhere the rocks have spherulites.

**Lithic-Rich Metavolcanic Rocks (Dlr)**
There are good exposures of facies Dlr in the Monaro Highway roadcut just south of Bredbo. The unit was mapped as "rhyolitic crystal tuff" by Richardson (1979). It consists of pale-green to pale-pink rocks composed of lithic fragments, sericitic lenticles, broken fragments of crystals (quartz, plagioclase, K-feldspar and altered mafic mineral(s)) supported in a microcrystalline matrix of quartz, K-feldspar and sericite. The rock has a good foliation, defined by the alignment of sericitic lenticles and thin sericite folia in the matrix. Relict spherulites are common in places.

**Cosgrove Porphyry (Dcp)**
The Cosgrove Porphyry forms a prominent hill to the north of Cosgrove Hill Trig. This unit was described by Pillans (1974) and was called the Cosgrove Porphyry by Richardson (1979). It is composed of massive, unfoliated, dark-brown rocks with phenocrysts of quartz, plagioclase and altered mafic minerals supported in a microcrystalline matrix of quartz and K-feldspar. The phenocrysts are commonly subhedral and are not broken. Quartz has primary absorption embayments. Skeletal microphenocrysts of feldspar are common. In places the unit appears to contain abundant banded fragments, however in thin section these "fragments" are areas in which the matrix has abundant planar zones of axiolites and spherulites.

**Massive, White, K-Feldspar-Rich Metavolcanic Rocks (Dk)**
The massive, white, K-feldspar-rich metavolcanic facies (Dk) occurs along strike to the north and south of the Cosgrove Porphyry (Dcp) and good exposures occur along the track leading to the Cosgrove Hill microwave tower. This unit was described as "white to cream crystal tuff" by
Richardson (1979). It consists of massive, unfoliated rocks composed of large crystals of quartz, feldspar, and mafic relics in a microcrystalline matrix of K-feldspar with minor quartz, chlorite and pyrite. Both K-feldspar and plagioclase crystals are present, however plagioclase shows various degrees of alteration to K-feldspar. Skeletal microphenocrysts of feldspar are common. In less-altered places the rock is very similar to the Cosgrove Porphyry (Dcp). Structures similar to lithophysae occur at G.R. 93621436 and G.R. 93701470.

**Mineralized, K-feldspar-Rich Metavolcanic Rocks (Dkb)**

The mineralized, K-feldspar-rich rocks are the main host to the mineralization at the Billilingra Prospect and will be described more completely in Section 5.5.b. They are composed of relict phenocrysts of quartz, ±K-feldspar, ±plagioclase in a matrix of quartz and K-feldspar with minor sericite, ±pyrite, ±carbonate, ±chlorite, ±barite. A feature of this unit is the lack of fragmental textures and the presence of phenocrysts which were subhedral and unbroken before the deformation. The rocks are similar to facies Dk except for a higher sericite and chlorite content and better S1 foliation.

**Sericitic, Siliceous, Gossanous Metavolcanic Rocks (Ds)**

The sericitic, siliceous gossanous metavolcanic rocks are a complex group of rocks with considerable variation in composition and texture. Outcrops are commonly very weathered. In general, the rocks contain relict volcanic phenocrysts of quartz, ±plagioclase, ±K-feldspar supported in a matrix of quartz, sericite, ±K-feldspar with minor amounts of ±hematite, ±gossanous material, ±zircon.

**Relict phenocrysts.** Quartz phenocrysts have embayments and usually show either undulose extinction or consist of polycrystalline aggregates of grains. K-feldspar phenocrysts sometimes show incipient alteration to sericite. Plagioclase phenocrysts show poor albite twinning, are of albite composition and in places show varying degrees of alteration to brown clay minerals. Some rocks contain aggregates of chlorite or sericite and opaques which are probably relics of mafic minerals.

**Matrix.** In the matrix there are folia of sericite which wrap around microlithons of quartz, ±K-feldspar, ±sericite. The degree of S1 foliation development in the rocks generally increases with increasing phyllosilicate content.

**Other features.** In places near the Billilingra and Driscoll's Hill Prospects the unit becomes more massive, siliceous and K-feldspar-rich and has a small amount of disseminated pyrite. These rocks are very similar to facies Dkb.

To the south of Cosgrove Hill, in area of the Cosgrove Hill Prospect (Fig. 5.6), there are zones which have fragmental textures. These rocks are commonly framework-supported with large sericitic rock fragments (<20 x 50 cm) and crystals of quartz and feldspar in a sericite-rich matrix.
Dark-Green Metavolcanic Rocks (Dv)

The dark-green metavolcanic rocks (Dv) form a unit from the Harnett Prospect to the Stonehenge Prospect. The Harnett Prospect diamond-drillhole, DDH-H3, provides an almost complete section through the unit and the following description is based on this. The rocks are composed of crystals of quartz and plagioclase supported in a matrix of quartz, chlorite, sericite, ±green biotite, ±plagioclase, ±K-feldspar with minor components including ±sphene, ±magnetite, ±epidote, ±rutile, ±hematite, ±pyrite and accessory apatite and zircon. Relics of mafic phenocrysts consist of clusters of opaques (iron oxides and/or fine grained sphene?) with coarse-grained chlorite or green biotite. The opaques occur in parallel planes in the grains suggestive of an original biotite (001) crystallographic direction. Magnetite microphenocrysts are subhedral and sometimes microboudinaged.

The rocks in the drill-core commonly have a diffuse lamination on the scale of a few millimetres to a few centimetres. It is defined by phyllosilicates-rich bands alternating with phenocryst-rich bands. On a mesoscale the rocks have a very well-developed, continuous foliation defined by the preferred orientation of the phyllosilicates. On a microscale the matrix is domainal with broad, phyllosilicate-rich folia wrapping around lenticular microlithons of two types:

(i) quartz, ±plagioclase, ±K-feldspar, ±hematite with minor amounts of phyllosilicates. In places these domains contain acicular feldspar grains. The chlorite and biotite in these microlithons may be either randomly oriented or be oriented parallel to the main foliation or in rare cases they are oriented to define a foliation at an angle to the main foliation. Spherulites occur in places. Some rocks have epidote in spherical aggregates of radiating, acicular grains, which probably represent vesicles.

(ii) massive, randomly oriented, coarse-grained chlorite and/or biotite. Individual grains are usually slightly deformed. The phyllosilicate-rich folia are crenulated in places and a weak crenulation cleavage (S2) is developed. Pressure beards and the spaces between microboudinage fragments are filled with carbonate, hematite and green biotite. Opaque grains are commonly microboudinaged.

Cherts (Dch)

The cherts (Dch) form lenses in the sericitic, siliceous, gossanous metavolcanic rocks at the Stonehenge Prospect. The lenses are approximately parallel to strike and are composed of relict phenocrysts of quartz supported in a matrix of microcrystalline quartz with minor sericite and/or pyrite. The rocks have a diffuse banding parallel strike of the lenses but no obvious bedding.
Veins

A feature of the sericitic, siliceous, gossanous metavolcanic rocks (Ds) and the mineralized, K-feldspar-rich metavolcanic rocks (Dkb) is that they contain abundant veins of quartz, ±chlorite, ±sericite, ±K-feldspar, ±carbonate, ±hematite, ±barite. The veins are commonly parallel to the foliation. The veins are usually massive but in places they have fibrous structures.

7 Interpretation of Unit D

(i) The lithic-rich metavolcanic facies (Dlr) is interpreted to have been a partly welded pyroclastic mass-flow deposit.

(ii) The Cosgrove Porphyry (Dcp) was considered to have been intrusive by Pillans (1974) and cited in Richardson (1979). The lack of fragmental textures, the well-formed nature of the phenocrysts, the fine grain size of the matrix and the presence of skeletal microphenocrysts, however, suggest that it was deposited as a lava flow or dome. The matrix minerals are probably at least partly metamorphic in origin but the rock is unusual in that it does not have a strong metamorphic fabric. The zones of hydrothermal alteration referred to by Pillans (1974) and cited by Richardson (1979) are in fact zones with abundant axiolites and spherulites.

(iii) The massive, K-feldspar-rich metavolcanic rocks (Dk) are texturally very similar to the Cosgrove Porphyry (Dcp) except for the K-feldspar flooding and the zones disseminated units probably an originally of lavas, parts of which were altered to K-feldspar, ±pyrite, ±chlorite.

(iv) The massive, hornblende-bearing metavolcanic rocks (Dhv) are interpreted as metamorphosed lavas based on the lack of fragmental textures, the well-formed nature of the phenocrysts and the framework-supported nature of the rocks. These rocks are unusual because they are unfoliated and relatively unaltered compared to the rest of Unit D. It is possible that they represent parts of Unit D (or facies Cv) which were not altered and only weakly deformed. Alternatively the rocks are very similar to the rocks of facies Ehv and Fhv which suggests that facies Dhv rocks may represent parts of facies Ehv or Fhv which have been faulted or folded into their present position.

(v) The sericitic, siliceous, gossanous metavolcanic rock (Ds) probably represent volcanic rocks which were altered by synvolcanic processes and have subsequently been deformed. These rocks will be covered in more detail in Chapter 5.

(vi) The mineralized, K-feldspar-rich metavolcanic rocks (Dkb) and the sericitic, siliceous, gossanous metavolcanic rocks (Ds) west of the Billilingra Prospect were probably deposited as lavas because these rocks generally lack fragmental textures and have well-formed phenocrysts. It is possible that they represent parts of the lavas deposited further north (Dk, Dcp).

(vii) The dark-green metavolcanic rocks (Dv) appear to represent alteration zones which have been metamorphosed. The characteristic assemblage now is chlorite, sericite,
green biotite and hematite with feldspars preserved. The diffuse lamination in these rocks may be due to metamorphic flattening of originally banded or fragmental rocks or it may be due to flattening of a hydrothermal alteration "breccia". Textures in the lenticular microliths between the phyllosilicate-rich folia suggest that the rock contained randomly oriented rosettes of chlorite prior to metamorphism. Some of this chlorite has been converted to biotite during metamorphism.

(viii) The area of facies Ds rocks at the Stonehenge Prospect and facies Dv at the Harnett Prospect probably represent parts of the same depositional unit(s). The present difference between the units is because they were altered to different mineral assemblages.

(ix) The cherts (Dch) probably represent zones of intense silicification of volcanic rocks. They are probably not exhalative since they are not associated with other sedimentary facies, do not have good bedding and contain matrix-supported, relict volcanic phenocrysts.

(x) The veins in Unit D may have formed due to synvolcanic hydrothermal processes or during metamorphism. A metamorphic origin for most of them is favoured for those which are are parallel to the foliation. The veins will be considered in more detail in Chapter 5.

(xi) The metamorphic textures in Unit D suggest a metamorphic history involving:
(1) metamorphism to biotite grade accompanied by development of the main foliation \( S_1 \).
(2) weak crenulation folding and formation of an incipient \( S_2 \) crenulation cleavage.

4.3.g Unit E; Metavolcanic and Metasedimentary Rocks

1 Facies

Unit E is composed of hornblende-bearing metavolcanic rocks (Ehv) with lesser amounts of framework-supported metavolcanic rocks (Ef); interbedded metavolcanic and metasedimentary rocks (Evs); mineralized, sericitic, siliceous, metasedimentary and metavolcanic rocks (Es); hematitic, sericitic metasedimentary rocks (Ehs); quartz arenites (Eq) and metapelites (Em).

2 Geometry

Unit E extends for the entire length of the mapping area. It has an outcrop width of >1200 m in the north and it narrows to about 250 m in the south.

3 Type Area

Accessable, good outcrops of Unit E occur along the farm access road around G.R. 94830650. Most of Unit E was intersected in the Stonehenge Prospect drill-holes (5.5.f).
Contacts
The base of Unit E appears to be an overlapping unconformity on Unit D.

Distribution of Facies
The mineralized, sericitic, siliceous metasedimentary and metavolcanic rocks (Es) and the hematitic, sericitic metasedimentary rocks (Ehs) occur along the base of Unit E. The quartz arenites (Eq) are more abundant along the western side of the unit. The metapelites (Em) are more abundant in the southern part of the unit.

Description of Facies

Hornblende-Bearing Metavolcanic Rocks (Ehv)
The hornblende-bearing metavolcanic rocks have a dark grey-green colour and are generally unfoliated or only weakly foliated. They are composed of subhedral to euhedral relict phenocrysts of quartz, plagioclase, altered amphibole and magnetite supported in a matrix of microcrystalline quartz, feldspar, sericite, chlorite, epidote and carbonate with accessory apatite and zircon. There are no lithic fragments.

Relict phenocrysts of quartz commonly have deep embayments. Relict phenocrysts of plagioclase show incipient alteration to sericite. Relict phenocrysts of amphibole (α=pale yellow, β=γ=dark-green to brown) show various stages of alteration to chlorite and sometimes have embayments filled with matrix material. Relict phenocrysts of other mafic minerals occur as prism-shaped aggregates of epidote, sphene and opaques usually with the sphene grains aligned in rows. The rocks also contain minor amounts of skeletal opaque grains.

Spherulites and axiolites occur in the matrix of some rocks. In rare cases there are subspherical grains of fibrous epidote.

The rocks along the western side of the unit have a poor to moderate foliation in places which is defined by the preferred orientation of the sericite in the matrix. Quartz phenocrysts may have undulose extinction and some occur as polycrystalline aggregates of grains. Carbonate, ±quartz, ±chlorite fill the fractures.

There are hematitic zones mainly along the western side of the hornblende-bearing metavolcanics, including zones at the Cosgrove Hill Prospect (Fig. 5.6. -600E 4380N) and at the Driscoll's Hill South Prospect (5.5.d). The rocks in these zones are composed of crystals of quartz supported in a matrix of quartz, sericite, hematite, ±epidote. The quartz crystals have embayments. In places there are large clots of sericite possibly after feldspar and prism-shaped masses of sericite and hematite possibly after mafic phenocrysts. The rocks have a strong continuous foliation (S1).

Framework-Supported Metavolcanic Rocks (Ef)
The framework-supported metavolcanic rocks form beds up to a few tens of metres thick which are massive and have no internal structures. The rocks have a dark, grey-green colour and
are composed of crystals of quartz, feldspar, magnetite and altered mafics in a matrix of chlorite, quartz, opaques, carbonate and sphene. Accessory minerals include apatite and zircon. Quartz grains have a subrounded shape, sometimes with scalloped margins and embayments. Crystal faces are rare. Plagioclase and K-feldspar form prismatic, anhedral to subhedral grains. Prism-shaped aggregates of chlorite, sphene, opaques and sericite, with the sphene and opaques concentrated into planes, probably represent relict mafic phenocrysts. In some cases the planes of opaques are crenulated.

Some of the beds have volcanic rock fragments and in one sample the fragments are very K-feldspar rich, similar to the rocks of the massive, white, K-feldspar-rich facies (Dk). Some of the rocks contain fragments of massive pyrite.

**Interbedded Metavolcanic and Metasedimentary Rocks (Evs)**

This unit consists of interbedded metavolcanic rocks, quartz arenites, metapelites, and framework-supported metavolcanic rocks (arkoses?). The metavolcanic rocks are commonly similar to the hornblende-bearing metavolcanics (Ehv). Some of the metasedimentary units contain abundant fine-grained magnetite.

**Mineralized, Sericitic, Siliceous Metasedimentary and Metavolcanic Rocks (Es)**

These rocks occur along the base of Unit E at the Harnett (5.5.e) and Driscoll’s Hill (5.5.c) Prospects. The unit is composed of interbedded metavolcanic rocks, metasandstones and metapelites which are sericitic, siliceous and gossanous. At Harnett pyrophyllite occurs in one area.

**Hematitic, Sericitic Metasedimentary Rocks (Ehs)**

The hematitic, sericitic metasedimentary rocks occur along the base of Unit E just east of the Cosgrove Porphyry (Dcp). They are composed of crystals of quartz, ±plagioclase in a strongly foliated matrix of sericite, hematite and quartz. In places the rocks are bedded based on variations in the abundance of quartz grains.

**Quartz Arenites (Eq)**

The quartz arenites (Eq) are composed of crystals of quartz and volcanic rock fragments supported in a matrix of microcrystalline quartz with minor sericite. The volcanic rock fragments are of a very fine-grained felsic volcanic rock. The quartz crystals are subrounded to subangular, only rarely have crystal faces and only rarely have embayments. Some of the arenites have abundant magnetite and/or zircon grains and in places hematite is an important matrix component. Prism-shaped aggregates of epidote, sphene, opaques ±brown clay are a minor component of the rocks and probably represent altered mafic grains. In places the rocks have a weak foliation defined by tiny folia of sericite. The rocks occur as thickly bedded units. Individual beds are devoid of internal structures and vary in thickness from a few decimetres to several metres.
Metapelites (Em)
Metapelites occur as thin lenses and are sometimes calcareous.

Veins
Veins are generally uncommon in Unit E except along the more-foliated, western side of the unit. The veins are usually parallel to the foliation and are composed of quartz, ±chlorite, ±carbonate, ±K-feldspar. Northeast of Cosgrove Hill around G.R. 94401665 there are abundant veins of banded jasper.

7 Interpretation of Unit E
(i) The hornblende-bearing metavolcanic rocks (Ehv) are interpreted as metamorphosed lavas based on the lack of fragmental textures, the well-formed nature of the phenocrysts and the framework-supported nature of the rocks. During metamorphism some of the phenocrysts were altered, some of the matrix minerals formed, and along the western side of the unit the rocks were foliated. The hematitic zones in these rocks probably represent local zones of synvolcanic alteration which have been metamorphosed.
(ii) The framework-supported metavolcanic rocks (Ef) are interpreted as metamorphosed, epiclastic or pyroclastic mass-flow deposits. The lack of amphibole is notable and implies that either the rocks were derived from amphibole-poor volcanics or that any amphibole in the source rocks was destroyed by weathering.
(iii) The quartz arenites (Eq) represent relatively mature, volcanically derived sediment which has been deposited in a fluvial and/or shoreline environment. The sericite folia in these rocks probably represent an incipient, domainal metamorphic foliation.
(iv) First impressions of the mineralized, sericitic, siliceous metasedimentary and metavolcanic rocks (Es) and the hematitic, sericitic metasedimentary rocks (Ehs) are that the rocks represent zones of synvolcanic alteration which have been metamorphosed.

4.3.h Unit F; Metapelites with Minor Metavolcanic Rocks

1 Facies
Unit F is composed of black metapelites (Fm), interbedded with hornblende-bearing metavolcanic rocks (Fhv) and minor lenses of metabasalt (Fb), metalimestone (Fl) and chert (Fch).

2 Geometry
Unit F extends to the east of the study area. The outcrop width of Unit F is in excess of 750 m and it extends over a strike length of 15 km in the central and southern part of the study area. It occupies the core of the inferred regional syncline in this area.
3 Type Area

Accessible good exposures of Unit F occur along the farm access road east of G.R. 94950650.

4 Contacts.

Unit F appears to be conformable on Unit E.

5 Distribution of Facies.

The hornblende-bearing metavolcanic rocks (Fhv) form lenses up to about 150 m thick and a few kilometers long enclosed in thick metapelite units (Fm).

6 Description of Facies.

Metapelites (Fm)

The metapelites are finely laminated and have a well-developed slatey cleavage (S₁). Samples from the Stonehenge Prospect drill-holes are composed of crystals of quartz (and feldspar?) in a matrix of seridte, quartz and chlorite, ±carbonate with minor pyrite. Pyrite grains have pressure-beards of fibrous quartz.

Hornblende-Bearing Metavolcanic Rocks (Fhv)

The hornblende-bearing metavolcanic rocks are petrographically very similar to the hornblende-bearing metavolcanic rocks of facies Ehv and the framework-supported metavolcanic rocks of facies Ef. The rocks are massive and have little or no metamorphic foliation.

Metabasalt (Fb)

The small lenses of metabasalt are composed of tiny laths of plagioclase and sericite pseudomorphs after ?pyroxene in a matrix of epidote, sericite, chlorite, sphene and opaques. The plagioclase laths are aligned to give the rock a lineation. The rocks have abundant spherical structures filled with fibrous chlorite and ?zeolites. Some of the rocks are strongly veined by pink carbonate.

Metalimestone (Fl)

There is a small metalimestone lens in the metapelites to the east of the Harnett Prospect (G.R. 95500040). It is coarse-grained and contains abundant crinoid ossicles. It has sharp contacts with the enclosing metapelites.

Chert (Fch)

In the eastern side of the Harnett Prospect there is a small lens of chert at the base of Unit F between metavolcanics of facies Ehv and metapelites of facies Fm. The chert is graded from a
massive chert in the west to a siliceous metapelite and then grades into the overlying metapelites. There are blocks of limonitic gossan after massive sulphide along the western side of the chert.

7 Interpretation of Unit F

(i) The hornblende-bearing metavolcanic rocks (Fhv) were probably deposited as lavas and pyroclastic and/or epiclastic mass-flows similar to Facies Ehv and Ef.
(ii) The metapelites (Fm) represent metamorphosed black shales.
(iii) The metabasalts (Fb) probably represent thin, vesicular lava flows.
(iv) The metalimestone (Fl) may be an allochthonous block.
(v) The chert (Fch) is probably related to the synvolcanic hydrothermal activity which produced the alteration and mineralization in the rocks to the west. The compositional grading in the unit indicates that the area faces east.

4.3.i Other Rocks in the Bredbo-Bunyan Study Area

1 The 500 Acre Granodiorite (I5)

The 500 Acre Granodiorite, known previously as the "white gneiss" (Joplin, 1943; Browne, 1944) is defined and described by Reid (1980). It is composed of quartz, plagioclase, K-feldspar, biotite, epidote, muscovite, magnetite, apatite and zircon. The unit has a well-developed metamorphic foliation and contains numerous felsic dykes. In my only thin section of the unit the foliation in the rock is defined by lenticular polycrystalline quartz grains and broad folia of well-formed, unstrained biotite, epidote and muscovite grains. The foliation tends to wrap around large unstrained feldspars.

2 Dolerite Dyke

There is a latitudinally trending dolerite dyke to the north of the Cosgrove Hill trig. It is composed of crystals of augite, plagioclase, magnetite, pyrite and amphibole with interstitial quartz, chlorite and apatite. The rock does not have a metamorphic foliation which suggests that the rock is no older than Devonian.

3 Aplite Dykes (Ia)

Aplite dykes are common in the 500 Acre Granodiorite along its eastern margin. In the area of the Gillans and Picasso Prospects there are some aplite dykes in Unit A and B. They are parallel to the strike of the host rocks. These aplites are probably related to the Murrumbidgee Batholith.

4 Tertiary Basalt (Tb)

There is an outcrop of Tertiary basalt near the Harnett Prospect.
5 Ferruginous Gravels and Silcrete (Tg).
Partly indurated, ferruginous gravels occur around G.R. 92301620 and G.R. 93451350. These have been described by Pillans (1974). There are blocks of silcrete around G.R. 92950180. These rocks are probably related to the Tertiary Lake Bunyan described by Taylor & Walker (1986a&b).

6 Ferricrete (Tf).
At the Harnett Prospect there are a number of outcrops of ferricrete around G.R. 425E 1500N. The rocks are composed of angular, metamorphosed rock fragments (mainly metapelite) in a limonitic matrix. The rocks may represent the remanents of a cemented talus breccia, possibly of Tertiary age.

4.4 STRUCTURE OF THE BREDBO-BUNYAN STUDY AREA

4.4.a Bedding and Facing
Bedding is generally not seen in the volcanics but occurs in the metapelite, calc-silicate and framework supported metavolcanic units. Bedding generally strikes about $170^0$ and dips $\approx 20^0$ either side of vertical.

Facing evidence is rare but it shows a consistently eastward facing. At G.R. 94400890 there is a trough at the top of Unit Ds filled with quartz arenite indicating that the sequence youngs to the east. Graded bedding occurs in facies Al (92750145), in facies Bf (94609840), in facies Cm (93650185), in facies Cv (94759865) and in facies Evs in the Stonehenge Prospect drill-holes. In all cases the sequence faces east. A thin (=20 cm), graded metapelite bed near the base of facies Dkb in the Billilingra Prospect drill-hole DDH-BL 1 (184.1 m) fines to the east. The thin chert unit (Fch) at the Harnett Prospect (4.3.h) is compositionally graded and indicates an eastward facing.

4.4.b Folds
Bedding and facing are consistent with the the area being on the western limb of the inferred regional syncline however I have not mapped in detail any fold axis which might confirm this. The mapping of smaller scale folds is hampered by the lack of good marker beds in the area. Bedding in Unit A rocks is folded into an anticline in the roadcut at G.R. 92720120. In the Numaralla River area there appears to be a very large open fold, probably with a roughly vertical east-west axis. This structure may be related to the suite of megakinks recognised in southeast New South Wales by Powell (1984).

Bedding in the metapelites (Fm) is strongly folded into folds with a wavelength of from a few centimetres to about one metre. The main foliation ($S_1$) is folded into small kink bands and minor folds in places. Phyllosilicate-rich domains in metavolcanic rocks sometimes have crenulations.
4.4.c Foliations and the Lineation

The main foliation (S1) is continuous to incipiently domainal. It generally strikes to 165° with subvertical dips. The second foliation (S2) is a crenulation cleavage and is best developed in the metapelites. The kink bands define a cleavage, S₂'. On the S₁ foliation surface in the metavolcanic rocks there is a lineation which is defined by bladelike aggregates of phyllosilicates and/or quartzofeldspathic material. It dips from 40° to 80° to the northwest.

4.4.d Estimate of Elongation

Measurements of microboudinaged plagioclase phenocrysts in the metavolcanic rocks gave elongation values of up to 150%. In each case this is probably a minimum value because the thin sections were not necessarily parallel to the elongation direction and the measurement does not account for the elongation at the ends of the crystals. How these measurements relate to the overall elongation in the rocks is not clear.

4.4.e Faults

A number of minor faults were recognised in the area. They are usually at a high angle to bedding and clearly offset units. Drag folds are associated with the faults in places. The Murrumbidgee Fault along the western margin of the area is marked by a zone with no outcrop.

A problem with the structural geology of the Bredbo Block is whether there are major meridional faults developed subparallel to the S₁ foliation and bedding as suggested by Henderson (1987). A particular problem is the nature of the eastern boundary of the Bransby Shear Zone (Henderson, 1987) which lies approximately along the contact between Units D and E and between Units C and D in the Cosgrove Hill area. Henderson (1987) interprets the boundary as a series of major left lateral strike-slip faults including the Bumbalong Fault and Middle Flat Faults in the Bredbo-Bunyan area. The argument is based on the interpretation of the Bullanamang Porphyry (Unit C) and the Livingstone Porphyry (which occurs north-west of Bredbo) as two slices of an originally saucer-shaped intrusive body. This interpretation is one way of explaining the diminished thickness of the Colinton Volcanics in the Bredbo-Bunyan area.

I see no convincing evidence, or need, for a fault along the boundary of the Bransby Shear Zone in the Bredbo-Bunyan area because:

(i) in their present stratigraphic position, the rocks form a coherent depositional sequence,
(ii) although the metamorphic zoning in this area is not tightly constrained there is no evidence to suggest that the boundary is a contact between rocks of significantly different grade,
(iii) in the Cosgrove Hill area the very distinctive metavolcanic rocks of facies Ck and Dk, which appear to be parts of the same unit, occur on opposite sides of the inferred fault. This suggests that there cannot have been any significant strike-slip movement between Unit C and Unit D in this area.
(iv) the poorly foliated nature of the metavolcanic rocks to the east of the Bransby Shear Zone may be due to:
(1) the slightly lower metamorphic grade in this area,
(2) the fact that the rocks are unaltered and hence deform in a different manner to the altered rocks,
(3) most of the strain being taken up by the surrounding metapelites which are strongly foliated.

4.4.f The Style and Age of Intrusion of the Bullanamang Porphyry (Cp)

Before a depositional history can be constructed for the area it is necessary to determine what effect the intrusion of Unit C had on the sequence. If Unit C simply intruded as a sill or dyke, by pushing the country rocks aside, then the rocks on either side of Unit C should still be in their original relative position. If Unit C stoped out parts of the sequence then a smaller succession would be left. The following points bear on this issue:

(i) South of the Numeralla River there are interbedded quartz arenites, metapelites and metavolcanics at the top of Unit B, in Unit C and at the base of Unit E. This suggests that in this area Units B, C and E are in their original relative position.
(ii) In the Cosgrove Hill area, the extensive K-feldspar-rich rocks (facies Dk and Ck) apparently do not continue into Unit B. Although outcrop in Unit B in this area is very poor one interpretation is that some of the sequence may have been been lost from that area.

For the moment I will assume that:

(i) large areas of the sequence have not been lost during intrusion of Unit C,
(ii) Unit B, facies Cm and Ck and Units D, E and F are in their original relative position,
(iii) part of Unit B may have been lost from the northern part of the area.

The Bullanamang Porphyry must have been intruded after the deposition of Unit D and before the main deformational event. Alteration zones in Unit D do not extend into the porphyry so intrusion must have occurred after the alteration event. The intrusion probably considerably postdates the deposition of the whole sequence because it is unreasonable to expect that such a large body of magma could intrude to very shallow crustal levels without venting.

4.5 CONCLUSIONS AND INTERPRETATIONS

4.5.a Late Silurian Depositional History

During the Late Silurian in the Bredbo-Bunyan area deposition included the following stages:

(i) deposition of mud and silt with areas of calcareous mud in a low-energy, shallow-marine environment with local, small bioherms developed on a muddy substrate. (Unit A).
(ii) accumulation of a series of lavas and pyroclastic mass-flow deposits separated by small pyroclastic-fall deposits and epiclastic rocks (Unit B, facies Cv and Unit D).
The lack of significant marine sedimentary rocks in the lower and middle parts of the unit indicate that the environment was dominantly subaerial at this time. The metasedimentary sequences at the top of Unit B in the southern part of the area, in facies Cv west of Harnett and towards the western side of Unit B in the northern part of the study area may represent local shallow-marine and possibly fluvial and/or lacustrine environments. The metavolcanic rocks of facies Bv and Unit D appear to thin to the south which suggests that the centre of volcanism lay to the north.

(iii) deposition of a transgressive shallow-marine sequence on the ?eroded, subaerial volcanics. The sequence consisted of interbedded volcanic sandstones, volcanics and muds (Es, Em) with local areas of quartz arenites (Eq) which probably represent shoreline gravel accumulations. This sedimentation was interrupted by the deposition of pyroclastic and/or epiclastic mass-flow volcanic units (Ef) and lavas (Ehv). The volcanics thicken to the north which suggests that the centre of volcanism lay to the north.

(iv) The deposition of a low-energy marine sequence in which the ambient accumulation of muds was interrupted periodically by the deposition of felsic lavas, pyroclastic and/or epiclastic mass-flow deposits (Fhv) and small basalt lavas (Fb).

4.5.b Late Silurian Intrusive History

The Bullanamang Porphyry was intruded during the latest Silurian. The aplite dykes in the sequence may be related to either the Bullanamang Porphyry or the intrusion of the Murrumbidgee Batholith.

4.5.c Metamorphic and Deformational History

The rocks were metamorphosed during a single, long-lasting metamorphic event generally with grades up to biotite grade and local areas of amphibole grade. During this metamorphic event there were at least two deformational events:

(i) \( D_1 \) produced the major regional syncline and the main foliation, \( S_1 \).

(ii) \( D_2 \) involved weak crenulation folding in the metapelites and the phyllosilicate-rich domains in the metavolcanics. Some of the kink folds may have formed and the Murrumbidgee Fault may have been active during this time.

The age of the deformation is probably latest Silurian and Early Devonian (2.7.e.).
CHAPTER 5

MINERALIZATION IN THE BREDBO-BUNYAN STUDY AREA

5.1 INTRODUCTION

This chapter presents descriptions of the zones of mineralization in the Bredbo-Bunyan study area. The zones are described in order of their present position from Unit A to Unit F and include:

(i) in Unit A, the Gillans Prospect and other gossans,
(ii) in Unit B, the Picasso and Gamma-Delta Prospects, and other gossans,
(iii) in Unit C, the western part of the Driscoll's Hill Prospect and other gossans,
(iv) in Unit D and the base of Unit E, the Cosgrove Hill, Billilingra-Barite, Driscoll's Hill, Driscoll's Hill South, Harnett and Stonehenge Prospects, and other mineralized zones,
(v) in Unit E, small jasper zones,
(vi) in Unit F, the small chert unit east of the Harnett Prospect.

The location of most of the zones of mineralization is given on Map 4.1 and the main prospects are given on Figure 5.1. Recall that in terms of the regional stratigraphy Unit A is probably the Cappanana Formation, Units B and D are part of the Colinton Volcanics, Unit C is the Bullanamang Porphyry and Units E and F are the base of the Rothlyn Formation. In the following sections initial interpretations of the mineralization are given but a more detailed discussion is given in Chapter 8.

5.2 MINERALIZATION IN UNIT A

5.2.a Gillans Prospect

1 Introduction

Of interest at the Gillans Prospect is a zone of disseminations and veins of pyrrhotite with minor pyrite and a trace of chalcopyrite in a sequence of metapelites and calc-silicate rocks of Unit A. The prospect is located 14 km north of Cooma and 500 m west of the intersection of the road to Chakola with the Monaro Highway (Fig. 5.1).

2 Exploration History

The Gillans Ironstones were located by Amax in 1970 (Young, 1974). Esso Exploration Production Australia Inc (Esso) found that the Ironstone had anomalous copper values and a Crone PEM survey showed a large anomaly just south of the ironstones (Beams, 1984b). Two diamond-drillholes (BRYG 001 and BRYG 002) were drilled to test the PEM anomaly and a
Fig. 5.1 Simplified geology and prospect locations in the Bredbo-Bunyan study area.
mise à la masse survey was done in BRYG 002. The drill-hole data showed that the mineralization extends over a strike length of at least 1 km.

3 My work at the Gillans Prospect

My work at the Gillans Prospect included:

(i) 1:1 000 scale mapping,
(ii) a petrographic and XRD study of the mineralization and host rocks in the drill-core,
(iii) a sulphur isotope study (Ch. 7).

4 Geology

Outcrop in the zone of interest is very poor and most of the information about the prospect comes from the two diamond-drillholes. The surface geology of the prospect, south of the Gillans Ironstones, is shown on Map 5.1. Cross-sections through drill-holes BRYG 001 and BRYG 002 are given in Figure 5.2. Stratigraphic relationships and limited structural information in and around the prospect indicate that the zone of interest lies on the western limb of a small meridionally trending and northerly plunging anticline as suggested by Henderson (1987). The inferred stratigraphic sequence from oldest to youngest is:

(i) metapelites (Am) with rare calc-silicate beds (Ac),
(ii) interbedded metapelites (Am), metavolcanic rocks (Av) and calcsilicate rocks (Ac),
(iii) metavolcanic rocks (Bv).

Detailed descriptions of the host rocks are given in Section 4.3.c. The metavolcanic rocks (Bv) in the western limb of the anticline are truncated by the Murrumbidgee Fault. Esso (Beams, 1984b) considered that the whole area faced east since graded bedding in a few thin sections from the drill-core show a down-hole younging. This grading evidence is questionable because there are isoclinal microfolds in the core.

---

Fig. 5.2 (pages 97 & 98) Interpreted cross-sections through the Gillans Prospect diamond-drillholes BRYG 001 (Fig. 5.2.a) and BRYG 002 (Fig. 5.2.b).
Fig. 5.2a BRYG 001
Section line 40,600N

Fig. 5.2.b BRYG 002
5 Mineralization

The mineralization at the Gillans Prospect consists of disseminations, veins and minor <8 cm thick massive sections of pyrrhotite with minor pyrite and a trace of chalcopyrite. It is concentrated in the fine- and medium-grained metapelites (Am) in the lower part of the sequence but also occurs in the calc-silicate units (Ac). The overall sulphide content is less than 1% but narrow zones of up to a few tens of metres have up to 5% sulphide. Geochemical analyses by Esso (Beams, 1984b) of 1 and 2 m intervals of the core gave maximum values of 840 ppm Cu, 41 ppm Pb, 1802 ppm Zn, <0.2 ppm Ag and 0.04 ppm Au.

Disseminated mineralization

Disseminations of pyrrhotite and pyrite occur throughout the rocks and larger grains are commonly elongate parallel to the $S_1$ foliation. The disseminations are usually coarse grained and have a similar granoblastic texture to the host. The margins of the sulphide grains are commonly complexly intergrown with the host rock minerals. Pyrite grains have fewer inclusions of silicate minerals than the pyrrhotite grains. In rare cases pyrite grains have pressure beards of fibrous quartz. In places the host rock is less deformed in pressure-shadows, parallel to the $S_1$ foliation, around pyrite grains.

Ilmenite and rutile are widespread accessory minerals in the metapelites. In one place grains of rutile contain tiny inclusions of ilmenite and pyrrhotite suggesting that:

\[
\text{ilmenite} \rightarrow \text{rutile} + \text{pyrrhotite}
\]

Vein and stringer mineralization

The veins are composed of coarse-grained quartz, pyrrhotite, chlorite, amphibole, plagioclase, and carbonate, with minor pyrite, biotite, rutile and apatite. The veins have compositional domains including:

(i) coarse grains of quartz which have numerous inclusions of acicular amphibole and/or chlorite,
(ii) masses of rosettes of chlorite and/or amphibole with minor opaques,
(iii) coarse-grained masses of plagioclase,
(iv) massive, fine-grained pyrrhotite which has abundant small inclusions of the other domain types,
(v) intergrowths of quartz, plagioclase, amphibole, chlorite and opaques which commonly occur along the margins of the veins and have gradational contacts with the host rock.

The silicate minerals in these domains are finer grained than in the rest of the vein but are coarser grained than the host rock.

In the least-deformed of the fine-grained metapelites deformation in the veins is restricted to narrow zones. In these zones quartz is strained to form long ribbons with sutured boundaries and chlorite grains have a parallel preferred alignment.

In a few places in the fine-grained metapelites there are veins which cut across the coarse-grained veins and have sharp contacts with the host rock. They are composed of quartz,
pyrrhotite, albite, carbonate, chlorite and pyrite with minor sericite. The quartz grains contain grains of acicular amphibole and the chlorite occurs in rosettes. Pyrrhotite tends to be free of inclusions and consists of coarse columnar subgrains.

**Semi-massive sulphide bands**

There are a few bands, up to 6 cm wide, composed of almost massive pyrrhotite with minor pyrite and a trace of chalcopyrite. In one place there is a band of massive pyrite. The pyrrhotite-rich bands consist of masses of tiny grains of pyrrhotite which enclose numerous inclusions of:

(i) coarse grains of quartz with polygonal subgrains. Some of the quartz grains have a few biotite or pyrrhotite grains along the subgrain boundaries. In places they have scalloped margins which are filled with other vein minerals, particularly chlorite,

(ii) anhedral to subhedral pyrite grains which tend to have a subhedral shape and are relatively free of inclusions,

(iii) grains of the host rock which are texturally identical to the host rocks away from the sulphide bands,

(iv) large sheafs of chlorite and/or biotite. In most places chlorite forms masses of rosettes and some show incipient conversion to biotite. The biotite may be either randomly oriented or show some degree of parallel preferred alignment. In a few places biotite forms in randomly oriented masses of tiny grains with little or no chlorite.

(v) fresh and/or partly sericitised plagioclase,

(vi) large masses of chlorite and yellow ?carbonate/?FeOx

In places pyrrhotite forms large, coarse-grained, poikiloblastic grains which enclose small grains of quartz and biotite. Chalcopyrite commonly occurs as tiny grains along the boundaries between pyrrhotite subgrains. In general the grainsize of the silicates in and around the mineralization is greater than in the host rock.

6 Other information

The mineralization in the medium-grained metapelites is more intensely deformed and has more biotite than that in the fine metapelites. The sericite-rich metapelites contain a small amount of pyrite and pyrrhotite in disseminations, stringers and veins. Of the accessory phases, magnetite is a much more abundant than rutile and ilmenite in these rocks.

In a few intervals in the drill-core pyrite is the dominant sulphide in the rocks and it forms subhedral, coarse grains which, compared to the pyrrhotite grains elsewhere in the drill-core, are relatively free of inclusions. The pyrite grains have complex, interfingering contacts with the host. The grainsize of the silicates around the pyrite is coarser than elsewhere in the host.

The only mineralization in the metavolcanic rocks is a trace of disseminated pyrite.
7 Initial interpretation of the Gillans Prospect

(i) The mineralization probably pre-dates the metamorphism because:
   (1) The S₁ foliation cuts the mineralization in places,
   (2) mineralized veins which are at an angle to the S₁ foliation have been folded,
   (3) disseminated sulphides are elongate parallel to the S₁ foliation,
   (4) the mineralization in the medium-grained metapelites (which have a well-developed S₁ foliation) is more strongly deformed than that in the fine-grained metapelites,
   (5) small folds and crenulations of the S₁ foliation are more complex around the mineralization.

(ii) Where biotite forms flakes or folia across the chlorite rosettes in the mineralization it is clear that the biotite formed during the metamorphism. In mineralization where biotite forms randomly oriented aggregates and there is little or no chlorite, it is likely that the biotite has replaced earlier chlorite during the metamorphism.

(iii) Where pyrite occurs along fractures in the brecciated pyrrhotite bands it is clear that it has formed by replacement of pyrrhotite. The well-formed, relatively inclusion-free pyrite grains in the bands probably also formed by replacement. Both features are probably due to metamorphism.

(iv) The fact that pyrite tends to be the dominant sulphide in the sericite-rich metapelites and that magnetite is a more abundant accessory phase than rutile or ilmenite in these rocks may reflect original variations in the composition of the rocks and mineralization. Alternatively, if the sericitic metapelites are zones of retrograde metamorphism (4.3.c) then it may be due to this metamorphism. My present bias is to interpret the sericite-rich metapelites as alteration zones and their sericitic, pyritic nature reflects some spatial variation in the mineralization.

(v) The semi-massive sulphide bands can be interpreted as disrupted veins. There is no good evidence to suggest that the semi-massive mineralization formed in stratiform bodies. The semi-massive pyrrhotite bands have been brecciated during the metamorphism probably due to pyrrhotite deforming in a very ductile manner so that the other domains in the veins as well as fragments of the host rock have been brecciated and incorporated into the bands. During the late-stage, recrystallization event the pyrrhotite formed a polygonal aggregate of tiny grains and it formed large columnar subgrains in relatively inclusion-free parts of veins.

(vi) Quartz has deformed plastically to form deformation lamellae and deformation bands with ribbon textures. It has commonly been recrystallized to form aggregates of polygonal subgrains and metamorphic biotite has crystallized along the subgrain boundaries.

(vii) The coarse-grained plagioclase in the veins may be an original vein mineral however it may represent earlier feldspar (or zeolites?) which have been recrystallized during
metamorphism. Coarse-grained aggregates of plagioclase do not occur in the host rocks.

(viii) The disseminated style of mineralization in the medium-grained metapelites has probably formed at least in part due to disruption of veins during deformation.

(ix) The presence of scalloped margins on quartz grains in the pyrrhotite breccias is due to dissolution of silica, however it is not clear whether this occurred during the formation of the vein or during the metamorphism.

(x) Before deformation and metamorphism the mineralization consisted of disseminations and veins in shales, siltstones and calcareous shales. The veins had the following domains:

1. coarse-grained quartz, with inclusions of acicular amphibole in places,
2. massive pyrrhotite,
3. coarse-grained aggregates of plagioclase,
4. rosettes of chlorite.

The veins were associated with a coarse-grained selvege in the host rocks.

(xi) The veining was probably originally related to the hydrothermal system responsible for mineralization in higher Units. If this is the case then the sericite-pyrite zones may represent a deep footwall feeder zones to the overlying mineralization and the surrounding pyrrhotite, chlorite, plagioclase, amphibole mineralization was the result of interaction between the fluids and the sedimentary sequence. Actinolite and tremolite are reported from the hotter parts of modern geothermal systems (eg. Henley & Ellis, 1983).

(xii) The mineralization is unlikely to have formed by pyrometasomatic processes associated with intrusion of the 500 Acre Granodiorite. The present contact between Unit A and the granites is a fault which probably post-dates the intrusion of the granite.

5.2.b Other Mineralization in Unit A

1 Gossans north of the Gillans Prospect

There are numerous small gossans in the rocks of Unit A to the north of the Gillans Prospect in the area around G.R. 9250030 to 92700350. The gossans are mainly in the calc-silicate units (Ac) but some occur in adjacent units of sericitic metavolcanic rocks. Analyses of samples by Esso (Beams, 1984b) gave maximum values of 1130 ppm Cu, 87 ppm Pb, 252 ppm Zn, 2.3 ppm Ag and 0.11 ppm Au.

2 Gossans south of "Riversdale" homestead

About 1.4 km south of the "Riversdale" homestead (around G.R. 91850870 on Map 4.1) there are sericitic, siliceous, gossanous zones in a sequence of metapelites (Am) with minor metavolcanic rocks (Av) and calc-silicate rocks (Ac) of Unit A. The gossanous zones are parallel to the strike of the surrounding units.
3 Initial interpretation of the other mineralization in Unit A

The gossans to the north of the Gillans Prospect hosted by calc-silicate rocks are probably similar to the Gillans Prospect mineralization. The other gossans, hosted by sericitic metavolcanic rocks, and the gossans south of "Riversdale" appear to be similar to the mineralization at the Picasso Prospect (5.3.a).

5.3 MINERALIZATION IN UNIT B

5.3.a Picasso Prospect

1 Introduction

Of interest at the Picasso Prospect are numerous long, thin gossans in the metavolcanic rocks. The prospect is located 13.5 km north of Cooma, immediately east of the Monaro Highway and 500 m south of the intersection of the Chakola road with the Monaro Highway (Fig. 5.1).

2 Exploration History

There are some shallow (<1 m) prospecting pits on pyritic quartz veins at the Picasso prospect but I have been unable to find any information about them. Esso mapped the area and did gossan, soil and host rock geochemistry surveys and IP and Crone PEM surveys (Beams, 1984b). Four percussion-drillholes were drilled to test the main gossans and the geochemical and geophysical anomalies. The work indicated that the gossans were developed on a number of zones of disseminated to semi-massive pyrite with only minor base-metal sulphides.

3 My Work at the Picasso Prospect

My work at the Picasso Prospect included:

(i) 1: 1000 scale mapping,
(ii) a review of Esso's geochemical data,
(iii) a petrographic and XRD study of the mineralization and host rocks using surface samples and percussion-drillchips from drill-holes BRYP 101 and 104,
(iv) a sulphur isotope study (Ch. 7).

4 Surface Geology

Mineralization at the Picasso Prospect is located in metavolcanic rocks (Bv) in the lower part of Unit B and in sericitic metavolcanic rocks (As) at the top of Unit A (Map 5.1).

Metavolcanic rocks (Bv)

The general nature of the metavolcanics of Unit B has been described in Section 4.3.d. The rocks have no obvious bedding but the small metapelite units (Am) and the crystal-rich metavolcanic rocks (Bf) indicate that the rocks have a meridional strike and subvertical dips. The S1 foliation is parallel to bedding in these small units.
Thin sections of the drill-chips from percussion-drillholes BRYP 101 and 104 contain tiny grains of ?orpiment/?rutile. It is not clear whether this mineral occurs throughout the metavolcanic rocks or if it is restricted to the mineralized zones.

Gossans

Individual gossan outcrops are usually less than a metre wide and vary from less than a metre to many tens of metres long. Outcrops of gossan commonly appear to represent parts of a single gossan unit which may be hundreds of metres long. The gossans are composed of disseminations and lenticular masses of limonite in the metavolcanic host. They have a cellular texture in places and strike parallel to the main foliation in the host rocks.

Gossan analyses by Esso (Beams, 1984b) indicate that most, but not all, of the gossans are associated with copper and/or zinc and/or lead soil geochemistry anomalies. Analyses from three gossans (G1 to G3 on Map 5.1) and averages for each gossan are given in Table 5.1. Gossan G3 which is located to the east of the main area of gossans has higher lead, zinc and silver values and is associated with higher lead, zinc and copper soil-geochemistry values compared to the main gossans. Gossan G3 was tested by drill-hole BRYP 104.

Pyritic quartz veins

There are a few veins in the prospect which are composed of massive, microcrystalline quartz with minor disseminated pyrite. Most veins are <50 cm wide, a few metres long and parallel to the S1 foliation in the rocks.

5 Percussion-drillholes

**BRYP 101.** BRYP 101 was sited on an area with no outcrop, however there are gossans along strike to the north and south of the area and it drilled below a large copper soil geochemistry anomaly. The hole intersected metavolcanic rocks with some pyritic intervals (Fig. 5.3.a). There is no variation in the size or abundance or relict volcanic phenocrysts in the hole which would indicate bedding in the rocks. The distribution of minerals in the hole is given in Figure 5.3.b. There is a pyrite-rich interval from 39 to 107 m with an overall overall pyrite content of about 2%, but varying from 1% to 40% locally. The interval is associated with little or no epidote which is in contrast with the rocks from outside the interval. Within this interval there are smaller zones of interest:

(i) from 43 to 44 m there is 40% disseminated pyrite,
(ii) from 52 to 58 m the metavolcanic rocks have a matrix of sericite, quartz and kaolinite with about 1% pyrite and little or no chlorite. (Unfortunately the top of this zone is oxidised, probably due to recent weathering, and the samples appear to be contaminated with material from the collar.
(iii) from 58 to 70 m there is about 7% pyrite and the abundance of sericite decreases down the hole in this zone.
Table 5.1 Picasso Prospect gossan geochemistry.  
Data from Esso; Beams (1984b). All values in ppm.

<table>
<thead>
<tr>
<th>Gossan G1 Sample No.</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>Ag</th>
<th>Au</th>
</tr>
</thead>
<tbody>
<tr>
<td>404930</td>
<td>122</td>
<td>6</td>
<td>14</td>
<td>&lt;0.2</td>
<td>0.01</td>
</tr>
<tr>
<td>404931</td>
<td>165</td>
<td>12</td>
<td>14</td>
<td>&lt;0.2</td>
<td>0.04</td>
</tr>
<tr>
<td>404929</td>
<td>72</td>
<td>8</td>
<td>15</td>
<td>&lt;0.2</td>
<td>0.01</td>
</tr>
<tr>
<td>404926</td>
<td>11</td>
<td>14</td>
<td>20</td>
<td>&lt;0.2</td>
<td>0.04</td>
</tr>
<tr>
<td>404927</td>
<td>18</td>
<td>10</td>
<td>13</td>
<td>&lt;0.2</td>
<td>0.02</td>
</tr>
<tr>
<td>404926</td>
<td>15</td>
<td>6</td>
<td>12</td>
<td>&lt;0.2</td>
<td>0.05</td>
</tr>
<tr>
<td>404925</td>
<td>19</td>
<td>7</td>
<td>18</td>
<td>&lt;0.2</td>
<td>0.04</td>
</tr>
<tr>
<td>404924</td>
<td>31</td>
<td>18</td>
<td>16</td>
<td>&lt;0.2</td>
<td>0.23</td>
</tr>
<tr>
<td>404923</td>
<td>20</td>
<td>10</td>
<td>22</td>
<td>&lt;0.2</td>
<td>0.05</td>
</tr>
<tr>
<td>404922</td>
<td>60</td>
<td>14</td>
<td>18</td>
<td>&lt;0.2</td>
<td>0.05</td>
</tr>
<tr>
<td>404903</td>
<td>94</td>
<td>7</td>
<td>20</td>
<td>&lt;0.2</td>
<td>0.03</td>
</tr>
<tr>
<td>404904</td>
<td>100</td>
<td>3</td>
<td>17</td>
<td>&lt;0.2</td>
<td>0.03</td>
</tr>
<tr>
<td>404905</td>
<td>51</td>
<td>6</td>
<td>16</td>
<td>1.4</td>
<td>0.05</td>
</tr>
<tr>
<td>404906</td>
<td>70</td>
<td>5</td>
<td>18</td>
<td>&lt;0.2</td>
<td>0.04</td>
</tr>
<tr>
<td>404907</td>
<td>95</td>
<td>4</td>
<td>18</td>
<td>1.4</td>
<td>0.06</td>
</tr>
<tr>
<td>404908</td>
<td>33</td>
<td>5</td>
<td>16</td>
<td>1.1</td>
<td>0.07</td>
</tr>
<tr>
<td>404909</td>
<td>35</td>
<td>11</td>
<td>26</td>
<td>0.9</td>
<td>0.07</td>
</tr>
<tr>
<td>404913</td>
<td>11</td>
<td>5</td>
<td>10</td>
<td>0.9</td>
<td>0.10</td>
</tr>
<tr>
<td>404914</td>
<td>119</td>
<td>4</td>
<td>30</td>
<td>&lt;0.2</td>
<td>0.04</td>
</tr>
<tr>
<td>404915</td>
<td>10</td>
<td>10</td>
<td>12</td>
<td>0.7</td>
<td>0.05</td>
</tr>
<tr>
<td>404916</td>
<td>16</td>
<td>5</td>
<td>17</td>
<td>0.6</td>
<td>0.05</td>
</tr>
<tr>
<td>404917</td>
<td>31</td>
<td>5</td>
<td>38</td>
<td>&lt;0.2</td>
<td>0.02</td>
</tr>
<tr>
<td>404918</td>
<td>35</td>
<td>15</td>
<td>21</td>
<td>1.1</td>
<td>0.05</td>
</tr>
<tr>
<td>404919</td>
<td>41</td>
<td>11</td>
<td>19</td>
<td>1.3</td>
<td>0.12</td>
</tr>
<tr>
<td>404920</td>
<td>25</td>
<td>11</td>
<td>21</td>
<td>&lt;0.2</td>
<td>0.04</td>
</tr>
<tr>
<td>404921</td>
<td>30</td>
<td>11</td>
<td>16</td>
<td>&lt;0.2</td>
<td>0.03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gossan G2 Sample No.</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>Ag</th>
<th>Au</th>
</tr>
</thead>
<tbody>
<tr>
<td>404913</td>
<td>11</td>
<td>5</td>
<td>10</td>
<td>0.9</td>
<td>0.10</td>
</tr>
<tr>
<td>404914</td>
<td>119</td>
<td>4</td>
<td>30</td>
<td>&lt;0.2</td>
<td>0.04</td>
</tr>
<tr>
<td>404915</td>
<td>10</td>
<td>10</td>
<td>12</td>
<td>0.7</td>
<td>0.05</td>
</tr>
<tr>
<td>404916</td>
<td>16</td>
<td>5</td>
<td>17</td>
<td>0.6</td>
<td>0.05</td>
</tr>
<tr>
<td>404917</td>
<td>31</td>
<td>5</td>
<td>38</td>
<td>&lt;0.2</td>
<td>0.02</td>
</tr>
<tr>
<td>404918</td>
<td>35</td>
<td>15</td>
<td>21</td>
<td>1.1</td>
<td>0.05</td>
</tr>
<tr>
<td>404919</td>
<td>41</td>
<td>11</td>
<td>19</td>
<td>1.3</td>
<td>0.12</td>
</tr>
<tr>
<td>404920</td>
<td>25</td>
<td>11</td>
<td>21</td>
<td>&lt;0.2</td>
<td>0.04</td>
</tr>
<tr>
<td>404921</td>
<td>30</td>
<td>11</td>
<td>16</td>
<td>&lt;0.2</td>
<td>0.03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gossan G3 Sample No.</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>Ag</th>
<th>Au</th>
<th>Mo</th>
<th>Ba</th>
<th>As</th>
<th>Sb</th>
</tr>
</thead>
<tbody>
<tr>
<td>404934</td>
<td>92</td>
<td>255</td>
<td>960</td>
<td>0.7</td>
<td>0.01</td>
<td>5</td>
<td>240</td>
<td>250</td>
<td>1</td>
</tr>
<tr>
<td>404940</td>
<td>79</td>
<td>160</td>
<td>750</td>
<td>0.6</td>
<td>&lt;0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404935</td>
<td>51</td>
<td>1920</td>
<td>3290</td>
<td>1.8</td>
<td>&lt;0.1</td>
<td>13</td>
<td>170</td>
<td>70</td>
<td>3</td>
</tr>
<tr>
<td>404936</td>
<td>75</td>
<td>1750</td>
<td>2360</td>
<td>5.9</td>
<td>&lt;0.1</td>
<td>11</td>
<td>230</td>
<td>95</td>
<td>2</td>
</tr>
<tr>
<td>404941</td>
<td>138</td>
<td>945</td>
<td>3640</td>
<td>2.5</td>
<td>0.01</td>
<td>11</td>
<td>110</td>
<td>200</td>
<td>2</td>
</tr>
<tr>
<td>404937</td>
<td>52</td>
<td>1940</td>
<td>1770</td>
<td>1.4</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404938</td>
<td>35</td>
<td>2680</td>
<td>900</td>
<td>1.4</td>
<td>&lt;0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404939</td>
<td>57</td>
<td>1440</td>
<td>2790</td>
<td>0.3</td>
<td>0.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Averages</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>Ag</th>
<th>Au</th>
<th>Mo</th>
<th>Ba</th>
<th>As</th>
<th>Sb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gossan G1</td>
<td>62</td>
<td>8</td>
<td>18</td>
<td>0.3</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gossan G2</td>
<td>35</td>
<td>9</td>
<td>20</td>
<td>0.5</td>
<td>0.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gossan G3</td>
<td>76</td>
<td>1386</td>
<td>2058</td>
<td>1.8</td>
<td>0.01</td>
<td>10</td>
<td>188</td>
<td>154</td>
<td>2</td>
</tr>
</tbody>
</table>
Fig. 5.3.a Interpreted cross-section through Picasso Prospect percussion-drillhole BRYP 101.
### Fig. 5.3.b Estimated mineral distribution in Picasso Prospect percussion-drillhole BRYP 101.

Estimates based on peak heights of X-ray diffraction charts and visual inspection of drill-chips and thin sections.
(iv) from 92 to 107 m there is about 3% disseminated pyrite in a rock which is more massive and richer in quartz and plagioclase.

Analyses by Esso (Beams, 1984b) of drill-chips from the pyritic interval gave maximum values of 460 ppm Cu (1 m interval), 36 ppm Pb (10 m interval) and 44 ppm Zn (10 m interval).

**BRYP 104.** BRYP 104 was sited to test a coincident lead and zinc soil-geochemistry anomaly and an associated gossan. There is a shallow prospecting pit on a pyritic quartz vein at one end of the gossan. The hole intersected metavolcanic rocks (Fig. 5.4.a) and there is no indication that the metavolcanics are bedded. The mineral distribution in the hole is shown in Figure 5.4.b. The hole intersected two zones of interest:

(i) from 57 to 90 m there is a zone marked by abundant chlorite and disseminated pyrite with little or no plagioclase. The average pyrite content is 1%, with 5% from 74 to 78 m. Within this interval there is a zone of rocks from 65 to 68 m rich in sericite, kaolinite and carbonate with no chlorite and a trace of partly oxidised pyrite. The carbonate is a mixture of siderite with either dolomite or ankerite.

(ii) from 114 m to the bottom of the hole (145 m) the rock is rich in chlorite with 1-2% pyrite and is poor in plagioclase.

Calcite occurs throughout the hole in small veins parallel to the foliation. Analyses by Esso (Beams, 1984b) of the main pyritic zone gave best values of 21 ppm Cu (10 m interval), 12 ppm Pb (10 m interval) and 52 ppm Zn (5 m interval).

6 Mineralization

The drill-chips from the sericite- and kaolinite-rich zones were too fine-grained to make thin sections. The chloritic, pyrite-rich zones are composed of relict phenocrysts of quartz and plagioclase (now albite) in a matrix of quartz, plagioclase, chlorite, opaques, apatite, sericite and rutile/orpiment with sporadic carbonate and epidote. The drill-chips usually have a banded appearance with lenticular chlorite-rich microlithons alternating with, and enveloped by, quartz-rich microlithons. Some chips also have bands of very coarse-grained quartz, chlorite and pyrite. In places hematite forms rims on magnetite and pyrite grains and very thin films on foliation surfaces.

The rocks have a well-developed foliation (S₁) (Plate 1) which is usually parallel to, but may cut across, the banding. Fibrous microstructures are developed in microboudinage sites in relict phenocrysts, in dilational sites across the foliation and in pressure beards. These microstructures indicate significant extension parallel to the foliation and measurements on microboudinaged plagioclase phenocrysts indicate elongation of up to 150%. Some chips appear to have a second foliation. In these chips there are domains with a continuous foliation which is at an angle to the main foliation and some pressure beards around relict phenocrysts and pyrite grains are parallel to this second foliation. In other parts of the same chips the main foliation is gently folded and the pressure beards are curved.
Fig. 5.4.a Interpreted cross-section through Picasso Prospect percussion-drillhole BRYP 104.
Fig. 5.4.b Estimated mineral distribution in Picasso Prospect percussion-drillhole BRYP 104. Estimates based on peak heights of X-ray diffraction charts and visual inspection of drill-chips and thin sections.
Plate 1  The $S_1$ foliation in the metavolcanic rocks (Bv) at the Picasso Prospect.

Plate 2  Chlorite-rich microlithon in the metavolcanic rock (Bv) from the Picasso Prospect.
Chlorite-rich microlithons. The chlorite-rich microlithons (Plate 2) are composed of masses of radiating aggregates of chlorite with minor fine-grained magnetite, sericite, rutile/orpiment and rare pyrite. The chlorite has a poorly to well-developed preferred orientation parallel to the \( S_1 \) foliation. Sericite occurs as tiny flakes which are aligned and form thin bands in places. Elsewhere some of the sericite grains are at angles to the foliation and have undulose extinction. The chlorite grains have complex extinction patterns suggesting that they are strained. Relict phenocrysts of quartz and plagioclase in the bands are subhedral and only rarely show scalloped, corroded margins with the chlorite. Rutile/orpiment in the domains occurs as aggregates of very small grains.

Quartz-rich microlithons. The quartz-rich microlithons (Plate 3) are composed of relict phenocrysts of quartz and plagioclase in a matrix of quartz and plagioclase with minor chlorite, a trace of magnetite and rutile/orpiment and variable amounts of carbonate and pyrite. They have a very well developed granoblastic texture with a foliation \( (S_1) \).

Very coarse-grained microlithons. The very coarse-grained microlithons (Plate 4) are composed of quartz, chlorite and pyrite. Chlorite occurs as radiating aggregates of grains and as coarse tabular grains. The chlorite grains are commonly elongate perpendicular to \( (001) \). Quartz has undulose and columnar extinction, and areas of unstrained subgrains. Pyrite occurs as subhedral grains up to 2 mm across and as interstitial masses of tiny anhedral grains. Commonly pyrite grains contain inclusions of matrix minerals, are fractured and have pressure beards of fibrous quartz. Chalcopyrite and galena occur as tiny grains in pyrite and as discrete grains with an interstitial texture in the silicate gangue. The microlithons commonly have a few small grains of green biotite which forms discrete, well-formed grains which are not intergrown with chlorite. Chlorite and biotite grains have wavy extinction and kink bands. These microlithons are unfoliated.

Initial interpretation of the Picasso Prospect

(i) Although the rocks have a strong, commonly dominal, metamorphic fabric the textures in the thicker bands predate the metamorphism. The chlorite-rich microlithons represent original domains in the rock such as xenoliths, lithic fragments, vitriclasts or zones of synvolcanic alteration. The quartz-rich microlithons represent the original matrix of the volcanic rocks.

(ii) The coarse-grained microlithons probably represent parts of disrupted veins. The veins predate the last strain event since they are strained. The presence of biotite suggests that they are of metamorphic origin.

(iii) The textures which suggest that there may be a second foliation in the rocks are not consistent enough to be certain that there is a second foliation. The textures may have a number of origins including:

1. folding of the \( S_1 \) foliation,
2. rotation of the phenocrysts during the main deformational event,
3. the presence of a premetamorphic fabric in the rocks,
Plate 3  A quartz-rich microlithon in the metavolcanic rock (Bv) at the Picasso Prospect.

Plate 4  A very coarse-grained microlithon in the metavolcanic rock (Bv) at the Picasso Prospect.
(4) the presence of an earlier metamorphic foliation.

(iv) The Picasso rocks record the same metamorphic history as Unit B rocks (4.3.d) with the exception that:

1. the coarse phyllosilicate grains have not recrystallized to form strain-free grains after the deformation,
2. calcite has filled extensional sites in the rocks such as pressure shadows around phenocrysts.

(v) Pyrite appears to have grown from fine aggregates of grains into porphyroblasts (with inclusions of matrix minerals) during metamorphism.

(vi) The mineralization is of epigenetic style. The only age constraint is that it must predate the end of the main deformational event (D1).

(vii) There are no obvious features in the metavolcanic rocks which might explain why the mineralized zones occur where they do. The zones presumably formed in particularly permeable horizons in the volcanics.

(viii) The narrow zones in the drill-holes which are rich in kaolinite and sericite, ±siderite, and marked by lower plagioclase and chlorite content, are probably equivalent to the sericitic metavolcanic rocks (As) on the surface. These zones may represent:

1. zones of recent, deep weathering,
2. zones of intense retrograde metamorphism, similar to zones described by Granath (1976) in the Ordovician metasedimentary rocks of the Cotter Block near Cooma,
3. zones of synvolcanic alteration which have been metamorphosed.

Both intervals in the drill-holes are partly weathered but the presence of fresh pyrite in the chips suggests that at least some of the minerals predate weathering. In the surrounding metavolcanic rocks (Bv) at least part of the sericite was produced during the metamorphism (4.3.d) and it is possible that the sericitic zones are metamorphic. Given the associated mineralization in the area, however, it is likely that the zones represent footwall zones of synvolcanic alteration which have been metamorphosed. The zones have mineral assemblages characteristic of intermediate argillic alteration (Meyer & Hemley, 1967; Rose & Burt, 1979).

(ix) The pyritic, chloritic zones in the rocks probably represent zones of synvolcanic hydrothermal alteration which have been metamorphosed. An important feature of the zones in BRYP 104 is their low plagioclase content which implies plagioclase destruction. These zones occur around the kaolinite, sericite, ±siderite zones in the drill-holes but are much wider on the eastern side of the zones.

(x) The pyritic quartz veins do not appear to be of metamorphic origin since they lack other metamorphic minerals. Instead it is possible that they may represent local zones of intense silicification within the other alteration zones.

(xi) The rocks around the mineralized zones have a number of features which may be interpreted as metamorphosed alteration textures (4.3.d):
Ch. 5 BREDBO-BUNYAN MINERALIZATION

(1) rocks with plagioclase altering to sericite or epidote,
(2) grains of coarse sericite in the matrix, presumably after plagioclase,
(3) lenticles of biotite and/or chlorite with minor epidote, sphene, magnetite and
tourmaline may represent altered vitriclasts or remnants of alteration veins,
(4) rocks with abundant carbonate in the matrix,
(5) the relics of mafic minerals composed of sphene, ±epidote, ±chlorite, ±biotite,
±opales.

These features occur throughout Unit B and if they do represent metamorphosed
alteration features then they would suggest a very widespread ?propylitic style of
alteration.

(xii) Overall, the inferred zones of metamorphosed synvolcanic alteration consist of:
(1) a central zone of kaolinite, sericite, ±siderite with some pyrite and partial
destruction of plagioclase,
(2) a surrounding zone of chlorite and pyrite with variable plagioclase destruction,
(3) surrounding metavolcanic rocks possibly with weak propylitic alteration.

5.3.b Gamma-Delta Prospect

1 Introduction

The Gamma-Delta Prospect is located 11.5 km north-northeast of Cooma and occurs along
a low ridge to the east of the Monaro Highway (Fig. 5.1). Of interest are a discontinuous series of
gossans which occur along a narrow stratigraphic zone in the metavolcanic rocks (Bv) for a
distance of about 1.5 km.

2 Previous Work

The Gamma-Delta Prospect includes the Gamma, Delta East and Delta West prospects
discovered during reconnaissance prospecting by Amax Exploration (Australia) Inc. in 1970.
Amax in joint venture with Alpex Ltd did mapping, soil and gossan geochemistry, IP, VEM, and
drilled three percussion holes (Bates & Shepherd, 1971; Young, 1974). There are two shallow pits
on the gossans and these were probably dug by Amax. Esso did mapping, Crone PEM, gossan,
soil geochemistry and drilled three percussion-drillholes (Beams, 1984b).

3 My Work at the Gamma-Delta Prospect

My work at the Gamma-Delta Prospect included:
(i) additional mapping,
(ii) logging drill-chips from Esso's percussion-drillhole BRYA 103,
(iii) limited petrography.
4 Geology

The geology of the Gamma-Delta Prospect is shown on Map 5.2. The gossans occur in an area of mainly metavolcanic rocks (Bv) with minor, thin lenses of metapelites (Bm). To the west there are metapelites, metavolcanics and calc-silicate rocks of Unit A. The gossans occur in the brown-biotite metamorphic zone.

The metavolcanic rocks (Bv) are described in detail in Section 4.3.d. The rocks are composed of relict volcanic phenocrysts (quartz, plagioclase and mafic relics) and phyllosilicate-rich lenticles supported in a matrix of quartz, feldspar, ±biotite, sercite, ±chlorite, epidote, ±carbonate, ±sphene, and magnetite with ubiquitous accessory zircon and apatite. Plagioclase shows various stages of alteration to sercite, ±epidote, ±chlorite. Relicts of mafic phenocrysts are composed of sphene, ±chlorite, ±biotite, ±sercite, ±opales. The phyllosilicate-rich lenticles are of two types. The first type is composed of granoblastic biotite and/or chlorite with minor amounts of epidote, sercite, sphene, magnetite and tourmaline. The second type is composed of well-foliated, fine-grained sercite. The rocks have a well-developed continuous, metamorphic foliation.

In the drill-chips plagioclase grains are commonly partly replaced by epidote. Hematite occurs in the matrix in places. There are also abundant veins of quartz, ±epidote, ±pyrite.

5 Mineralization

Individual gossans are <1 m wide and vary up to 400 m long. The gossans occur in the metavolcanic rocks along a narrow stratigraphic interval (<<150 m). Correlation between the drill-holes and the surface units suggests that the mineralization is confined to narrow zones in the volcanics which are parallel to the strike and dip of the host units. The gossans are composed of limonitic material which forms thin (<2 mm) bands and disseminations which replace the matrix of the host metavolcanic rock.

Mineralization in Esso's drill-holes BRYA 101 and 102 consists of thin zones (<7 m) in the metavolcanic rocks with up to about 5% pyrite which occurs as disseminations and thin bands parallel to the foliation and in quartz veins (Beams, 1984b). Analyses of 5- and 10-m intervals gave maximum values of 71 ppm Cu, 18 ppm Pb and 122 ppm Zn.

In Esso's drill-hole BRYA 103 (Fig. 5.5) mineralization occurs in zones up to 5 m wide with <10% pyrite as disseminations, as thin (<1 mm) bands parallel to the foliation in the host and in quartz, ±epidote veins. The matrix of the host is more sericitic in these zones and one zone is very siliceous. Analyses by Esso (Beams, 1984b) of 5- and 10-m intervals gave maximum values of 107 ppm Cu, 39 ppm Pb and 380 ppm Zn.

6 Gossan Geochemistry

Analyses of samples from six of the gossans (G1 to G6 on Map 5.2) and averages for each gossan are given in Table 5.2. Gossan G4 has consistently higher copper, lead and zinc values which is consistent with the drill-hole analyses from BRYA 103. Samples 404991 to 404996 from
UNIT B METAVOLCANIC ROCKS

LATE SILURIAN

<table>
<thead>
<tr>
<th>Bv</th>
<th>Metavolcanic rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bs</td>
<td>Sericitic, pyritic metavolcanic rock</td>
</tr>
</tbody>
</table>

- Geological boundary, position accurate
- " " , inferred
- Outcrop inspected

Fig. 5.5 Interpreted cross-section through Gamma-Delta prospect percussion-drillhole BRYA 103.
Table 5.2 Gamma-Delta Prospect gossan geochemistry.
Data from Esso, Beams (1984b). Values are in ppm.

<table>
<thead>
<tr>
<th>Gossan G1</th>
<th>Sample No.</th>
<th>Cu</th>
<th>Fe</th>
<th>Zn</th>
<th>Ag</th>
<th>Au</th>
<th>Mo</th>
<th>Ba</th>
<th>As</th>
<th>Sb</th>
</tr>
</thead>
<tbody>
<tr>
<td>404866</td>
<td>121</td>
<td>112</td>
<td>250</td>
<td>&lt;0.2</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404867</td>
<td>70</td>
<td>116</td>
<td>42</td>
<td>0.9</td>
<td>0.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404868</td>
<td>42</td>
<td>155</td>
<td>83</td>
<td>0.2</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404869</td>
<td>48</td>
<td>64</td>
<td>66</td>
<td>1.3</td>
<td>1.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404870</td>
<td>74</td>
<td>280</td>
<td>630</td>
<td>&lt;0.2</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404871</td>
<td>32</td>
<td>485</td>
<td>400</td>
<td>&lt;0.2</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gossan G2</th>
<th>Sample No.</th>
<th>Cu</th>
<th>Fe</th>
<th>Zn</th>
<th>Ag</th>
<th>Au</th>
<th>Mo</th>
<th>Ba</th>
<th>As</th>
<th>Sb</th>
</tr>
</thead>
<tbody>
<tr>
<td>404953</td>
<td>79</td>
<td>715</td>
<td>750</td>
<td>1.0</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404954</td>
<td>69</td>
<td>380</td>
<td>169</td>
<td>1.0</td>
<td>&lt;0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404955</td>
<td>82</td>
<td>415</td>
<td>290</td>
<td>0.9</td>
<td>0.01</td>
<td>13</td>
<td>110</td>
<td>90</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>404956</td>
<td>23</td>
<td>255</td>
<td>22</td>
<td>1.2</td>
<td>&lt;0.01</td>
<td>3</td>
<td>30</td>
<td>20</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>404957</td>
<td>29</td>
<td>185</td>
<td>17</td>
<td>0.9</td>
<td>&lt;0.01</td>
<td>8</td>
<td>75</td>
<td>22</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>404958</td>
<td>28</td>
<td>128</td>
<td>32</td>
<td>2.0</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404959</td>
<td>41</td>
<td>110</td>
<td>10</td>
<td>1.2</td>
<td>&lt;0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gossan G3</th>
<th>Sample No.</th>
<th>Cu</th>
<th>Fe</th>
<th>Zn</th>
<th>Ag</th>
<th>Au</th>
<th>Mo</th>
<th>Ba</th>
<th>As</th>
<th>Sb</th>
</tr>
</thead>
<tbody>
<tr>
<td>404960</td>
<td>22</td>
<td>141</td>
<td>11</td>
<td>&lt;0.2</td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404961</td>
<td>39</td>
<td>305</td>
<td>23</td>
<td>0.8</td>
<td>0.06</td>
<td>8</td>
<td>200</td>
<td>130</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>404962</td>
<td>37</td>
<td>220</td>
<td>117</td>
<td>0.6</td>
<td>0.05</td>
<td>7</td>
<td>140</td>
<td>650</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>404963</td>
<td>132</td>
<td>310</td>
<td>101</td>
<td>&lt;0.2</td>
<td>0.02</td>
<td>1</td>
<td>90</td>
<td>200</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>404964</td>
<td>43</td>
<td>137</td>
<td>48</td>
<td>&lt;0.2</td>
<td>0.01</td>
<td>1</td>
<td>190</td>
<td>160</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>404965</td>
<td>16</td>
<td>113</td>
<td>22</td>
<td>0.3</td>
<td>&lt;0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gossan G4</th>
<th>Sample No.</th>
<th>Cu</th>
<th>Fe</th>
<th>Zn</th>
<th>Ag</th>
<th>Au</th>
<th>Mo</th>
<th>Ba</th>
<th>As</th>
<th>Sb</th>
</tr>
</thead>
<tbody>
<tr>
<td>404966</td>
<td>245</td>
<td>390</td>
<td>442</td>
<td>0.3</td>
<td>0.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404967</td>
<td>225</td>
<td>3540</td>
<td>1110</td>
<td>1.9</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404968</td>
<td>260</td>
<td>1730</td>
<td>117</td>
<td>0.3</td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404969</td>
<td>225</td>
<td>380</td>
<td>9</td>
<td>&lt;0.2</td>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404970</td>
<td>250</td>
<td>380</td>
<td>118</td>
<td>0.7</td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404971</td>
<td>260</td>
<td>845</td>
<td>1580</td>
<td>0.5</td>
<td>&lt;0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404972</td>
<td>190</td>
<td>470</td>
<td>420</td>
<td>0.2</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404973</td>
<td>225</td>
<td>485</td>
<td>650</td>
<td>&lt;0.2</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404974</td>
<td>220</td>
<td>460</td>
<td>480</td>
<td>0.4</td>
<td>&lt;0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404975</td>
<td>225</td>
<td>595</td>
<td>600</td>
<td>&lt;0.2</td>
<td>0.02</td>
<td>17</td>
<td>320</td>
<td>550</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>404976</td>
<td>119</td>
<td>180</td>
<td>560</td>
<td>&lt;0.2</td>
<td>0.01</td>
<td>3</td>
<td>360</td>
<td>15</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gossan G5</th>
<th>Sample No.</th>
<th>Cu</th>
<th>Fe</th>
<th>Zn</th>
<th>Ag</th>
<th>Au</th>
<th>Mo</th>
<th>Ba</th>
<th>As</th>
<th>Sb</th>
</tr>
</thead>
<tbody>
<tr>
<td>404977</td>
<td>215</td>
<td>31</td>
<td>6</td>
<td>0.2</td>
<td>&lt;0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404978</td>
<td>88</td>
<td>170</td>
<td>15</td>
<td>&lt;0.2</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404979</td>
<td>65</td>
<td>160</td>
<td>15</td>
<td>&lt;0.2</td>
<td>0.01</td>
<td>6</td>
<td>410</td>
<td>25</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>404980</td>
<td>285</td>
<td>99</td>
<td>360</td>
<td>&lt;0.2</td>
<td>0.02</td>
<td>4</td>
<td>260</td>
<td>400</td>
<td>35.0</td>
<td></td>
</tr>
<tr>
<td>404981</td>
<td>132</td>
<td>92</td>
<td>270</td>
<td>&lt;0.2</td>
<td>&lt;0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404982</td>
<td>97</td>
<td>106</td>
<td>590</td>
<td>&lt;0.2</td>
<td>0.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404983</td>
<td>117</td>
<td>155</td>
<td>640</td>
<td>0.2</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404984</td>
<td>41</td>
<td>245</td>
<td>350</td>
<td>&lt;0.2</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404985</td>
<td>42</td>
<td>775</td>
<td>280</td>
<td>0.7</td>
<td>0.07</td>
<td>17</td>
<td>1400</td>
<td>250</td>
<td>35.0</td>
<td></td>
</tr>
<tr>
<td>404986</td>
<td>58</td>
<td>230</td>
<td>320</td>
<td>0.2</td>
<td>0.05</td>
<td>13</td>
<td>720</td>
<td>350</td>
<td>25.0</td>
<td></td>
</tr>
<tr>
<td>404987</td>
<td>66</td>
<td>165</td>
<td>260</td>
<td>3.7</td>
<td>0.03</td>
<td>4</td>
<td>120</td>
<td>80</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>404988</td>
<td>70</td>
<td>190</td>
<td>128</td>
<td>0.4</td>
<td>0.15</td>
<td>7</td>
<td>450</td>
<td>300</td>
<td>35.0</td>
<td></td>
</tr>
<tr>
<td>404989</td>
<td>115</td>
<td>450</td>
<td>640</td>
<td>0.3</td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404990</td>
<td>139</td>
<td>195</td>
<td>530</td>
<td>0.5</td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404991</td>
<td>57</td>
<td>1800</td>
<td>1480</td>
<td>7.2</td>
<td>0.06</td>
<td>30</td>
<td>80</td>
<td>35</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>404992</td>
<td>113</td>
<td>2000</td>
<td>630</td>
<td>62.0</td>
<td>0.06</td>
<td>24</td>
<td>1200</td>
<td>1140</td>
<td>125.0</td>
<td></td>
</tr>
<tr>
<td>404993</td>
<td>215</td>
<td>57000</td>
<td>820</td>
<td>205.0</td>
<td>0.06</td>
<td>47</td>
<td>410</td>
<td>1230</td>
<td>60.0</td>
<td></td>
</tr>
</tbody>
</table>
Table 5.2  Gamma-Delta Prospect gossan geochemistry. Continued.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>Ag</th>
<th>Au</th>
<th>Mo</th>
<th>Ba</th>
<th>As</th>
<th>Sb</th>
</tr>
</thead>
<tbody>
<tr>
<td>404994</td>
<td>38</td>
<td>390</td>
<td>590</td>
<td>1.2</td>
<td>&lt;0.01</td>
<td>6</td>
<td>270</td>
<td>55</td>
<td>3.5</td>
</tr>
<tr>
<td>404995</td>
<td>119</td>
<td>3340</td>
<td>760</td>
<td>16.0</td>
<td>0.03</td>
<td>12</td>
<td>390</td>
<td>90</td>
<td>4.0</td>
</tr>
<tr>
<td>404996</td>
<td>23</td>
<td>2280</td>
<td>128</td>
<td>2.4</td>
<td>0.01</td>
<td>15</td>
<td>540</td>
<td>1260</td>
<td>35.0</td>
</tr>
<tr>
<td>404997</td>
<td>60</td>
<td>475</td>
<td>240</td>
<td>0.2</td>
<td>0.02</td>
<td>15</td>
<td>400</td>
<td>250</td>
<td>30.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>Ag</th>
<th>Au</th>
<th>Mo</th>
<th>Ba</th>
<th>As</th>
<th>Sb</th>
</tr>
</thead>
<tbody>
<tr>
<td>404062</td>
<td>14</td>
<td>10</td>
<td>4</td>
<td>&lt;0.2</td>
<td>0.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404063</td>
<td>6</td>
<td>20</td>
<td>2</td>
<td>&lt;0.2</td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Gossan G5 Continued.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>Ag</th>
<th>Au</th>
<th>Mo</th>
<th>Ba</th>
<th>As</th>
<th>Sb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gossan G1</td>
<td>44</td>
<td>183</td>
<td>204</td>
<td>0.4</td>
<td>&lt;0.01</td>
<td>8</td>
<td>72</td>
<td>44</td>
<td>1.5</td>
</tr>
<tr>
<td>Gossan G2</td>
<td>50</td>
<td>313</td>
<td>402</td>
<td>1.2</td>
<td>&lt;0.01</td>
<td>8</td>
<td>72</td>
<td>44</td>
<td>1.5</td>
</tr>
<tr>
<td>Gossan G3</td>
<td>48</td>
<td>204</td>
<td>39</td>
<td>0.3</td>
<td>0.03</td>
<td>4</td>
<td>155</td>
<td>285</td>
<td>1.3</td>
</tr>
<tr>
<td>Gossan G4</td>
<td>222</td>
<td>860</td>
<td>553</td>
<td>0.4</td>
<td>0.02</td>
<td>10</td>
<td>340</td>
<td>283</td>
<td>2.5</td>
</tr>
<tr>
<td>Gossan G5</td>
<td>103</td>
<td>4978</td>
<td>430</td>
<td>17.4</td>
<td>0.03</td>
<td>10</td>
<td>317</td>
<td>260</td>
<td>18.9</td>
</tr>
<tr>
<td>Gossan G6</td>
<td>10</td>
<td>15</td>
<td>3</td>
<td>&lt;0.2</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Gossan G5, taken from around the small prospecting pit, have very high lead, silver, arsenic and antimony values.

7 Initial Interpretation of the Gamma-Delta Prospect

The mineralization appears to be similar to the mineralization at the Picasso Prospect. It is of epigenetic style, with sericitic, pyritic, ±siliceous zones developed along ?permeable horizons in the volcanics.

5.3.c Other Mineralization in Unit B

1 Harnett West Gossans

The Harnett West Gossans were found by Tenneco in 1972 (Young, 1974). They are located west of the intersection of the Chakola road with the Monaro Highway (G.R. 9,940E 40,300N on Map 5.1 and G.R. 92850210 on Map 4.1). The gossans consist of massive and cellular limonite in bands parallel to the foliation in metavolcanic rocks (Bv). The gossans strike parallel to the S1 foliation and the strike of a nearby metapelites in Unit A. Analyses of three samples by Esso (Beams, 1984b) gave maximum values of 70 ppm Cu, 5 ppm Pb, 7 ppm Zn, <1 ppm Ag and 0.01 ppm Au.

2 Gossans South-Southeast of the Picasso Prospect

There is a small area of gossanous, medium-grained metavolcanic rocks south-southeast of the Picasso Prospect (G.R. 94180000 on Map 4.1). The rocks are located in a thin band of facies Bv metavolcanics with metapelites (Bm) to the west and coarse-grained metaporphyry (Cp) to the east. The gossans are composed of relict phenocrysts of quartz supported in a matrix of quartz, limonite (after pyrite) and fine clays (?sericite). Six samples of the rocks analysed by Esso
(Beams, 1984b) gave maximum values of 16 ppm Cu, 210 ppm Pb, 12 ppm Zn, 1.2 ppm Ag and 0.01 ppm Au.

3 Jasper Bands East of the Gamma-Delta Prospect

To the east of the Gamma-Delta Prospect around G.R. 94949626 (Map 4.1) the medium-grained metavolcanic rocks (Bv) have abundant thin (<10 cm) bands of jasper parallel to the S₁ foliation.

4 The Riversdale Gossans

The Riversdale Gossans (Beams, 1984a) are located 250 m northwest of "Riversdale" homestead around G.R. 91801040 (Map 4.1). They occur in a narrow strip of sericitic, siliceous, gossanous metavolcanic rocks (Bs) between the Murrumbidgee Batholith to the west and the extensive alluvium and Tertiary sediments along the Murrumbidgee River to the east. The sericitic rocks are composed of relict volcanic phenocrysts of quartz, ±plagioclase and grains of limonite after pyrite supported in a matrix of quartz and sericite with accessory zircon and apatite. The rocks have a strong S₁ foliation with the sericite concentrated in broad folia which wrap around more siliceous microlithons. The rocks are crenulated and have an incipient crenulation cleavage (S₂).

The main gossans occur in an area <2m wide and about 150 m long parallel to the foliation. They appear to be developed on seritic and siliceous metavolcanic rocks with a high disseminated pyrite content. Analyses of four samples by Esso gave best individual values of 28 ppm Cu, 39 ppm Pb, 13 ppm Zn, <0.2 ppm Ag and 0.28 ppm Au.

5 Gossans North of "Riversdale" homestead

About 2.3 km north of the "Riversdale" homestead, around G.R. 91651250 (Map 4.1), there are outcrops of gossanous, siliceous, sericitic metavolcanic rocks.

6 Mount Oak Area

Across the Murrumbidgee River from the Mt Oak Community there are gossans and gossanous, sericitic, siliceous rocks in a sequence of metavolcanics, metapelites, hematitic metapelites and meta-arkoses of Unit B. The gossanous rocks appear to form a zone <50 m wide which extends for a distance of at least 1.5 km from G.R. 91651660 to 91901530 (Map 4.1), parallel to the strike of the host rocks. The zone has a central pyritic, cherty ?metavolcanic rock which is surrounded by gossanous, sericitic metavolcanic rocks. The gossanous zone is parallel to the strike of the enclosing rocks.

7 Initial Interpretation of the Other Mineralization in Unit B

(i) The veins of banded jasper in facies Bv south-southeast of the Gamma-Delta Prospect probably represent metamorphic veins since they are parallel to the foliation in the host. They suggest that the metamorphic fluid and the surrounding rocks were very oxidised.
Ch. 5 BREDBO-BUNYAN MINERALIZATION 121

(ii) The other gossanous zones in Unit B appear to be similar to the mineralization and alteration at the Picasso Prospect. The Harnett West Gossans are probably the northern extension of the Picasso mineralization. The mineralized zones have a stratabound, epigenetic style. The zones probably represent originally highly permeable beds in the rocks which allowed considerable fluid flow.

(iii) An alternative interpretation for the gossans south-southeast of the Picasso Prospect is that they may have formed due to pyrometasomatic processes during intrusion of the porphyry (Cp).

5.4 MINERALIZATION IN UNIT C

5.4.a The Western Part of the Driscoll's Hill Prospect

1 Description

The main part of the Driscoll's Hill Prospect is described below in Section 5.5.c. In the western part of the prospect there are numerous small gossanous zones in the medium-grained metavolcanic rocks (Cv), the coarse-grained metaporphyry (Cp) and in the metavolcanics (Bv).

The coarse-grained metaporphyry (Cp) have been described in Section 4.3.e and in this area it is strongly foliated and has abundant sericite and chlorite in the matrix. The medium-grained metavolcanic rocks (Cv) are composed of relict phenocrysts of quartz and plagioclase supported in a matrix of sericite, chlorite and rare epidote. Thin gossanous zones occur in all facies and appear to be zones in which the matrix of the rocks is very siliceous and sericitic with abundant disseminated pyrite. The rocks have veins of quartz, chlorite and pink K-feldspar.

Esso's percussion-drillhole BRAD 103 (Fig. 5.6) was drilled to test an area of gossans (Beams, 1984a) and intersected medium-grained metavolcanics (Cv). Most rocks have a dark-green colour with a chloritic, sericitic matrix and throughout the hole the matrix of the rocks has thin chloritic folia with a abundant disseminated pyrite. Some of these folia also have small grains of yellow ?orpiment. The hole intersected a 25 m zone (67-92 m) with abundant sericite, quartz and pyrite. The overall pyrite content for the zone is about 15% with a maximum of 40% pyrite in one 3 m interval. Chips from the sericitic zone are composed of:

(i) sericitic metavolcanics with abundant disseminated pyrite in the matrix,
(ii) veins(?) of coarse-grained milky quartz and pyrite with a trace of chalcopyrite, galena and ?sphalerite,
(iii) semi-massive pyrite with a trace of chalcopyrite in a microcrystalline, siliceous matrix.

Correlation with the surface suggests that the mineralized zone dips about 80°E whereas the foliation dips steeply to the west. Analyses by Esso (Beams, 1984a) of the drill-chips gave very low values with much less than 100 ppm Cu, Pb and Zn, however a 1 m interval had 6300 ppm Cu.
Fig. 5.6 Interpreted cross-section through Driscoll’s Hill Prospect percussion-drillhole BRAD 103.
2 Initial Interpretation of the Western Part of the Driscoll's Hill Prospect
   (i) The mineralization occurs in a block of volcanic rocks which have been enveloped by the coarse-grained metaporphry (Cp).
   (ii) The mineralization appears to be of epigenetic style and is probably related to mineralization in Units B and D.
   (iii) The inferred alteration zoning consists of a central sericitic zone surrounded by a broad propylitic zone.

5.4.b Other Mineralization in the Medium-Grained Metavolcanic Rocks (Cv) and the Metasedimentary Rocks (Cm)

1 West of Cosgrove Hill
   West of Cosgrove Hill around G.R. 92451555, between the former highway and the present Monaro Highway, there are a few outcrops of massive gossan interbanded with sericitic, medium-grained metavolcanic rocks (Cv). The rocks are enclosed in coarse-grained metaporphry (Cp).

2 The Cattle Yards Area
   Between the Picasso and Harnett Prospects around G.R. 93650190, southeast of some cattle yards, there are mineralized rocks in an area of metasedimentary rocks (Cm) and medium-grained metavolcanic rocks (Cv). The metasedimentary rocks include metapelites, meta-arkoses and metalimestone. Some of the rocks contain abundant hematite and there are float blocks of banded jasper. The northern end of the small limestone body is very hematitic. At the northern end of the area there are blocks of massive quartz with <5% disseminated pyrite which form in a ?vein which appears to cut across the strike of the other units.

3 Initial Interpretation of the Other Mineralization in the Medium-Grained Metavolcanic (Cv) and Metasedimentary Rocks (Cm)
   (i) The main problem in interpreting this mineralization is deciding the role (if any) of the porphyry (Cp). The mineralization may have formed either prior to the intrusion of the porphyry (as synvolcanic epigenetic deposits?) or during intrusion of the porphyry due to pyrometasomatic processes.
   (ii) At the Cattle Yards area the siliceous, pyritic rocks may represent the central, most-altered zone of a hydrothermal feeder (to the Harnett mineralization?) and the surrounding hematitic alteration may be due to interaction of the fluids with the surrounding rocks.
5.4.c Mineralization in the Coarse-Grained Metaporphry (Cp)

1 Hematitic Quartz Band

Around G.R. 95209665 (Map 4.1) there is a ≈400 m long band of hematitic quartz. It is parallel to the strike of the surrounding rocks. Maximum values from three analyses by Esso (Beams, 1984b) are 36 ppm Cu, 10 ppm Pb, 23 ppm Zn, <1 ppm Ag and 0.03 ppm Au.

2 Driscoll's Hill South Prospect

There are gossanous zones in facies Cp around G.R. 94300485 in an area called the Driscoll’s Hill South Prospect by Esso (Beams, 1984a). The gossans appear to be after disseminated pyrite.

3 Sheep Shelter Shed Area

Around G.R. 93300985, near a sheep shelter shed, facies Cp contains numerous thin (<5 cm) veins of jasper parallel to the S₁ foliation and apparently formed by dilation of the foliation.

4 The Driscoll's Hill Prospect

There are a number of small gossanous zones in the coarse-grained metaporphry at the Driscoll’s Hill Prospect. The gossans are usually lenticular zones parallel to the foliation and are probably after disseminated pyrite. Around 600E 2400N there is a very long siliceous zone which is parallel to the foliation in the rocks and is associated with disseminated limonite (after pyrite).

5 Interpretation of the Other Mineralization in Facies Cp

(i) The long band of hematitic quartz may be either a metamorphic vein or a metamorphosed synvolcanic alteration zone.

(ii) The jasper veins in facies Cp are probably metamorphic in origin.

(iii) The disseminated pyrite at the Driscoll’s Hill and Driscoll’s Hill South Prospects may have formed:

1. during intrusion of the porphyry (Cp) due to hydrothermal interaction between the volcanics and the porphyry, possibly involving redistribution of pre-existing, synvolcanic mineralization in the medium-grained metavolcanics (Bv) into the porphyry (Cp),

2. during metamorphism by remobilising mineralization from the medium-grained volcanics (Bv) into the porphyry (Cp).
5.5 MINERALIZATION IN UNIT D AND THE BASE OF UNIT E

5.5.a The Cosgrove Hill Area

1 Introduction

Of interest in the Cosgrove Hill area are metavolcanic rocks which contain zones of:

(i) pyrophyllite, ±alunite, ±kaolinite,
(ii) K-feldspar- and pyrite-rich rocks,
(iii) sericite-rich rocks.

The area of interest is centered around the Cosgrove Hill Trig and Microwave Tower 3.5 km south of Bredbo (Map 4.1, G.R. 93651500).

2 Exploration History

Regional mapping by Esso (Beams, 1984a) revealed two outcrops of pyrophyllite-bearing rocks in the Cosgrove Hill area. Follow-up work was centred around the southern pyrophyllite outcrop (Map 4.1, G.R. 94051370) and this was called the Cosgrove Hill Prospect. Work at the prospect included a whole rock geochemistry survey, a PEM survey, a soil geochemistry survey and two percussion-drillholes.

3 My Work in the Cosgrove Hill Area

My work in the Cosgrove Hill area included:

(i) 1:12 000 scale mapping,
(ii) additional mapping at the Cosgrove Hill Prospect,
(iii) a petrographic study of the area,
(iv) a petrographic and XRD study of the surface rocks and drill-chips from the Cosgrove Hill Prospect.

4 Geology of the Cosgrove Hill Area

The main units in the Cosgrove Hill area have been described in Sections 4.3.e to 4.3.g. The stratigraphic sequence, from west to east, consists of:

(i) coarse-grained metaporphry (Cp) which contains irregularly shaped zones of cream metavolcanic rocks (Ck) and medium-grained metavolcanic rocks (Cv). Facies Ck is similar to facies Dk to the east.

(ii) sericitic, siliceous, gossanous metavolcanic rocks (Ds),

(iii) lithic-rich metavolcanic rocks (Dlr), interpreted to be a pyroclastic mass-flow deposit,

(iv) the Cosgrove Porphyry (Dcp) with areas of massive, white, K-feldspar-rich metavolcanic rocks (Dk) along strike to the north and south. These rocks are interpreted to be parts of an originally continuous series of lavas, parts of which have been altered to a K-feldspar, pyrite assemblage. Further south the rocks change to sericitic, siliceous, gossanous metavolcanic rocks (Ds).
a narrow zone of hematitic, sericitic metasedimentary rocks (Ehs) occurs immediately above the Cosgrove Porphyry (Dcp) and is interpreted to be either an alteration zone or a palaeoweathering horizon.

(vi) hornblende-bearing metavolcanic rocks (Ehv) with local interbeds of quartz arenites (Eq).

5 Small Zones of Interest

The Northern Pyrophyllite, ±Kaolinite Outcrop

At G.R. 92951630 (Map 4.1) there is a large outcrop composed of quartz crystals supported in a matrix of pyrophyllite, ±kaolinite. The rocks have a well-developed S1 foliation which is intensely folded and crenulated. Analyses by Esso (Beams, 1984a) indicate that the rocks have high As values (Table 5.3).

Table 5.3 Cosgrove Hill area; geochemistry of the northern pyrophyllite outcrop.
Data from Esso, Beams (1984a). All values in ppm.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>Ag</th>
<th>Au</th>
<th>Mo</th>
<th>Ba</th>
<th>As</th>
<th>Sb</th>
<th>Bi</th>
<th>Mn</th>
<th>Ni</th>
<th>Co</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAG 77</td>
<td>33</td>
<td>52</td>
<td>27</td>
<td>0</td>
<td>0.04</td>
<td>7</td>
<td>298</td>
<td>700</td>
<td>2</td>
<td>&lt;0.5</td>
<td>40</td>
<td>16</td>
<td>5</td>
</tr>
<tr>
<td>BAG 78</td>
<td>30</td>
<td>80</td>
<td>21</td>
<td>0</td>
<td>0.03</td>
<td>3</td>
<td>132</td>
<td>740</td>
<td>3</td>
<td>&lt;0.5</td>
<td>18</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>BAG 79</td>
<td>28</td>
<td>52</td>
<td>15</td>
<td>4.1</td>
<td>0.03</td>
<td>2</td>
<td>219</td>
<td>600</td>
<td>3</td>
<td>&lt;0.5</td>
<td>23</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>BAG 80</td>
<td>58</td>
<td>23</td>
<td>42</td>
<td>1.3</td>
<td>0.07</td>
<td>15</td>
<td>210</td>
<td>120</td>
<td>3</td>
<td>&lt;0.5</td>
<td>42</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>BAG 81</td>
<td>23</td>
<td>28</td>
<td>21</td>
<td>1.2</td>
<td>0.08</td>
<td>10</td>
<td>99</td>
<td>120</td>
<td>3</td>
<td>&lt;0.5</td>
<td>56</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>BAG 82</td>
<td>33</td>
<td>26</td>
<td>27</td>
<td>1.8</td>
<td>0.06</td>
<td>12</td>
<td>83</td>
<td>270</td>
<td>4</td>
<td>&lt;0.5</td>
<td>26</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>Average</td>
<td>34</td>
<td>44</td>
<td>26</td>
<td>1.4</td>
<td>0.05</td>
<td>8</td>
<td>174</td>
<td>425</td>
<td>3</td>
<td>&lt;0.5</td>
<td>34</td>
<td>10</td>
<td>8</td>
</tr>
</tbody>
</table>

K-Feldspar-Rich Rocks in Facies Dk

Facies Dk contains numerous zones of very K-feldspar-rich rocks. The zones are massive and unfoliated and are composed of relict phenocrysts of quartz and K-feldspar supported in a matrix of microcrystalline quartz and K-feldspar with large chlorite flakes and pyrite cubes. In less-altered zones the K-feldspar crystals have small inclusions of plagioclase. In places the feldspars show variable degrees of alteration to sericite and thin sericite veinlets lead away from these altered grains.

Jaspers and Sericitic, Hematitic Rocks in Unit E

Jasper and zones rich in sericite, hematite, ±epidote are common along the western side of the hornblende-bearing metavolcanics (Ehv) in the Cosgrove Hill area. Blocks of banded jasper occur on the surface and small jasper veins occur in joints in the metavolcanics. In places (e.g. Fig. 5.7, G.R. -6000E 4370N, ) the metavolcanics are weakly foliated with a sericitic, hematitic
Ch. 5 BREDBO-BUNYAN MINERALIZATION

matrix and contain veins of quartz and epidote which cut thin jasper veins. Along the base of Unit E there is a thin zone of bedded, sericitic, hematitic metasedimentary rocks (Ehs).

6 The Cosgrove Hill Prospect

The Cosgrove Hill Prospect (Fig. 5.7) is located in an area of sericitic, siliceous, gossanous metavolcanic rocks (Ds) which contains local zones metavolcanic breccias. Interest centres around a zone of very sericite-rich and feldspar-poor rocks close to the top of Unit D. The rocks in the zone have high base-metal, Al₂O₃ and K₂O contents and low Na₂O and K₂O contents. Soils have sporadic high Pb, As and Cu values (Beams, 1984a).

In the southern part of the zone of interest, around G.R. -690E4200N, there is a zone approximately 100 m long and from 1 to 2 m wide which is composed of quartz crystals in a matrix of phyllicite, kaolinite, alunite, quartz, and limonite after pyrite (Eaa). Parts of the rock are very siliceous and the distribution of quartz crystals shows that the rock was originally bedded. The rock occurs at the base of Unit E and is parallel to the contact with Unit D. The irregular nature of the contact in this area suggests that the facies occurs in a palaeodepression. A single whole-rock geochemical analysis of a surface sample of the rock (Table 5.4) by Esso (Beams, 1984a) indicates the aluminous nature of the rock.

<table>
<thead>
<tr>
<th>Element</th>
<th>Wt %</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>73.3</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.71</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>19.9</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.16</td>
</tr>
<tr>
<td>CaO</td>
<td>0.03</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.05</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.11</td>
</tr>
<tr>
<td>MnO</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.288</td>
</tr>
<tr>
<td>Total</td>
<td>98.86</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Element</th>
<th>ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>11</td>
</tr>
<tr>
<td>Pb</td>
<td>305</td>
</tr>
<tr>
<td>Zn</td>
<td>4</td>
</tr>
<tr>
<td>As</td>
<td>7</td>
</tr>
<tr>
<td>Au</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Two percussion-drillholes were drilled to test the zone of interest in the sericitic, siliceous, gossanous metavolcanic rocks (Ds) at the Cosgrove Hill Prospect. A petrographic and XRD study of drill-chips from percussion-drillhole BRAC 101 did not find any pyrophyllite but indicated that there are sericite-rich zones in the rocks (Fig. 5.8).

Sericite-rich zones. The sericite-rich zones are narrow (<10 m wide in the drill-hole) and commonly have minor sulphides and slightly higher Cu, Pb and Zn values. The rocks are composed of quartz crystals supported in a matrix of quartz, sericite and opaques. Quartz crystals are anhedral, angular and commonly have scalloped margins. Relict mafic grains are composed of opaques, sphene, sericite and an unidentified brown ?clay/?carbonate. The sericite in the mafic relicts is usually well aligned but in places it is oriented at an angle to the foliation in the rock.
Legend for Fig. 5.7  Geology of the Cosgrove Hill Prospect.
Fig. 5.7 Geology of the Cosgrove Hill Prospect.
Fig. 5.8 Interpreted cross-section through Cosgrove Hill Prospect percussion-drillhole BRAC 101.
Plate 5  Randomly oriented sericite flakes in the sericite-rich rocks at the Cosgrove Hill Prospect. (Crossed polars).

Plate 6  Background rock at the Cosgrove Hill Prospect.
In some mafic relicts the sericite is crenulated. The rocks have a well-developed domainal foliation. Phyllosilicate-rich bands of sericite wrap around siliceous bands which commonly have randomly oriented sericite flakes (Plate 5). Chlorite and quartz occur in some pressure beards. The pressure beards are oriented at various angles to the foliation in places suggesting some rotation of the crystals during the deformation. The rocks contain rare, disseminated, tiny grains of pyrite, galena and chalcopyrite.

**Background rocks.** The rocks around the sericite-rich zones are matrix-supported with relict phenocrysts of quartz and plagioclase. The plagioclase grains are anhedral and have large inclusions of quartz and/or chlorite and/or carbonate and are remarkably clear of the inclusions of tiny phyllosilicate flakes which are characteristic of all other rocks in the region. Carbonate also occurs in fractures in the crystals. Quartz crystals are commonly polycrystalline aggregates of grains but the least-deformed grains are anhedral and only rarely have embayments and crystal faces. Tiny grains of zircon and apatite are ubiquitous.

The rocks have a good domainal foliation with alternating sericitic and siliceous bands. Thicker sericite bands are crenulated in some rocks. In the siliceous bands the matrix is composed of microcrystalline quartz, randomly oriented chlorite flakes and well-aligned sericite flakes (Plate 6). Quartz has sutured grain boundaries. Pressure beards are composed of quartz and sericite.

The rocks have veins of quartz and chlorite. The chlorite forms randomly orientated clusters of flakes. Disrupted vein fragments enveloped in sericite folia are common. Chips of jasper veins occur rarely.

7 Initial Interpretation of the Cosgrove Hill Area

(i) The K-feldspar-rich metavolcanic rocks (Dk) are interpreted as being originally dacitic lavas, probably originally part of the Cosgrove Porphyry (Dcp), which were altered and then deformed. During alteration the original plagioclase phenocrysts were altered to K-feldspar, and mafic minerals were altered to aggregates of chlorite, opaques and sphene. The matrix has altered to K-feldspar, quartz, chlorite and pyrite. During metamorphism the feldspar has started to alter to sericite and sericite veins have formed. (ii) The sericitic, siliceous, gossanous metavolcanic rocks (Ds) at the Cosgrove Hill Prospect appear to represent a mixture of lavas and fragmental volcanic rocks.

(iii) In the rocks of the Cosgrove Hill Prospect the randomly oriented phyllosilicate grains in the siliceous microlithons were produced before the metamorphism, probably due to synvolcanic, hydrothermal alteration. In the sericite-rich zones the alteration destroyed the feldspar and mafic phenocrysts and the matrix was altered to sericite, quartz and opaques. This assemblage is consistent with the sericitic assemblage of Meyer & Hemley (1967). During metamorphism sericite formed in the matrix and calcite filled fractures in crystals. In the rocks surrounding the sericitic zones the matrix altered to quartz, chlorite and opaques; mafic minerals altered to opaques, sphene and sericite;
and plagioclase was partly altered to quartz and/or carbonate and/or chlorite. This assemblage is similar to the propylitic style of alteration of Meyer & Hemley (1967). The quartz, chlorite veins formed either during the alteration event or during the early stages of metamorphism.

(iv) During metamorphism the quartz crystals in the sericitic, siliceous, gossanous metavolcanic rocks (Ds) deformed in a plastic manner and plagioclase crystals fractured in a brittle fashion. The rocks produced sericite folia and carbonate formed in crystal fractures. The presence of chlorite in some pressure beards indicates that it was stable during the early stages of metamorphism.

(v) The pyrophyllite in the small zones may be an original alteration phase or it may have formed by the metamorphism of a kaolinitic lithology. Nevertheless, the assemblage, pyrophyllite, ±kaolinite, ±alunite, ±quartz, ±opaques at the Cosgrove Hill Prospect is typical of the advanced-argillic assemblage (Meyer & Hemley, 1967). It is generally considered to be produced by CO$_2$- and H$_2$S-rich steam, rising from deeper parts of the hydrothermal system, interacting with oxidised ground-waters (Browne & Houghton, 1984). The bedded nature of the rocks at the Cosgrove Hill Prospect zone suggests that they were originally sediments such as alluvium, lacustrine deposits or air-fall pyroclastics. The hematitic, sericitic metasedimentary rocks (Ehs), further north, may represent a similar facies along the same palaeosurface.

(vi) The northern pyrophyllite, ±kaolinite outcrop is apparently devoid of alunite. It may be a zone of deep-footwall acid alteration, similar to zones described by Hayba et al. (1985) associated with epithermal gold deposits. The alteration is due to interaction of deep acid waters (not necessarily produced by near-surface oxidation of gases) and the country rocks.

(vii) The contact between Units D and E may be, at least in part, a palaeo-erosion surface because:

1. it is very irregular,
2. the hematitic, sericitic metasedimentary rocks (Ehs) along the top of the Cosgrove Porphyry and the pyrophyllite zone at the Cosgrove Hill prospect both contain bedded sedimentary rocks.
3. the K-feldspar-rich alteration zone does not grade up into any of the near-surface zones which are common in epithermal systems such as zones of advanced-argillic alteration, stockwork veins, or siliceous sinters.

5.5.b Billilingra and Barite Prospects

1 Introduction

The Billilingra and Barite Prospects are located ≈6-8 km south of Bredbo and cover a prominent ridge approximately one kilometer east of "Billilingra" homestead and the Monaro
Highway. Of interest at the prospects are bands of sulphidic barite in siliceous, sericitic, K-feldspar-rich metavolcanic rocks along the eastern side of Unit D.

2 Previous Work

There are two small prospecting pits on barite bands at the Billilingra Prospect but no information is available about them. The prospect was found during regional geological mapping by Esso in 1981. Esso carried out geological mapping, rock-chip and soil geochemistry surveys and drilled one diamond-drillhole, DDH-BL1 (Beams, 1984a).

The Barite Prospect is referred to as the Chakola Prospect in a review of the barite deposits in the Cooma-Bredbo area by Stevens (1974) and is deposit No. 13 on the Bega 1:250 000 Metallogenic Sheet (Herzberger & Barnes, 1978). Two shallow prospecting pits have been dug on the barite bands and the larger pit produced approximately 20 tonnes of barite, during 1917 to 1919 (Stevens, 1974). Jododex Australia Pty Ltd found an anomaly north of the pits during a regional soil geochemistry survey and did a rock-chip geochemistry survey over the prospect (Jododex Australia Pty Ltd Staff, 1979a). Esso mapped the area and did a gossan geochemistry survey (Beams, 1984a).

3 My Work at the Billilingra and Barite Prospects

My work at the Billilingra and Barite Prospects included:

(i) compilation of previous mapping and the investigation of important areas,
(ii) a petrographic study of the core from diamond-drillhole DDH-BL1 and surface samples,
(iii) reassessment of previous geochemical work,
(iv) whole rock geochemical analysis of four samples from DDH-BL1 (Ch. 7),
(v) a sulphur isotope study (Ch. 7).

4 Geology

General features

The surface geology of the Billilingra and Barite Prospects is shown on Map 5.3 which is a modified version of the maps of Esso (Beams, 1984a). A cross-section through drill-hole DDH-BL1 is given in Fig. 5.9. The mineralization occurs along the eastern side of a thick sequence of sericitic, siliceous, ±K-feldspar-rich metavolcanic rocks of Unit D. The rocks have a moderate to strong metamorphic foliation but bedding is rare. Minor interbedded metapelite beds (Dm) and the overlying metapelites (Fm) strike to the NNW and dip steeply to the east. A thin (20 cm) graded metapelite bed in drill-hole DDH-BL1 fines to the east. The stratigraphic sequence at the Billilingra Prospect, from west to east, includes:

(i) crystal-rich metavolcanic rocks with local sericitic or K-feldspar-rich zones (Dx) and rare metapelites (Dm),
UNIT D MINERALIZED METAVOLCANIC ROCKS

- Dkb: Mineralized, K-feldspar-rich metavolcanic rock
- Dm: Metapelite
- Dx: Crystal-rich metavolcanic rock
- Barite band

Geological boundary, position accurate
Position approximate
Inferred
Fining direction of graded unit
Outcrop inspected

Fig. 5.9 Interpreted cross-section through Bilingingra Prospect diamond-drillhole DDH-BLI.
(ii) mineralized, K-feldspar-rich metavolcanic rocks (Dkb) with bands of barite,
(iii) hornblende-bearing metavolcanic rocks (Ehv),
(iv) metapelites (Fm).

The structural and stratigraphic relationships at the Barite Prospect in the area around the two prospecting pits are not clear. Beams (1984a) considered that the sequence in this area had been folded into a series of north-northwest trending minor folds, however the evidence for this is not compelling. An important feature is the northeast-trending right-lateral fault which marks the southern end of many of the units occurring at the Billilingra Prospect. The metamorphic foliation and the barite band (Band G13) are drag-folded near the fault. The stratigraphic sequence in the area of the Barite Prospect, south of the fault, from west to east, includes:

(i) sericitic, siliceous, gossanous metavolcanic rocks (Ds),
(ii) magnetite-rich metavolcanic rocks (Emt),
(iii) sericitic, siliceous metavolcanic rocks with barite bands (Ess) with interbedded metapelites (Em),
(iv) hornblende-bearing metavolcanic rocks (Ehv),
(v) metapelites (Fm).

South of the Barite Prospect stratigraphic relationships are obscure due to poor outcrop and extensive alluvium. There are blocks of gossanous barite and gossanous, siliceous metavolcanic rocks along the contact between metavolcanic rocks of Unit ?E and the overlying metapelites (Fm). The outcrop in this area is too poor to determine the nature of the metavolcanics. The subdued topography south of the Barite Prospect suggests that the K-feldspar-rich metavolcanic rocks (Dkb), which normally form a steep ridge, do not extend into this area.

**Crystal-Rich Metavolcanic Rocks (Dx)**

The crystal-rich metavolcanic rocks outcrop poorly and occur in an area of subdued relief. My best samples of the unit come from DDH-BL1 from 203.2 to 262.7 m. The rocks are bedded with 1 to 40 cm thick crystal-rich and crystal-poor beds. There are no obvious lithic fragments in the rocks.

**Relict phenocrysts.** Quartz phenocrysts in less-deformed rocks are subhedral with embayments. In more-strongly foliated rocks they form lenticular, polycrystalline aggregates of grains. The grains have scalloped margins where they are in contact with sericite in the matrix. Plagioclase forms subhedral grains or microboudinaged grains with some subgrain development. In places the grains contain numerous inclusions of dark-brown ?limonite along the cleavage. There are no relics of mafic phenocrysts in the rocks.

**Matrix.** The matrix is composed of sericite and quartz with minor grains of chlorite, pyrite and ?orpiment, with accessory zircon ±apatite. The matrix is strongly foliated and in some rocks there are folia of sericite. Carbonate occurs in fractures in phenocrysts and in extensional sites in the matrix. The rocks are matrix-supported but are crystal-rich compared to other rocks in the area.
**Other features.** The crystal-rich metavolcanic rocks have local variations. In the drill-core there is a zone \( \approx 30 \, \text{m} \) thick (203.2 to 232m) along the margin of the mineralized, K-feldspar-rich metavolcanic rocks (Dkb) and a few narrower zones deeper in the drill-hole which have a very sericite-rich matrix and no plagioclase phenocrysts. At G.R. 93801260 (Map 4.1) there is a large outcrop of the unit in which the matrix of the rocks has abundant K-feldspar and disseminated pyrite and is similar to the mineralized, K-feldspar-rich rocks (Dkb) to the east.

**Veins** in the crystal-rich metavolcanic rocks include:

(i) chlorite, pyrite, quartz and sericite veins parallel to, and cutting, the foliation with diffuse contacts with the host.

(ii) quartz, chlorite, barite, carbonate and pyrite veins, up to 12 cm wide and zoned from:
   (1) a marginal zone with abundant chlorite and pyrite in the host rock,
   (2) banded barite,
   (3) carbonate, chlorite, quartz, pyrite and minor barite.

(iii) thick veins of quartz, carbonate and chlorite which contain inclusions of the host rock. Chlorite forms rosettes and the quartz and carbonate grains have undulose extinction and subgrain development.

**Metapelites** (Dm, Em)

There are a few small lenses of metapelites mainly in the area of the Barite Prospect. They are bedded and the finer beds are strongly foliated. In places the lenses contain thin arkosic siltstone beds and some beds contain abundant magnetite.

**Mineralized, K-Feldspar-Rich Metavolcanic Rocks** (Dkb)

The mineralized, K-feldspar-rich metavolcanic rocks form a steep ridge to the east of the crystal-rich metavolcanic rocks (Dx). They are composed of relict phenocrysts of quartz in a matrix of quartz and K-feldspar with minor sericite, ±pyrite, ±carbonate, ±barite with a trace of zircon, ±sphalerite, ±galena, ±?orpiment. Relict phenocrysts of plagioclase and/or K-feldspar occur in places. The rocks are matrix-supported, have a weak foliation, and do not have any obvious bedding.

**Relict phenocrysts.** Relict phenocrysts of quartz are usually anhedral and rarely subhedral and have deep embayments. Relict phenocrysts of plagioclase occur in places and show varying degrees of alteration to very-fine-grained masses of brown ?clay/?carbonate or sericite. They have a prismatic shape and the composition is albite. K-feldspar rarely forms phenocrysts and they have a prismatic, subhedral shape. Aggregates of sericite and opaques are ubiquitous and may be relics of mafic phenocrysts.

**Matrix.** The matrix has a domainal texture with sericite folia wrapping around lenticular microlithons of quartz and K-feldspar.

**Other features.** In mineralized zones in the drill-core there are parts of the core with a green colour due to the matrix being rich in chlorite, carbonate and pyrite. In places there are aggregates of fine grained epidote possibly replacing ?plagioclase phenocrysts. Some of the rocks along the
eastern side of the unit have abundant sericite in the matrix with only minor K-feldspar. Sericite forms thick folia which wrap around K-feldspar-rich microlithons. These rocks are more strongly foliated than the rest of the unit.

**Hornblende-Bearing Metavolcanic Rocks (Ehv)**

The poorly foliated, dark green metavolcanic rocks are composed of crystals of quartz, partly altered plagioclase and altered mafics in a matrix of sericite, quartz, carbonate and minor K-feldspar. The rocks are usually massive with a poor foliation but tend to be more strongly foliated along the western side of the unit. The contact with the mineralized, K-feldspar-rich metavolcanic rocks (Dkb) to the east of the Billilingra Prospect is usually gradational over a few metres and in places where both rocks are well foliated it is very difficult to locate precisely. In the area of the Barite Prospect the contact is irregular and the two units interdigitate parallel to the foliation.

**Relict phenocrysts.** Relict phenocrysts of quartz are subhedral to anhedral and have embayments. Chlorite occurs in fractures in the grains. Plagioclase grains show varying degrees of alteration to sericite. Mafic relics are composed of aggregations of chlorite, ±sphene, ±green amphibole, ±opaque, ±carbonate, ±sericite.

**Matrix.** The matrix contains folia of sericite which wrap around lenticular domains of microcrystalline quartz, sericite, ±carbonate, ±K-feldspar and accessory magnetite, zircon, apatite, sphene and zoisite. Zoisite grains have dark-brown cores.

**Other features.** In places there are small grains of magnetite in the rocks. Some of the rocks are very crystal-rich and moderately sorted. To the east of the Barite Prospect there are rare small veins of barite in the rocks.

**Sericitic, Siliceous, Gossanous Metavolcanic Rocks (Ds)**

These rocks have outcrop poorly. They are composed of relict phenocrysts supported in a well-foliated matrix of quartz and phyllosilicates (mainly sericite).

**Magnetite-Rich Metavolcanic Rocks (Emt)**

The magnetite-rich metavolcanic rocks have a dark-green colour and are poorly foliated, crystal-rich rocks with subequal amounts of matrix and phenocrysts. There are no obvious lithic fragments. Relict phenocrysts of quartz have subrounded shapes and embayments. Plagioclase phenocrysts are of albite composition and are remarkably fresh and unaltered. A few grains without albite twinning may be K-feldspar. Aggregates of sericite and sphene with minor chlorite and opaques are probably relics of mafic phenocrysts. The matrix is composed of chlorite and quartz with abundant microphenocrysts of magnetite and accessory zircon and apatite. Some rocks have abundant carbonate in the matrix.
Sericitic, Siliceous Metavolcanic Rocks (Ess)

These rocks are composed of quartz phenocrysts in a matrix of quartz and sericite with sporadic, minor, disseminated pyrite. These rocks contain two barite bands.

Metapelites (Fm) and Metabasalt (Fb)

The metapelites (Fm) and metabasalt units (Fb) are described in Section 4.3.h.

5 Mineralization

At the Billilingra Prospect mineralization consists of very long, thin, bands of sulphidic barite and the host rocks have minor (<2%) pyrite and a trace of galena, sphalerite, chalcopyrite and barite in disseminations. Most of the mineralization occurs in the mineralized, K-feldspar-rich metavolcanic rocks (Dkb) with only a few bands along the eastern side of the crystal-rich metavolcanic rocks (Dx). The sulphidic barite bands strike northwest to north-northwest and are subparallel to the foliation in the host rocks which is subparallel to the inferred strike of the host rocks. The bands are usually up to a few tens of metres long however some bands can be followed for up to 300 m. They are mostly <10 cm wide but are up to 40 cm wide in places. At the Barite Prospect the barite band in the larger of the pits (Band G13) reached a maximum width of about 4 m (Stevens, 1974).

The barite bands are composed of barite and pyrite with variable amounts of quartz, sericite, sphalerite, galena, chalcopyrite, ?orpiment, tennantite-tetrahedrite, chalcocite, siderite, calcite and limonite. Barite content varies up to nearly 100% and the total sulphide content is less than 20%. The combined sphalerite, galena and chalcopyrite content is usually less than 5%.

Barite has a bimodal grainsize distribution with large blades up to 3 x 10 mm surrounded by <0.02 mm grains. Some of the larger grains have a fanning texture.

Pyrite occurs as disseminations of subhedral to anhedral grains and as lenticular aggregates of grains. Some grains have euhedral cores outlined by inclusions. In places, even deep in the drill-core, the pyrite grains have rims of limonite.

Galena, sphalerite and chalcopyrite commonly occur together as fine-grained (<0.05 mm) inclusions in pyrite, as rims around pyrite grains and as disseminations. Sphalerite also forms thin, wispy anhedral grains. Some chalcopyrite grains have a few chalcocite grains associated with them. A few grains of tennantite-tetrahedrite occur with the sulphides in places.

Siderite forms large subhedral grains and as masses of smaller microcrystalline grains. Some of the large grains have optically continuous rims of clear carbonate, probably calcite.

Orpiment? forms lenticular masses and is commonly associated with pyrite.

Quartz occurs in the bands as embayed volcanic phenocrysts and as masses of fine grains. Fibrous quartz occurs in extensional microstructures and in pressure shadows around pyrite.

Sericite forms thin wispy grains which help to define a foliation in the bands.

Limonite occurs sporadically as rims on pyrite grains and as very thin (<<0.01 mm) anastomosing networks of veins along the foliation.
The barite bands are banded parallel to the long axis of the bands. The width of individual bands usually varies from 2 to 5 mm but is up to several centimetres locally. The banding is defined by either variations in the proportions of barite, carbonate and pyrite or by differences in grainsize. In some coarser-grained bands high-angle grain boundaries are common. The banding is commonly enhanced by lenticular inclusions of the host rock in the bands. The contacts between the bands and the host metavolcanic rocks are either sharp, with the band truncating quartz phenocrysts in the host, or gradational.

The sulphidic barite bands contain some cross-cutting veins composed of calcite, barite and sphalerite or siderite and pyrite. In places on the surface there are veins of coarse-grained quartz, K-feldspar and sericite which are parallel to the foliation.

At the Barite Prospect there are two bands of sulphidic barite. The southern band (Band G14) is enclosed in the metavolcanic unit but strikes parallel to the contact of the host with underlying metapelitic unit (Em). There are a few tiny barite veins in the hornblende-bearing metavolcanic rocks (Ehv). South of the main barite bands there are blocks of barite and siliceous, gossanous metavolcanic rocks at the contact between the metapelites of facies Fm and the underlying metavolcanics. Outcrop is too poor in these areas to recognise the style of mineralization or the nature of the host rocks.

6 Geochemistry

Analyses by Esso (Beams, 1984a) of the best intersections in the drill-hole are given in Table 5.5. The analyses were done using =1 m intervals of split drill-core from DDH-BL1 and include sulphidic barite bands and the intervening metavolcanic rocks. Base-metal values are generally much less than one percent. Analyses of up to 4 ppm silver are common and the best gold value is 1.85 mat 1.09 ppm. There is a tendency for the lower intervals (to the west) to have higher gold values.

Table 5.5 Geochemistry of Billilingra Prospect diamond-drillhole DDH-BL1.
Data from Esso, Beams (1984a). All values in ppm except Ba in %.

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Width</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>Ag</th>
<th>Au</th>
<th>Ba</th>
<th>As</th>
</tr>
</thead>
<tbody>
<tr>
<td>47.00</td>
<td>50.60</td>
<td>3.60</td>
<td>147</td>
<td>2589</td>
<td>8431</td>
<td>8.3</td>
<td>0.11</td>
<td>4.80</td>
<td>195</td>
</tr>
<tr>
<td>51.40</td>
<td>54.50</td>
<td>3.10</td>
<td>46</td>
<td>645</td>
<td>3093</td>
<td>3.1</td>
<td>0.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>57.22</td>
<td>59.96</td>
<td>2.73</td>
<td>36</td>
<td>635</td>
<td>3387</td>
<td>3.4</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80.40</td>
<td>84.00</td>
<td>3.60</td>
<td>39</td>
<td>3028</td>
<td>9748</td>
<td>9.2</td>
<td>0.10</td>
<td>4.06</td>
<td>49</td>
</tr>
<tr>
<td>86.80</td>
<td>90.50</td>
<td>3.70</td>
<td>49</td>
<td>1376</td>
<td>4334</td>
<td>4.1</td>
<td>0.04</td>
<td>3.09</td>
<td>40</td>
</tr>
<tr>
<td>103.80</td>
<td>104.80</td>
<td>1.00</td>
<td>120</td>
<td>1760</td>
<td>6500</td>
<td>3.1</td>
<td>0.11</td>
<td>8.95</td>
<td>65</td>
</tr>
<tr>
<td>105.65</td>
<td>106.55</td>
<td>0.90</td>
<td>88</td>
<td>2370</td>
<td>3500</td>
<td>4.1</td>
<td>0.08</td>
<td>4.70</td>
<td>12</td>
</tr>
<tr>
<td>130.70</td>
<td>131.65</td>
<td>0.95</td>
<td>680</td>
<td>15</td>
<td>50</td>
<td>0.3</td>
<td>0.65</td>
<td>3.00</td>
<td>40</td>
</tr>
<tr>
<td>140.05</td>
<td>146.60</td>
<td>6.55</td>
<td>56</td>
<td>17</td>
<td>69</td>
<td>0.2</td>
<td>0.35</td>
<td>3.95</td>
<td>50</td>
</tr>
<tr>
<td>155.85</td>
<td>158.70</td>
<td>2.85</td>
<td>879</td>
<td>9375</td>
<td>1293</td>
<td>14.0</td>
<td>0.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>180.25</td>
<td>182.10</td>
<td>1.85</td>
<td>1861</td>
<td>174</td>
<td>1474</td>
<td>1.8</td>
<td>1.09</td>
<td>7.19</td>
<td>77</td>
</tr>
<tr>
<td>190.50</td>
<td>193.20</td>
<td>2.70</td>
<td>35</td>
<td>3043</td>
<td>9338</td>
<td>3.9</td>
<td>0.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>197.20</td>
<td>199.00</td>
<td>1.80</td>
<td>176</td>
<td>909</td>
<td>3616</td>
<td>2.7</td>
<td>0.50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Analyses by Esso (Beams, 1984a) of the gossanous barite bands are given in Table 5.6. The geochemical values from the bands on the surface are much higher than in the drill-core possibly because the core samples were diluted with poorly mineralized metavolcanic rocks. The survey shows that each band tends to be geochemically different to the others. The best gold and silver values come from bands G4, G5, G6 and G7. The drill-hole DDH-BL1 tested the northern part of this area. The western bands (G4 and G5) have high gold values and this is consistent with the zoning of gold values in the drill-core. Further north, however, in bands G1, G2 and G3 the gold values increase to the east. Although bands G4, G5, G6 and G7 have comparatively high copper, lead and zinc values the highest values come from the next group of bands to the south; the highest copper and zinc values are from band G8 and the highest lead values are from Band G10. Throughout the Billilingra Prospect there is a tendency for arsenic values to be higher in the western bands and for silver values to increase to the east. Bands G13 and G14 at the Barite Prospect have comparatively high silver and molybdenum and low bismuth values. Band G14 has particularly high arsenic values.

7 Initial Interpretation of the Billilingra and Barite Prospects

(i) The rocks at the Billilingra and Barite Prospects were originally mainly volcanic rocks which were affected by synvolcanic hydrothermal alteration and have subsequently been metamorphosed.

(ii) The crystal-rich metavolcanic rocks (Dx) were probably deposited as pyroclastic flows. During alteration:

(1) plagioclase was stable,

(2) any mafic minerals were altered,

(3) the matrix was altered and after metamorphism is composed of sericite, quartz, pyrite and ?orpiment.

In local zones, mainly along the margin of the K-feldspar alteration zone to the east, plagioclase was also altered and there was intense sericite development. The outcrop at G.R. 93801260 in which the matrix of the rocks is rich in K-feldspar and pyrite appears to represent a deep zone of K-feldspar and pyrite alteration similar to that in facies Dk to the east. During metamorphism the relict phenocrysts were deformed and the matrix has been foliated. The scalloped margins on quartz phenocrysts suggests that during metamorphism quartz was dissolved by pressure solution.

(iii) The few small lenses of metapelite (Dm) at the top of the crystal-rich metavolcanic rocks (Dx) are clearly epiclastic deposits and suggest either an alluvial or a lacustrine environment. Overall, the rocks of Units D and E at the Billilingra Prospect appear to have been deposited in a subaerial setting. At the Barite Prospect the crystal-rich nature of the magnetite-rich metavolcanic rocks (Emt) suggests that they were epiclastic deposits. These were followed by deposition of pelitic sediments and volcanics. The Barite Prospect rocks appear to have a greater sedimentary component and be at a higher stratigraphic level than the Billilingra Prospect host rocks.
Table 5.6 Geochemistry of the gossanous barite bands at the Billilingra Prospect.
Data from Esso, Beams (1984a). All values in ppm except Ba in %.

<table>
<thead>
<tr>
<th>Averages for each band</th>
<th>Band</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>Ag</th>
<th>Au</th>
<th>Mo</th>
<th>Ba</th>
<th>As</th>
<th>Sb</th>
<th>Bi</th>
<th>Mn</th>
<th>Ni</th>
<th>Co</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band G1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band G2</td>
<td></td>
<td>20</td>
<td>1.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band G3</td>
<td></td>
<td>2.9</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band G4</td>
<td></td>
<td>2.0</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band G5</td>
<td></td>
<td>2.0</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band G6</td>
<td></td>
<td>2.0</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band G7</td>
<td></td>
<td>2.0</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band G8</td>
<td></td>
<td>2.0</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band G9</td>
<td></td>
<td>2.0</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band G10</td>
<td></td>
<td>2.0</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band G11</td>
<td></td>
<td>2.0</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band G12</td>
<td></td>
<td>2.0</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band G13</td>
<td></td>
<td>2.0</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band G14</td>
<td></td>
<td>2.0</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Band G1                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G2                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G3                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G4                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G5                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |

| Band G1                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G2                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G3                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G4                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G5                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |

| Band G1                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G2                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G3                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G4                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G5                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |

| Band G1                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G2                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G3                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G4                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G5                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |

| Band G1                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G2                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G3                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G4                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Band G5                |      |     |     |     |     |     |     |     |     |     |     |     |     |     |
Table 5.6 Geochemistry of the gossanous barite bands at the Billilingra Prospect. Continued.

<table>
<thead>
<tr>
<th>Band</th>
<th>No.</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>Ag</th>
<th>Au</th>
<th>Mo</th>
<th>Ba</th>
<th>As</th>
<th>Sb</th>
<th>Bi</th>
<th>Mn</th>
<th>Ni</th>
<th>Co</th>
</tr>
</thead>
<tbody>
<tr>
<td>G6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAG 53</td>
<td>103</td>
<td>20000</td>
<td>425</td>
<td>63.0</td>
<td>0.12</td>
<td>2</td>
<td>51.40</td>
<td>5</td>
<td>12.0</td>
<td>&lt;0.5</td>
<td>121</td>
<td>3</td>
<td>&lt;2</td>
<td></td>
</tr>
<tr>
<td>BAG 52</td>
<td>230</td>
<td>6800</td>
<td>510</td>
<td>30.0</td>
<td>0.38</td>
<td>2</td>
<td>50.30</td>
<td>20</td>
<td>55.0</td>
<td>&lt;0.5</td>
<td>425</td>
<td>2</td>
<td>&lt;2</td>
<td></td>
</tr>
<tr>
<td>BAG 57</td>
<td>270</td>
<td>1560</td>
<td>115</td>
<td>18.0</td>
<td>1.80</td>
<td>2</td>
<td>56.70</td>
<td>35</td>
<td>90.0</td>
<td>&lt;0.5</td>
<td>5</td>
<td>3</td>
<td>&lt;2</td>
<td></td>
</tr>
<tr>
<td>BAG 56</td>
<td>62</td>
<td>49</td>
<td>27</td>
<td>1.3</td>
<td>2.00</td>
<td>2</td>
<td>50.60</td>
<td>40</td>
<td>1.5</td>
<td>1.0</td>
<td>8</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Band</th>
<th>No.</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>Ag</th>
<th>Au</th>
<th>Mo</th>
<th>Ba</th>
<th>As</th>
<th>Sb</th>
<th>Bi</th>
<th>Mn</th>
<th>Ni</th>
<th>Co</th>
</tr>
</thead>
<tbody>
<tr>
<td>G7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample</td>
<td>No.</td>
<td>Cu</td>
<td>Pb</td>
<td>Zn</td>
<td>Ag</td>
<td>Au</td>
<td>Mo</td>
<td>Ba</td>
<td>As</td>
<td>Sb</td>
<td>Bi</td>
<td>Mn</td>
<td>Ni</td>
<td>Co</td>
</tr>
<tr>
<td>-------</td>
<td>-----</td>
<td>------</td>
<td>-----</td>
<td>-----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>BAG 6</td>
<td>43</td>
<td>88</td>
<td>16</td>
<td>1.4</td>
<td>0.44</td>
<td>8</td>
<td>34.20</td>
<td>8</td>
<td>&lt;0.5</td>
<td>1.5</td>
<td>2</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td></td>
</tr>
<tr>
<td>BAG 3</td>
<td>210</td>
<td>150</td>
<td>615</td>
<td>0.8</td>
<td>0.76</td>
<td>0.76</td>
<td>0.07</td>
<td>1</td>
<td>61.20</td>
<td>120</td>
<td>2.5</td>
<td>2</td>
<td>24</td>
<td>&lt;1</td>
</tr>
<tr>
<td>G8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample</td>
<td>No.</td>
<td>Cu</td>
<td>Pb</td>
<td>Zn</td>
<td>Ag</td>
<td>Au</td>
<td>Mo</td>
<td>Ba</td>
<td>As</td>
<td>Sb</td>
<td>Bi</td>
<td>Mn</td>
<td>Ni</td>
<td>Co</td>
</tr>
<tr>
<td>-------</td>
<td>-----</td>
<td>------</td>
<td>-----</td>
<td>-----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>BAG 53</td>
<td>103</td>
<td>20000</td>
<td>425</td>
<td>63.0</td>
<td>0.12</td>
<td>2</td>
<td>51.40</td>
<td>5</td>
<td>12.0</td>
<td>&lt;0.5</td>
<td>121</td>
<td>3</td>
<td>&lt;2</td>
<td></td>
</tr>
<tr>
<td>BAG 52</td>
<td>230</td>
<td>6800</td>
<td>510</td>
<td>30.0</td>
<td>0.38</td>
<td>2</td>
<td>50.30</td>
<td>20</td>
<td>55.0</td>
<td>&lt;0.5</td>
<td>425</td>
<td>2</td>
<td>&lt;2</td>
<td></td>
</tr>
<tr>
<td>BAG 57</td>
<td>270</td>
<td>1560</td>
<td>115</td>
<td>18.0</td>
<td>1.80</td>
<td>2</td>
<td>56.70</td>
<td>35</td>
<td>90.0</td>
<td>&lt;0.5</td>
<td>5</td>
<td>3</td>
<td>&lt;2</td>
<td></td>
</tr>
<tr>
<td>BAG 56</td>
<td>62</td>
<td>49</td>
<td>27</td>
<td>1.3</td>
<td>2.00</td>
<td>2</td>
<td>50.60</td>
<td>40</td>
<td>1.5</td>
<td>1.0</td>
<td>8</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td></td>
</tr>
</tbody>
</table>

Continued...
(iv) The mineralized, K-feldspar-rich metavolcanic rocks (Dkb) may have been deposited as lavas because they do not appear to have been bedded and commonly have unbroken phenocrysts. Alteration involved:

1. plagioclase → sericite,
2. mafic phenocrysts → sericite, opaques,
3. matrix → K-feldspar, quartz, sericite, pyrite and barite,
4. deposition of sulphides and barite.

The small zones of chlorite, carbonate and pyrite in the rocks probably represent areas with a propylitic style of alteration. The sericitic nature of the rocks along the eastern side of the unit suggests a change to phyllic alteration in this area. The pervasive nature of the alteration suggests that the rocks were originally very permeable and that fluids were not confined to local zones of high permeability.

(v) Nearly all of the bands of sulphidic barite at the Billilingra Prospect and south to Band G13 at the Barite Prospect are probably not exhalative accumulations since they are not associated with any sedimentary facies. Instead the bands appear to be veins which have formed by replacing the matrix of the host rock and precipitation in dilational sites. It is possible that the veins were produced during metamorphism by dilation parallel to the foliation and the remobilisation of pre-existing disseminated mineralization into the veins by pressure solution processes. The low amount of disseminated barite in the host rocks would argue against this model. Furthermore, metamorphic veins in these rocks might be expected to contain abundant K-feldspar which is not seen in the veins. Overall, it appears that most of the veins were produced during the synvolcanic alteration event. If this is the case then the veins would originally have had a subhorizontal orientation which would suggest a strong component of horizontal flow in the hydrothermal system. The observed zoning, with chlorite in the veins along the stratigraphically lower areas suggests some change in the properties of the fluid in this area, possibly an increase in pH.

(vi) The absence of K-feldspar from the veins and the observation that, in places, the veins truncate quartz phenocrysts in the host rocks suggests that the veins formed after the period of K-feldspar and pyrite alteration and that they formed at least in part by brittle fracturing of the host rocks.

(vii) The hornblende-bearing metavolcanic rocks (Ehv) to the east of the Billilingra Prospect have been only mildly altered with:

1. plagioclase → sericite,
2. mafic phenocrysts (including amphibole) → chlorite, opaques,

The assemblage is similar to the sericitic assemblage of Meyer & Hemley (1967). It is possible that the K-feldspar was produced by devitrification of the groundmass and is not related to alteration. Nevertheless the assemblage suggests that the rocks in this area represent the less-altered margins to the intense alteration of the mineralized rocks.
to the west (Dkb). If this is the case then the tiny barite veins to the east of the pits at the Barite Prospect were probably produced during this alteration event.

(viii) The two barite bands at the Barite Prospect probably formed in a similar manner to the bands in the Billilingra Prospect. If the stratigraphic interpretation is correct then these bands are at a higher stratigraphic level than the bands at the Billilingra Prospect and therefore they may be at a higher level in the hydrothermal system.

(ix) The small barite blocks and gossanous volcanics south of the Barite Prospect, just below Unit F, are probably very close to the top of Unit E. This mineralization is significant because it appears to be stratigraphically higher than that at Billilingra. It is possible that it represents a surface discharge zone or the eroded remnant of a subsurface zone.

(x) According to Silberman & Berger (1985) and Hedenquist & Reid (1984) near-surface mineralization in epithermal systems can have very high, but sporadic, arsenic and antimony contents. Barite band G14 at the Barite Prospect has very high arsenic values but very low antimony values. If the antimony results are ignored then the arsenic values imply that fluid flow in the epithermal system was from north to south; the Billilingra mineralization was at deeper part of the system and that Band G14 at the Barite Prospect was closer to the palaeosurface.

(xi) Although the mineralization and alteration at the prospects is similar to that in epithermal style deposits (Berger & Bethke, 1985) there are features common to epithermal deposits which are either missing or have not yet been found there. In particular, near-surface zones of advanced-argillic alteration and siliceous sinters formed at surface discharge sites. It is possible that these features if they existed were eroded off prior to the deposition of Unit F. Alternatively they could be found by careful inspection of Unit E.

5.5.c Driscoll's Hill Prospect

1 Introduction

The Driscoll's Hill Prospect straddles the Monaro Highway ~10 km south of Bredbo. Of interest are a number of gossanous zones in siliceous, sericitic, ±K-feldspar-rich metavolcanic rocks along the eastern side of Unit D and the base of Unit E. In the western part of the prospect (5.4.a) there are pyritic, sericitic, siliceous zones in the medium-grained metavolcanic rocks enclosed in the coarse-grained metaporphyry (Cp). The main part of the prospect is east of the Monaro Highway.

2 Previous Work

The prospect was discovered by Esso during regional mapping in 1981. Esso mapped the prospect; did soil, rock-chip and gossan geochemistry; did a ground magnetics survey and drilled three percussion-drillholes (Beams, 1984a).
3 My Work at Driscoll's Hill Prospect

My work at Driscoll's Hill Prospect included:

(i) additional mapping in important areas,
(ii) logging the drill-chips,
(iii) limited petrography and XRD work,
(iv) a sulphur isotope study (Ch. 7).

4 Geology

General Features

The geology of the prospect is shown on Map 5.4 and cross-sections through the percussion-drillholes are given in Figure 5.10. The sequence, from west to east, consists of:

(i) coarse-grained metaporphyry (Cp) which has gossanous zones,
(ii) sericitic, siliceous gossanous metavolcanic rocks (Ds) with local zones of K-feldspar-rich metavolcanic rocks (Dk),
(iii) sericitic, siliceous, gossanous metavolcanic rocks (Ess) interbedded with metapelites (Em), quartz arenites (Eq) and metalimestone (El),
(iv) hornblende-bearing metavolcanic rocks (Ehv).

Sericitic, Siliceous, Gossanous Metavolcanic Rocks (Ds and Ess)

The composition of these rocks changes from west to east. West of BRAD 102 the rocks are a dark green colour, strongly foliated and composed of crystals of quartz and plagioclase supported in a matrix of quartz, sericite and chlorite with a trace of disseminated pyrite. Hematite occurs in the matrix in places. Along the eastern side of the sequence the rocks are a pale, yellow-green colour and are composed of crystals of quartz in a strongly foliated matrix of quartz, sericite, pyrite and ?K-feldspar.

K-Feldspar-Rich Metavolcanic Rocks (Dk)

Around G.R. -2000N 1100E the rocks have abundant K-feldspar in the matrix and are very similar to the mineralized, K-feldspar-rich metavolcanic rocks (Dkb) at the Billilingra Prospect.

Minor Sedimentary Units in Unit E

The metapelites (Em) appear to form lenticular bodies and have a dark green colour. One metapelite lens has a coarse quartz arenite unit along it's western side and contains a thin lens of buff limestone (El). A metapelite unit intersected in BRAD 101 contains abundant fine magnetite. The rocks along the eastern margin of Unit E, just below the rocks of facies Ehv are commonly very rich in hematite.
Fig. 5.10.a BRAD 102

UNIT E METAVOLCANIC AND METASEDIMENTARY ROCKS
- Esr Sericitic, siliceous, pyritic metavolcanic rock
- Em Metapelite
- Esf Fine-grained, sericitic, metavolcanic rock

UNIT D MINERALIZED METAVOLCANIC ROCKS
- Ds Sericitic, siliceous, pyritic metavolcanic rock

Geological boundary, position accurate
" " inferred
\ Outcrop inspected

Fig. 5.10 Interpreted cross-sections through Driscoll's Hill Prospect percussion-drillholes BRAD 102 (Fig. 5.10.a) and BRAD 101 (Fig. 5.10.b page 148).
Hornblende-Bearing Metavolcanic Rocks (Ehv)

The hornblende-bearing metavolcanic rocks (Ehv) have a weak foliation close to their western margin but are unfoliated further east. The rocks have been described in Section 4.3.g.

Veins

The rocks west of Unit Ehv have abundant veins of quartz, ±pyrite, ±chlorite, ±galena.
5 Mineralization

The siliceous, sericitic, gossanous metavolcanic rocks of facies Ess were intersected in drill-hole BRAD 101 (Fig. 5.10.b). The rocks generally have from three to five percent disseminated pyrite with local zones, from 3 to 10 m wide, with up to fifty percent pyrite. The chips from these pyritic zones consist of:

(i) metavolcanic rocks with abundant disseminated pyrite in the matrix,
(ii) semi-massive pyrite bands with up to sixty percent pyrite and a trace of galena and chalcopyrite in a microcrystalline, siliceous matrix,
(iii) coarse-grained veins of quartz, chlorite, and pyrite, ±galena, ±chalcopyrite. The pyrite commonly occurs along the margins of the veins.

The best individual analyses for 1 m intervals were 305 ppm Cu, 6000 ppm Pb, 9200 ppm Zn, 5.1 ppm Ag and 0.14 ppm Au (Beams, 1984a).

BRAD 102 drilled a stratigraphically lower part of the sequence (Fig. 5.10.a). The hole intersected chloritic metavolcanic rocks generally with <1% disseminated pyrite and narrow zones of sericitic, siliceous, pyritic metavolcanic rocks. The mineralization in these zones is essentially the same as in BRAD 101 except for much lower base-metal sulphide contents. The best individual analyses for 1 m intervals were 99 ppm Cu, 45 ppm Pb, 66 ppm Zn (Beams, 1984a).

6 Other Information

The ground magnetic survey over the prospect by Esso (Beams, 1984a) shows a stepped pattern: Units C and Ds have low total magnetic intensities, unit Es has slightly higher values and unit Ehv has high values. There is a spike in unit Ess, presumably due to the magnetite-rich metapelitic unit.

The soil and rock-chip geochemistry surveys by Esso (Beams, 1984a) showed that the eastern-most gossans have the highest lead and zinc values. Rock chips from some of the gossans had high arsenic values (up to 2500 ppm). One sample had 3200 ppm barium, however no barite was found at the prospect.

7 Initial Interpretation of the Driscoll's Hill Prospect

(i) Most of the mineralization at the Driscoll's Hill Prospect appears to be of synvolcanic, epigenetic style, formed by replacing the matrix of the host rock. The mineralization and alteration envelopes the metapelitic units and there are no obvious exhalative units, especially within Unit Ess. Although it is possible that the chips of semi-massive pyrite are parts of exhalative sulphide beds it is more likely that they represent parts of thick sulphide veins.

(ii) Taking the mineral assemblages in the rocks at face value and not allowing for any metamorphic changes it appears that:

(1) the narrow zones of quartz, sericite and pyrite in facies Ds appear to represent feeder zones to the mineralization to the east,
(2) the feeder zones are enclosed in propylitically altered rocks,
(3) the mineralization along the eastern side of unit Ds and in unit Es is marked by alteration to sericite, quartz, pyrite, ±K-feldspar. These assemblages, with the generally low base-metal values and high arsenic values, suggest that the mineralization is of epithermal style.

(iv) The hematite-rich nature of the rocks of Unit E just below the contact with Unit Ehv may be due to palaeoweathering or it may indicate very oxidised zone of hydrothermal fluids. The ground magnetic results suggest that any magnetite in the volcanics of Unit D were destroyed during the alteration.

(v) The massive, unfoliated nature of Unit Ehv suggests that is unaltered. The hydrothermal activity responsible for the alteration in Unit D may have ceased prior to deposition of Unit E. Alternatively facies Ehv may have been impermeable to the fluids.

5.5.d Driscoll's Hill South Prospect

Around G.R. 94600495 (Map 4.1) in an area called the Driscoll's Hill South Prospect by Esso (Beams, 1984a) there is a hematitic, siliceous zone in the hornblende-bearing metavolcanic rocks (Ehv). Close to the contact with the underlying sericitic, siliceous, gossanous metavolcanic rocks (Ds) there are zones of intensely silicified metavolcanic rocks and blocks of massive and banded jasper.

5.5.e Harnett Prospect

1 Introduction

Of interest at the Harnett Prospect is a stratabound zone of sericitic metavolcanic and metasedimentary rocks which contains numerous bands of gossan, barite and cherty rocks. The prospect is located 14 km north of Cooma and access is by farm tracks from the Chakola road. It is deposit No. 15 on the Bega Metallogenic Sheet (Herzberger & Barnes, 1978).

2 Previous Work

At the Harnett prospect there are a number of small prospecting pits on the gossans but there cannot have been much production (Young, 1974). The prospect was delineated during a reconnaissance stream sediment geochemistry survey by Electrolytic Zinc Company of Australasia Ltd (EZ) during the late 1960's (Cottle, 1970). Since then, companies including EZ; Amax in joint venture with Alpex (Bates & Shepherd, 1971); Tenneco in joint venture with Amax and Alpax (Besley, 1972); Aberfoyle (Rabone & Richardson, 1979); and Newmont in joint venture with Aberfoyle and ICI (Oxenford, 1981) have been involved in exploring the prospect. The companies have done geological mapping; soil, rock-chip and gossan geochemistry; I.P.; Turam E.M.; EMP; shallow percussion drilling, and have drilled five diamond-drillholes. All of these companies were searching for massive sulphide mineralization, similar to the Captains Flat deposit. Newmont attempted to evaluate the gold potential of the area using a rock-chip survey.
The mapping and geochemical work outlined a zone of interest, up to 150 m wide and 4.5 km long, which extends south to the Stonehenge Prospect. The centre of the zone of interest is the area from 1000S 1500E to 2000N 300W (Map 5.5) which contains most of the gossans, gossanous cherts and barite as well as the main geochemical and geophysical anomalies. Grab samples and rock-chip samples of the gossans and gossanous cherts have up to 1160 ppm Cu, 1.35% Pb, 2320 ppm Zn, 26 ppm Ag and 6.95 ppm Au and 15.8% Ba. Within this central area, exploration activity has concentrated around the gossans at 1100N 000E which were tested by drill-holes NP 41, NP 43 and DDH-H3. Immediately north of, and upslope from, these gossans there are coincident soil geochemical anomalies (>200 ppm Cu and >1000 ppm Pb), and IP and Turam EM anomalies which were tested by diamond-drillhole HDD-1. The Newmont EMP survey revealed no conductors indicative of a massive sulphide body.

EZ drilled three, shallow, diamond-drillholes at the prospect (Cottle, 1970) to test coincident geochemical and IP anomalies. The zone of interest intersected in each hole was described as a pyritic, sericitic metavolcanic rock. In NP 41 the zone of interest had generally <20% pyrite with local zones of up to 50% pyrite. The best interval was 5.18 m @ 0.9% Cu, 0.62% Pb, 1.41% Zn, 17 ppm Ag and 1.1 ppm Au. In NP 43 the rock had <20% pyrite in disseminations and bands parallel to the foliation and the banding in the host. It was noted that the banding in the host may be bedding. The hole contained a 43 m interval with 0.3% Cu including a 1.8 m interval with 0.65% Cu, 0.5% Pb, 1.35% Zn, 9.1 ppm Ag and 3.6 ppm Au. In NP 42, which was drilled to the south of the main gossans, the zone of interest contained about 9% disseminated pyrite with a 1.3 m interval @ 0.08% Cu, 0.75% Pb, 2.05% Zn.

HDD-1 was drilled by Tenneco (Besley, 1972). The zone of interest was a siliceous, sericitic metavolcanic rocks with disseminations and bands of pyrite and minor bands of sphalerite and galena. Chalcopyrite occurred in blebs associated with the other sulphides. The overall sulphide content varied from 5 to 10%. The hole intersected a 67 m interval with 0.036% Cu, 0.027% Pb, 0.46% Zn, and <6 ppm Ag. The best 1.5 m interval had 0.9% Cu, 2.0% Pb, 3.0% Zn, 12 ppm Ag and occurs on the western side of the zone of interest. In the metavolcanic rocks to the east of the zone of interest the hole intersected small (<3 m) intervals of magnetite, pyrite and chlorite. These zones are probably responsible for some of the Turam EM anomalies.

DDH-H3 was drilled by Aberfoyle (Rabone & Richardson, 1979) and is described in detail in the following sections. It intersected two zones of sericitic metavolcanic and metasedimentary rocks. The first zone contained a 12.2 m interval with 0.45% Cu, 0.14% Pb, 0.36% Zn and 0.79 ppm Au and the second zone contained a 4.15 m interval with 0.24% Cu, 0.24% Pb, 0.42% Zn and 0.2 ppm Au.

Lachlan Resources N.L. in joint venture with the Shell Company of Australia Ltd did rock-chip sampling and reported 14 m @ 10.5 ppm Au, <18 ppm Hg, 1400 ppm As, 1400 ppm Sb and 120 ppm Mo. Shallow percussion-drilling gave numerous zones with from 1 to 4.4 ppm Au including 14.4 m @ 4.42 ppm Au, 10 m @ 3.60 ppm Au. The sampling showed that the gold is associated with the barite (Lachlan Resources N.L., 1986).
To the north and south of the central area there are fewer gossanous and cherty rocks, no obvious barite and the rocks have low geochemical values. The southern end of the zone of interest is covered by the Stonehenge Prospect (5.5.f).

3 My Work at Harnett

My work at the Harnett Prospect included:

(i) compilation of previous mapping with additional observations in some areas,
(ii) a detailed petrographic and XRD study of the core from DDH-H3,
(iii) a whole rock geochemical study of the drill-core,
(iv) a sulphur isotope study.

4 Geology

General Features

The surface geology of the Harnett Prospect is shown on Map 5.5. A cross-section through drill-holes NP 41, NP 43 and DDH-H3 is given in Figure 5.11.a and the distribution of minerals in DDH-H3 is shown in Figure 5.11.b. The sequence strikes north-northwest (335°) and dips steeply to the west. It is inferred to face eastwards and is therefore slightly overturned. Most of the rocks have a strong foliation which strikes parallel to the strike of the lithological units and has a subvertical dip. The sequence from west to east consists of:

(i) coarse-grained metaporphyry (Cp),
(ii) dark-green metavolcanic rocks (Dv), with minor lenses of black, hematitic chert, gossanous chert and fine-grained sericitic, siliceous metavolcanic rocks.
(iii) the zone of interest, which is composed of mineralized, sericitic, siliceous metasedimentary and metavolcanic rocks (Es) with numerous bands of gossan, gossanous chert and minor bands of pyritic/gossanous quartz arenites (Dq),
(iv) hornblende-bearing metavolcanic rocks (Ehv) with lenses of quartz arenite (Eq) and rare thin metapelite units (Em) in the north which grade to a sequence of interbedded metavolcanic and metasedimentary rocks (Evs) in the south,
(v) metapelites (Fm) with minor interbedded lenses of hornblende-bearing metavolcanic rocks (Fhv). There is a lens of chert along the base of this unit (Fch).

Coarse-Grained Metaporphyry (Cp)

The coarse-grained metaporphyry (Cp) has been described in Section 4.3.e. It is considered to represent a metamorphosed intrusive porphyry with local aplitic and pegmatitic zones.
Fig. 5.11a
Fig. 5.11.a Interpreted cross-section through Harnett Prospect diamond-drillholes DDH-H3, NP 43 and NP 41.
Fig. 5.11.b  Estimated mineral distribution in Harnett Prospect diamond-drillhole DDH-H3. Estimates are based on heights of X-ray diffraction peaks and visual inspection of drill core and thin sections.
**Dark-Green Metavolcanic Rocks, (Dv)**

The dark-green metavolcanic rocks were intersected in the first 288 m of DDH-H3. They are composed of banded and massive metavolcanic rocks which form individual units from a few metres up to several tens of metres thick.

**Relict phenocrysts.** Most relict phenocrysts of quartz have primary embayments. Some have undulose extinction, others form lenticular polycrystalline grains parallel to the foliation and many are microboudinaged. The grains commonly have scalloped margins where they are in contact with sericite folia. Plagioclase phenocrysts originally had a prismatic, subhedral to anhedral shape and some occurred as cumulophyric aggregates of grains, but most are now fractured and microboudinaged. Some of the grains have scalloped margins where they are in contact with folia of phyllosilicates. Some grains show various stages of alteration to sericite, ±green biotite, ±carbonate. The composition of plagioclase is albite.

Relicts of mafic phenocrysts consist of clusters of opaques (iron oxides and/or fine-grained sphene?) with coarse-grained chlorite or green biotite. The opaques occur in parallel planes in the grains suggestive of an original crystallographic direction (biotite (001))? K-feldspar grains occur below 238 m and are texturally the same as plagioclase grains. Magnetite microphenocrysts are usually subhedral and some have been microboudinaged. In places they have rims which contain numerous inclusions of matrix minerals.

**Matrix.** The matrix is composed of quartz, chlorite, ±green biotite, ±sericite, ±K-feldspar with minor amounts of minerals including ±sphene, ±magnetite, ±epidote, ±rutile, ±hematite, ±pyrite and accessory apatite and zircon. On a mesoscale the rocks are matrix-supported and have a very well-developed, apparently continuous foliation defined by the preferred orientation of the phyllosilicates. On a microscale, however, the matrix is domainal with broad phyllosilicate-rich folia wrapping around two types of lenticular microlithons:

(i) microlithons of quartz, ±K-feldspar, ±hematite with minor amounts of phyllosilicates. In places these microlithons contain tiny acicular feldspar grains. The chlorite and biotite in these microlithons may be either randomly oriented or be oriented parallel to the main foliation. In rare cases the phyllosilicate grains are oriented to define a foliation at an angle to the main foliation. Some microlithons have spherulites and others have epidote in spherical aggregates of radiating, acicular grains (relict amygdales?).

(ii) microlithons of massive, randomly oriented, coarse-grained chlorite and/or biotite. Individual grains are usually slightly deformed.

The phyllosilicate-rich folia are crenulated in places and a weak crenulation cleavage (S2) is developed. Pressure beards and the spaces between microboudinage fragments are filled with carbonate, hematite and green biotite. Opaque grains are commonly microboudinaged. The abundance of K-feldspar and sericite increases toward the bottom of the unit and is associated with a decrease in the amount of green biotite.

**Other features.** The banding in the banded metavolcanic rocks is a diffuse lamination on the scale of a few millimetres to a few centimetres and is defined by phyllosilicate rich-phenocryst
poor bands alternating with phenocryst-rich bands. In rare cases the bands have complex interfingering contacts.

**Veins.** There are three types of veins in these rocks (Dv):

(i) thin (<1 cm) veins of carbonate, ±quartz, ±hematite, usually parallel to the main foliation (S₁), and in the axial plane of microfolds of the foliation.

(ii) thick veins, up to ≈2 m wide but usually <20 cm, composed of quartz, K-feldspar, calcite, chlorite, sericite, pyrite, sphalerite, galena, siderite, ±magnetite, ±apatite. One such vein at 157.7 m has three textural domains:

1. fine-grained sericite with minor disseminated pyrite and siderite occurring as a ?selvage along the vein margins and within the veins. The sericite has a good foliation which is crenulated in some rocks. Pyrite commonly has tiny inclusions of chalocpyrite, galena and sphalerite.

2. coarse-grained quartz, K-feldspar, chlorite, siderite, ±magnetite which forms the bulk of the vein. The larger grains are slightly strained with mosaic extinction. Chlorite occurs as masses of rosettes which are not foliated and have a layered appearance in places.

3. euhedral quartz and carbonate.

Most of these veins are parallel to the foliation and in places quartz along the vein margins has scalloped contacts with the enclosing foliated metavolcanic rock. The veins become increasingly abundant down the hole and are most abundant in the interval from the small mineralized zone around 230 m (see below) down to 270 m.

(iii) veins of very coarse-grained milky quartz, sericite and specular hematite. At 5000N 1800W there is a prospecting pit developed on one of these veins.

**Minor Units in Facies Dv**

In DDH-H3 there is 13.2 m interval (223.8 to 237.0 m) of fine-grained, sericitic, siliceous, pyritic metasedimentary and metavolcanic rocks. The interval contains interbanded (interbedded?) quartz-phyric metavolcanics; aphyric cherty rocks; aphyric sericitic pyritic (<20%) rocks (metapelites?) and a few thin (<3 mm) bands of massive pyrite. The rocks contain little or no relict phenocrysts of feldspar but K-feldspar occurs in the matrix in places. Most pyrite grains have a subhedral shape.

This interval probably correlates with the zone of gossanous and hematitic cherts on the surface. In places there are magnetite-rich metapelites associated with these outcrops.

**Zone of Interest**

The zone of interest has a maximum width of about 150 m on the surface and was intersected in DDH-H3 from 288-378 m. A thin, relatively unmineralized and unaltered metavolcanic unit from 341 to 353 m divides the zone into two parts and the western, stratigraphically lower, part is the most important. The zone of interest is composed of mineralized, sericitic, siliceous metasedimentary and metavolcanic rocks (Es) with minor thin
bands of semi-massive sulphide, barite, pyritic chert, metapelite (Em) and pyritic quartz-arenite. The rocks have a strongly banded appearance because the foliation, bedding, most veins and a diffuse lamination in the metavolcanic units are subparallel. The northern part of the zone of interest, including the area intersected by DDH-H3, is dominated by metavolcanic rocks. Further south, however, metasedimentary units become more abundant.

Mineralized, sericitic, siliceous metasedimentary and metavolcanic rocks (Es). The metavolcanic rocks have from two to twenty percent relict phenocrysts of quartz, K-feldspar, ±plagioclase in a matrix of sericite, quartz, pyrite, K-feldspar, ±chlorite, ±hematite and ±?orpiment with accessory zircon. Quartz grains are embayed and have thin rims of polycrystalline quartz. Plagioclase phenocrysts are restricted to the interval from 341 to 353 m. K-feldspar occurs as large, prism-shaped grains, similar to relict plagioclase phenocrysts. The grains have diffuse margins which appear to be intergrown with the matrix. Relict phenocrysts have undulose extinction and are commonly broken and microboudinaged. There are no obvious lithic fragments, however lenticles of sericite, mostly 1 x 5 mm, may be after vitriclasts.

The metavolcanic rocks are matrix-supported and the relict phenocrysts are very poorly sorted. The rocks are banded on a scale from 1 mm to 40 cm, with fine-grained, almost-aphyric bands and coarse-grained, phric bands. The matrix is strongly foliated and domainal with thin folia of sericite wrapping around microlithons rich in microcrystalline quartz and K-feldspar, ±sericite, ±pyrite. In places there are spherulites in the siliceous microlithons in the matrix.

The metasedimentary rocks on the surface consist of arkosic sandstones and quartz arenites. The rocks have a moderate foliation and usually have a weak bedding.

A pyritic, quartz arenite unit occurs in DDH H3 from =336 to 340 m. It is composed of poorly sorted, sand-size quartz grains with a matrix of pyrite and minor zircon, ?orpiment, sericite and quartz. The quartz grains have a subrounded to subangular shape with very rare embayments and commonly have diffuse margins of intergrown quartz and sericite. The rock is framework-supported and bedding is defined by slight variations in the grain size of the quartz grains and the quartz:pyrite ratio. There are float-blocks of gossanous quartz arenite (Dqa) on the surface (around G.R. 200E 1200N) which probably correlate with these rocks. It is possible that these rocks are part of the long quartz arenite unit (Eq) which extends north from this area in the hornblende-bearing metavolcanic rocks (Ehv).

Sulphide mineralization. The sulphide mineralization consists of approximately ten percent pyrite which occurs as disseminations in all rock types and in narrow (<10 cm) banded, massive intervals. Individual bands are up to 5 cm thick and are composed of:

(i) massive coarse-grained pyrite with a trace of chalcopyrite, sphalerite and galena,
(ii) subequigranular, massive pyrite, barite and quartz,
(iii) microcrystalline quartz and sericite with minor pyrite.

The bands of massive, coarse-grained pyrite have interstitial quartz, K-feldspar and carbonate. Pyrite grains are mostly very fine grained (<<1 mm) but are coarse grained (<3 mm) in places. They are anhedral to subhedral and slightly fractured. The fractures are filled with fibrous quartz. Larger grains have inclusions of quartz around their margins. Chalcopyrite, galena
and sphalerite commonly occur together as tiny inclusions in pyrite grains, along fractures in pyrite grains and as interstitial masses between pyrite grains.

In the bands of pyrite, barite and quartz there are minor amounts of chalcopyrite, sphalerite and galena which occur as tiny grains in pyrite. Quartz forms equant grains and as fibrous aggregates in extensional microfractures.

Some of the bands of microcrystalline quartz and sericite with minor pyrite have some larger quartz grains which are probably either volcanic phenocrysts or detrital grains.

**Gossans and gossanous cherts.** On the surface the gossans are composed of thin bands of massive and cellular limonite and yellow jarosite interbanded with bands of metasedimentary and metavolcanic rocks. Most gossanous cherts are <1 m thick and are up to several tens of metres long. They have a diffuse banding which is parallel to strike and only rarely have a good banding. Most are composed of quartz grains (relict volcanic phenocrysts) supported in a matrix of microcrystalline quartz with minor sericite, ± disseminated pyrite.

**Barite bands.** Around the centre of the zone of interest there are sulphidic barite bands up to about 30 cm thick and several metres long. To the south of these bands there are a few thin veins of barite which are <10 cm thick and several tens of metres long and parallel to the foliation in the enclosing rocks. The barite bands are commonly interbanded with, and contain lenticular domains of, matrix-supported metavolcanic rocks and metasedimentary rocks.

**Metapelites.** No metapelites (Em) were intersected in DDH-H3 however there are numerous thin zones of aphyric, sericitic metapelites on the surface. At the northern end of the prospect, around 5500N 2000W, there is a small metapelite unit which is composed of pyrophyllite, sericite, kaolinite, hematite and quartz. It grades to the east, into a hematitic metapelite and then to a gossanous chert.

**Veins.** Veins in the zone of interest are of two main types:

(i) veins of quartz and pyrite with minor sphalerite, galena, chalcopyrite and ? siderite which are parallel to, or cut across, the foliation. In places the quartz has columnar fibrous microstructures perpendicular to the vein walls.

(ii) veins of quartz, K-feldspar, carbonate, pyrite, sericite, ± white albite, ± chlorite, and minor ± barite, ± sphalerite, ± chalcopyrite, ± galena, ± orpiment. The larger grains are fractured and have undulose extinction, and carbonate fills fractures in the grains. Chlorite occurs as undeformed rosettes.

**Hornblende-Bearing Metavolcanic Rocks (Ehv)**

On the surface facies Ehv is composed of dark-grey metavolcanic rocks which are commonly poorly foliated and contain hornblende. The western side (base) of the unit is more strongly foliated and contains more phyllosilicates. In DDH-H3 (378 to 394.1 m) the unit is composed of relict phenocrysts of quartz, K-feldspar, minor plagioclase and mafic relicts in a matrix of quartz, sericite, chlorite, K-feldspar and accessory zircon. The rocks have a matrix-supported texture and a good dominal foliation with sericitic folia anastomosing around
siliceous microlithons. Some of the siliceous microlithons contain fibrous textures which may be relict spherulites. In places there are thin (<1 cm) beds which are very crystal rich.

In the hornblende-bearing metavolcanic rocks (Ehv) intersected in diamond-drillhole HDD-1 Besley (1972) reports thin intervals rich in chlorite, magnetite and pyrite.

Veins in the hornblende-bearing metavolcanic rocks (Ehv) are composed of quartz, K-feldspar, calcite, pyrite, chlorite and ±barite. Most are <1 cm wide, subparallel to the foliation and are markedly more abundant in the foliated rocks close to the contact with the zone of interest.

**Quartz Arenite (Eq)**

There is a discontinuous series of outcrops of quartz arenite (Eq) extending from 4000N 150E to near the zone of interest at 1200N 200E. The outcrop pattern suggests that there is a single unit which cuts across most of Unit E. The unit is notable because:

1. it strikes at an angle to the strike of Units D and F,
2. the numerous quartz veins in the rocks are parallel to the strike of the unit and not parallel to the foliation in the surrounding metavolcanics.

The rocks are moderately sorted, framework-supported and in places are feldspathic. They have a weak banding, parallel to strike, which is probably bedding.

**Interbedded Metavolcanic and Metasedimentary Rocks (Evs)**

In the interbedded metavolcanic and metasedimentary rocks (Evs) the metavolcanic rocks are very similar to the hornblende-bearing metavolcanics (Ehv). The metasedimentary rocks include quartz arenites, metapelites and framework-supported metavolcanic rocks (meta-arkoses?). In places the sedimentary beds contain abundant fine-grained magnetite.

**Chert (Fch)**

Along the base of Unit F, east of the central part of the Harnett prospect, there is a <2 m wide unit of chert. It is bedded in places and is graded from a clean chert in the west to a muddy chert further east. In places it contains gossanous bands and there are large blocks of limonitic gossan (after massive pyrite?) on the western side of the unit. The chert has a weak foliation and the metavolcanic rocks immediately west of the chert are strongly foliated and relatively phyllosilicate-rich.

**Interbedded Metapelites (Fm) and Metavolcanics (Fv).**

These units are described in Section 4.3.h.

**Notes on the Distribution of Minerals in DDH-H3**

The distribution of minerals in DDH-H3 (Fig. 5.11.b) shows that plagioclase is absent from the zone of interest except for the metavolcanic unit from 341 to 353 m. K-feldspar occurs as a matrix mineral in the small siliceous microlithons in the rocks throughout the area. It also occurs as relict volcanic phenocrysts in the lower part of the dark-green metavolcanic rocks (Dv) and in the
zone of interest, however it is not clear if it formed as a primary volcanic phenocryst or by replacement of plagioclase phenocrysts. Hematite is common in the dark-green metavolcanic rocks (Dv) but is rare or absent in the zone of interest. The XRD charts of samples of the dark-green metavolcanic rocks (Dv) from 62 to 65 m show amphibole peaks. This suggests that the relicts of mafic phenocrysts may contain some of the original amphibole, but this was not seen in thin section.

5 Initial Interpretation of the Harnett Prospect

(i) The dark-green metavolcanic rocks (Dv) have a predominantly metamorphic fabric and most of the thin, phyllosilicate-rich folia were probably produced by pressure-solution processes during metamorphism. In some rocks, however, there are indications of premetamorphic textures. The small siliceous microlithons between the phyllosilicate-rich folia preserve premetamorphic textures (and minerals?) such as spherulites. The microlithons which contain randomly oriented grains of chlorite and biotite, and particularly the microlithons composed of large masses of randomly oriented chlorite and/or biotite, may be preserving premetamorphic alteration textures and minerals. It is reasonable to assume that the biotite in these microlithons was produced during metamorphism, probably due to reaction of chlorite with K-feldspar in the matrix of the rocks. Overall, the textures suggest that the rocks were altered prior to metamorphism and that alteration included the production of randomly oriented grains and large aggregates of chlorite.

(ii) The spherulites and possible amygdales in parts of the dark-green metavolcanics (Dv) suggest that at least part of the unit was originally deposited as lavas, although a pyroclastic origin cannot be ruled out. The banding in parts of the rocks may have been produced by:
   (1) original volcanic bedding,
   (2) flattening of volcanic lithic fragments during metamorphism,
   (3) flattening of an original hydrothermal breccia fabric.

(iii) The zone of fine-grained, sericitic, siliceous, pyritic metasedimentary and metavolcanic rocks, with gossanous and hematitic cherts, close to the top of the dark-green metavolcanic rocks (Dv) represents a thin sedimentary horizon enclosed in thick volcanic units. The rocks have been altered, presumably before metamorphism, to an assemblage of what is now quartz, sericite, pyrite, ±K-feldspar. Any plagioclase was destroyed during the alteration. The zone may represent either a small exhalative horizon which was subsequently buried or a zone of footwall alteration, perhaps along a particularly permeable sedimentary horizon. The hematitic nature of some of the units in this zone may be due to:
   (1) the formation of oxidised exhalites at an early stage of the hydrothermal deposition,
(2) late-stage alteration which overprinted the earlier ?sulphidic units,
(3) alteration of magnetite-rich sedimentary units.

(iv) The rocks in the zone of interest accumulated as a sequence of volcanics and sediments in a shallow-water environment. The volcanic units probably include both epiclastic and pyroclastic units. The quartz arenites were probably produced by the reworking of volcanic sediments in a high-energy environment such as a river or beach.

(v) The gossanous cherts represent zones in which the matrix of matrix-supported volcanic units has been replaced by silica with minor sericite and pyrite. This suggests that the cherts are not exhalative. They also lack the bedding which might be expected in exhalative units.

(vi) The mineralization may have formed:

(1) as exhalites,
(2) as subsurface zones, parallel to strike, of replacement and/or veining,
(3) as veins during the metamorphism due to the redistribution of pre-existing mineralization into sites formed by dilating the foliation,

The fact that the bands of mineralization are separated by matrix-supported metavolcanic bands a few centimeters wide strongly suggests that the bands are veins rather than exhalites. The mineralization is deformed and so it must predate the last deformational event and my present bias is to say that it formed during a synvolcanic event. The mineralization probably originally had the assemblage quartz, pyrite, sericite, barite, ±K-feldspar and was associated with destruction of any plagioclase and mafic minerals.

(vii) The small metapelite unit at 5500N 2000W composed of pyrophyllite, sericite, kaolinite, hematite and quartz probably represents a zone of synvolcanic alteration which has been metamorphosed. It is possible that the pyrophyllite has been formed by reaction of kaolinite with quartz during metamorphism. Nevertheless, in its present form, the mineral assemblage is similar to the advanced-argillic assemblage (Meyer & Hemley, 1967). Problems with this interpretation may be the apparent lack of any sulphate minerals and the presence of sericite. Pyrophyllite and kaolinite were not detected in DDH-H3.

(viii) The poorly foliated nature of the hornblende-bearing metavolcanic rocks (Ehv) suggests that they are unaltered except along the western side of the unit and below the chert unit (Fch).

(ix) The discordant nature of the quartz arenite unit (Eq) is probably due to it being deposited on a palaeosurface which was at an angle to the bedding in most of the other units. This surface may have been produced by erosion or it may be the primary depositional surface of the underlying volcanic unit.

(x) The compositional grading, bedding and the stratigraphic position of the small chert (Fch) at the base of Unit F suggest that it was deposited as an exhalatite. The gossanous bands in the chert and the blocks of limonitic gossan associated with the
unit suggests the possibility of massive sulphide mineralization akin to Kuroko style along this contact.

(xi) The rocks at the Harnett Prospect record a range of depositional environments. The thick volcanic units with only minor sedimentary rocks of Units B, Cv, Cm and Dv suggest a subaerial setting with local shallow-marine and/or lacustrine environments. The interbedded metasedimentary and metavolcanic rocks of Unit E were probably deposited in a mixed shallow marine, subaerial (and lacustrine?) environment at the time of a marine transgression. The thick metapelites of Unit F, with (allochthonous?) limestone, clearly indicate a low-energy (deep-water?) marine environment.

(xii) The metamorphic textures suggest that the main foliation \((S_1)\) in phyllosilicate-rich microlithons has been crenulated by a later event to form a weak crenulation cleavage \((S_2)\). The siliceous microlithons which have phyllosilicates at a consistent angle to \(S_1\) may represent:

1. an earlier foliation which has been obliterated and not obviously crenulated by \(S_1\),
2. zones of recrystallization after the formation of \(S_1\),
3. relict domains of a premetamorphic (alteration?) fabric.

(xiii) The sericite in folia parallel to the foliation probably formed during the metamorphism and may be the result of dissolution of matrix K-feldspar due to pressure solution processes associated with foliation development. Sericite in the siliceous microlithons may represent premetamorphic sericite originally produced by alteration.

(xiv) The K-feldspar in the matrix of the rocks may have formed due to either synvolcanic alteration or devitrification unrelated to alteration. The spherulites in the rocks are probably composed of K-feldspar and quartz and suggest that much of the K-feldspar in the rocks could be the result of devitrification of an originally glassy matrix. Similarly, the K-feldspar phenocrysts may be primary volcanic phenocrysts, however this would suggest that the volcanics in the mineralized horizon have an unusual composition, because volcanic rocks elsewhere in the study area do not have primary K-feldspar phenocrysts. An alternative interpretation is that the K-feldspar phenocrysts were produced by alteration of plagioclase phenocrysts.

(xv) Summary of the inferred alteration assemblages and zoning:

1. facies Dv; widespread development of chlorite and hematite with plagioclase stable,
2. facies Es; strong development of sericite, pyrite, barite and quartz with some K-feldspar; plagioclase altered to K-feldspar; local zones of intense silicification and local zone(s) of kaolinite, sericite, ?pyrophyllite , hematite, quartz.
3. facies Ehv; little or no alteration with K-feldspar, sericite, pyrite development in zones along the western side of the unit.
(xvi) The veins in the rocks may be either synvolcanic hydrothermal veins which have been metamorphosed or metamorphic veins. The mineral assemblages are typical of veins in epithermal systems (Hayba et al., 1985) and the presence of K-feldspar and carbonate is characteristic of boiling zones (Henley, 1985). This interpretation is supported by the increased abundance of veins in the mineralized zone. Alternatively the veins may be metamorphic because:

1. they are parallel to the foliation and do not appear to be broken fragments of premetamorphic veins which have been rotated into their present orientation.
2. the chlorite in the veins is virtually undeformed whereas sericitic zones are foliated which suggests that the veins formed during the metamorphism and enveloped pieces of foliated host rocks.

(xvii) The mineralization is syngenetic but not exhalative. Initial impressions are that there are two likely genetic models for the mineralization:

1. Synsedimentary Model. The mineralized horizon may have formed at the surface discharge site of a hydrothermal system at the time of deposition of facies Es. The cherts may represent silicified zones and the mineralization does not form a single stratiform horizon because either it was diluted due to the influx of sedimentary and volcanic material or it formed below the surface. The small metapelites (Dm) composed of minerals which are typical of the advanced-argillic alteration assemblage may represent a metamorphosed boiling mud pool deposit similar to those in the Taupo Volcanic Zone of New Zealand (Hedenquist, 1985). The exhalative chert (Fch) was deposited during the waning stages of the same hydrothermal system, after the mineralized horizon had been buried.

2. Synvolcanic epithermal model. In this model the mineralized horizon formed prior to the deposition of Unit F by subsurface replacement along permeable lithologies. The thick volcanics of facies Ehv acted as aquicludes which resulted in extensive, near-surface, lateral flow of the fluids through the permeable sedimentary units. The exhalative chert (Fch) is a surface discharge site. This model implies that the hydrothermal system was operating immediately after the marine transgression and at the start of deep water sedimentation. One problem with this model is the lack of mineralization in the quartz arenite (Fq) which should have been a good aquifer.

5.5.f Stonehenge Prospect

1 Introduction

Of interest at the Stonehenge Prospect is a chert horizon in slightly gossanous, sericitic metavolcanic rocks. The is prospect located 7 km northeast of Cooma and approximately 2.5 km along strike to the south of the Harnett Prospect.
2 Previous Work

The Stonehenge Prospect was treated as the southern part of the Harnett Prospect by exploration companies prior to the work of Esso. Esso (Beams, 1984b) outlined two ground PEM anomalies to the east of the chert unit and tested these with two diamond-drillholes. Only a trace of disseminated pyrite was intersected and the anomalies were considered to be due to the contact between metavolcanic rocks in Unit E and the metapelites (Fm). Crone PEM, soil geochemistry and ground magnetic surveys were also conducted.

3 My Work at Stonehenge Prospect

My work at Stonehenge Prospect included:
(i) mapping,
(ii) logging both diamond-drillholes,
(iii) limited petrography,
(iv) whole rock geochemistry on three samples (Ch. 7).

4 Geology

The surface geology at the Stonehenge Prospect is shown on Map 5.6 and a cross-section through drill-hole BRYZ 001 is shown in Fig. 5.12. The sequence strikes north-northwest, has subvertical dips and faces east. The sequence, from west to east, consists of:
(i) interbedded metavolcanic rocks and metasedimentary rocks at the top of Unit B (Not shown on Map 5.6 but see Map 4.1).
(ii) coarse-grained metaporphyry (Cp) which contains a small zone of medium-grained metavolcanic rocks with minor quartz arenite (Cv),
(iii) sericitic, siliceous, gossanous metavolcanic rocks (Ds) with cherts (Dch) and local areas of dark-green metavolcanic rocks (Dv) and crystal-rich metavolcanic rocks ( Dx). The sericitic, siliceous, gossanous metavolcanic rocks (Ds) are composed of relict volcanic phenocrysts of embayed quartz, partly sericitised plagioclase and mafic relicts (chlorite and sphene) supported in a strongly foliated matrix of quartz, chlorite, sericite and accessory zircon and apatite. In the matrix, folia of chlorite or sericite with opaques, wrap around siliceous microlithons. In places, the rocks contain gossanous zones after disseminated sulphides (probably mainly pyrite). There are also cream-coloured, sericitic zones in the unit which contain K-feldspar phenocrysts. The cherts (Dch) form abundant large blocks and true outcrop width is difficult to determine but is probably no more than 20 m at most. The cherts are composed of minor volcanic quartz crystals supported in a matrix of microcrystalline quartz with minor limonite after ?pyrite and rare sericite wisps. The rocks have a diffuse banding in places but are not laminated.
The dark-green metavolcanic rocks (Dv) are similar to facies Dv at Harnett.
(iv) a sequence of interbedded metavolcanic and metasedimentary rocks (Evs). The matrix of the metavolcanic rocks is sericitic with only minor chlorite. There is a trace of
UNIT F  METAPELITES WITH MINOR META VOLCANIC ROCKS
- Fm  Metapelite

UNIT E  META VOLCANIC AND META SEDIMENTARY ROCKS
- Ev  Metavolcanic rock
- Eva  Bedded volcanic metasandstone and metasiltstone
- Emc  Metapelite with calcareous metasiltstone

UNIT D  MINERALIZED META VOLCANIC ROCKS
- Ds  Sericitic, siliceous, gossanous metavolcanic rock
- Dch  Chert

Fig. 5.12  Interpreted cross-section through Stonehenge diamond-drillhole BRYZ 001.
disseminated pyrite in the rocks and some thin beds have high disseminated pyrite content. There are rare thin <2 mm bands of massive pyrite and toward the top of the unit there are rare 2 x 20 mm lenses of chlorite and pyrite. In places the quartz arenites have thin (<3 cm) beds with abundant magnetite. Veins in the rocks are composed of quartz with minor ±chlorite, ±pyrite, ±galena, ±K-feldspar, ±carbonate.

(v) finely laminated metapelites (Fm) which have a trace of disseminated pyrite and small (up to 4 x 30 mm) massive lenses of pyrite in places. The metapelites have veins of quartz, ±carbonate, ±pyrite.

5 Initial Interpretation of the Stonehenge Prospect

(i) The sericitic, siliceous, gossanous metavolcanic rocks (Ds) appear to represent the southern extension of the same depositional unit as the dark-green metavolcanic rocks (Dv) at the Harnett Prospect. The difference between the rocks is due to differences in the type of alteration.

(ii) The sericitic, siliceous, gossanous metavolcanic rocks (Ds) appear to be free of metasedimentary units and have a present thickness of at least 150 m. Assuming that Units B and D are in their original relative position and that none of the sequence has been lost during intrusion of Unit Cp then this volcanic unit occurs above and below shallow-marine sequences. This suggests a shallow-marine environment of deposition for the volcanics although the possibility that the Unit D volcanics were subaerially deposited (and possibly eroded) prior to deposition of Unit E cannot be ruled out.

(iii) The cherts (Dch) are probably silicified volcanic rocks and not exhalites since they are not bedded, have volcanic quartz crystals supported in the matrix and do not appear to be directly associated with other sedimentary facies.

(iv) The dark-green metavolcanic rocks (Dv) appear to represent zones with more chlorite. It is not clear whether this is an alteration feature or not.

(v) Although no detailed study of the alteration assemblages has been done initial impressions are that the alteration consisted of a broad zone of sericitic alteration with local pyrite development, partial plagioclase destruction and local silicified zones at the top of unit Ds and throughout unit Evs.

(vi) Compared to the Harnett Prospect, the mineralization and alteration at the Stonehenge Prospect is much weaker with much less sulphide and apparently no barite. The zones of silicification at Stonehenge are concentrated in the thick metavolcanic units (Dv) which appears to be a stratigraphically lower level than at Harnett.
5.6 OTHER MINERALIZATION IN UNITS E AND F

5.6.a Jaspers Northeast of Cosgrove Hill
Northeast of Cosgrove Hill (Map 4.1, around G.R.94401660), there are abundant blocks of banded jasper in well-foliated outcrops of the hornblende-bearing metavolcanic rocks (Ehv). The jaspers may be either metamorphic veins or synvolcanic alteration zones. If the latter is true then this implies that the hydrothermal system persisted during the deposition of Unit E.

5.6.b Chert Unit at Harnett
At the Harnett Prospect there is a chert unit at the base of the thicks metapelites (Fm). The unit is described in Section 4.3.h and above in Section 5.5.e. Further south, there is nothing in the Stonehenge Prospect drill-holes which might be correlated with this chert.
CHAPTER 6

THE GEOLOGY OF THE PEAK VIEW PROSPECT

6.1 INTRODUCTION

6.1.a General
At the Peak View Prospect there is a small massive sulphide lens in a sequence of ?Silurian metavolcanic and metasedimentary rocks. This style of mineralization does not occur in the Bredbo-Bunyan area and so it provides an opportunity for comparison.

6.1.b Location
The Peak View deposit is located 53 km south of Captains Flat and 22 km east-southeast of Bredbo (Fig. 1.1). It is approximately two kilometres northwest of the Peak View Post Office and is reached using farm tracks, fire trails and exploration company tracks. On the Cooma 1:100 000 Sheet the prospect is surrounds G.R. 134070.

6.1.c Previous Work
There are two shallow prospecting pits in the mineralized horizon at 3350E, 6820N and 3450E, 6550N (Map 6.1). There is no information about them and they were presumably dug by gold prospectors earlier this century. The Peak View Prospect (Western Mining Corporation, 1984) was delineated by the Western Mining Corporation Ltd (WMC) during 1977. Exploration at the prospect by WMC included reconnaissance mapping, gridding, soil and gossan geochemistry surveys, ground magnetics, I.P. and TEM surveys and drilling 14 diamond-drillholes. The work outlined the small massive sulphide body. CSIRO did a whole-rock geochemical study of the host rocks (73 samples) as part of a research program into the use of primary haloes and lithogeochemistry in mineral exploration (Whitford, et. al., 1984).

6.1.d My Work at Peak View
My work at the Peak View prospect included:
(i) 1:1 000 scale mapping,
(ii) logging diamond-drillholes PVD 2, 3, 6, 7, 12, 14 and 15B,
(iii) a detailed petrographic study using surface samples and drill-core,
(iv) an XRD study of the footwall and hangingwall sequence,
(v) a whole-rock geochemical study of 12 drill-core samples.
6.2 REGional GEOLOGY

6.2.a General
The Peak View prospect is located in the southern part of the Rocky Pic Block (Figs 2.5 and 4.1) in one of the small, meridionally trending outliers of ?Silurian metavolcanic and metasedimentary rocks which occur along the Narongo Fault, south of the Captains Flat Block. The Narongo Fault separates the Cullarin Block from the southern part of the Rocky Pic Block. The Peak View Outlier is faulted along both sides and the western side is shown as the Narongo Fault by Hayden (1980).

West of the Peak View Outlier the Cullarin Block is composed of Ordovician metasediments with minor elliptical granite bodies. The metasedimentary rocks are well-foliated and metamorphism varies from chlorite to andalusite grade (Hayden, 1980). To the east in the Rocky Pic Block there is a narrow (<2 km) belt of Ordovician metasedimentary rocks followed by the very extensive granites of the Jerangle Igneous Complex. The Ordovician rocks in this narrow belt to the north of the Peak View area only reach chlorite grade (Hayden, 1980).

6.2.b Ordovician Metasedimentary Rocks (Om)
The Ordovician rocks to the east of the Peak View Outlier, intersected (and cored) in diamond-drillhole PVD 14, consist of well-bedded metapelites with minor metasandstones. The metapelites are composed of quartz, muscovite, tourmaline, and zircon grains with rare pyrite porphyroblasts in a matrix of microcrystalline quartz and sericite. The rocks have a well-developed slatey cleavage (S1) which is parallel to bedding and is weakly crenulated. The sequence in this area dips east and graded beds indicate that it faces east.

6.3 GEOLOGY OF THE PEAK VIEW OUTLIER

6.3.a General
The Peak View Outlier is up to three hundred metres wide and has been mapped for a strike length of three kilometres. The extent of the outlier beyond this is not known. The contacts with the surrounding Ordovician rocks are interpreted to be faults since beds in the outlier are truncated at the contacts. The eastern contact was intersected in PVD 14 and is marked by a few centimetres of intense slickensides which cut across bedding in an Ordovician metasiltstone unit. The eastern fault dips east at about 70°.

The Peak View Outlier contains a central mineralized horizon which is underlain by chloritic metavolcanic rocks with minor metasedimentary rocks and is overlain to the east by siliceous, sericitic metavolcanic rocks. The sequence dips east at about 60° and one graded bed in PVD 14 fines east. This grading and the inferred alteration zoning suggest that the sequence faces east. The bounding faults have cut the sequence at a low angle to strike. The eastern fault truncates the mineralized horizon at about 6050N and only footwall rocks occur to the south of this area.
There is no internal evidence for the age of the Peak View sequence but on lithological grounds it is readily correlated with the Late Silurian sequence in the Captains Flat Block to the north. The sequence is unlikely to be of Ordovician age because:

(i) there are no Ordovician metavolcanic rocks in the surrounding structural blocks,
(ii) the Ordovician metavolcanics elsewhere in the Canberra region have dominantly mafic compositions, in contrast to the felsic compositions at Peak View.

6.3.b Footwall Sequence

1 General

The footwall sequence at Peak View consist of mainly chloritic, pyritic metavolcanic rocks (Fc) with minor K-feldspar-bearing metavolcanics (Fk), sericitic metasiltstones (Fsm), metalimestone (Fl), metapelite (Fm), coarse-grained metavolcanic rocks (Fvo) and interbedded volcaniclastic rocks and limestones (Fvs). The metasedimentary units are an important component of the footwall sequence south of about 6300N.

2 Description of Facies

Chloritic, Pyritic Metavolcanic Rocks, (Fc)

The chloritic, pyritic metavolcanic rocks (Fc) are composed of relict phenocrysts of quartz and plagioclase in a matrix of quartz, feldspar, ±chlorite, ±sericite, ±biotite, ±carbonate with minor pyrite and accessory zircon, apatite and ?sphene/?epidote.

Relict phenocrysts. Relict phenocrysts of quartz in least deformed rocks are equant, subhedral to anhedral grains with embayments. Most are less than two millimetres in diameter. In more deformed rocks quartz phenocrysts have undulose extinction, deformation lamellae and zones of subgrain development. In strongly deformed rocks they occur as lenticular polycrystalline aggregates. Chlorite commonly occurs along subgrain boundaries.

Relict phenocrysts of plagioclase have a tabular, anhedral to rarely subhedral shape with a diameter of less than two millimetres. Most grains are albite, however rare grains have more calcic cores. The grains are fractured, bent or microboudinaged and most contain abundant tiny grains of chlorite, ±biotite, ±sericite, ±carbonate, especially along cleavages. Some grains have rims of albite which are free of these inclusions but elsewhere the grains have diffuse margins which grade into the matrix. Cumulophyric grains of plagioclase occur rarely.

A few of the rocks contain aggregates of tiny epidote grains which may represent relicts of mafic phenocrysts.

Porphyroblasts. Porphyroblasts of pyrite occur as disseminations in the rocks and they are concentrated in the phyllosilicate-rich folia in the matrix. Most are single subhedral to euohedral grains but some are aggregates of small grains. The S1 foliation abuts the grains and does not wrap around them. The pyrite grains sometimes contain inclusions of matrix minerals. Pyrite is a common inclusion in relict phenocrysts of plagioclase in some rocks.
Matrix. The matrix has a well-developed domainal foliation ($S_1$). Phyllosilicate-rich folia form anastomosing networks or parallel bands which wrap around relict phenocrysts and quartzofeldspathic microlithons. The phyllosilicate-rich folia are up to about five millimetres wide and are composed of chlorite, ±biotite, (±sericite) with a strong preferred orientation, parallel to the foliation. The folia tend to have sharp contacts with relict phenocrysts and the phenocrysts in the folia are may be smaller than those in the quartzofeldspathic microlithons. Tiny grains of ?epidote/?sphene are concentrated in the folia in some rocks. An incipient crenulation cleavage ($S_2$) is developed in some folia and others have inclusions of grains of chlorite, ±biotite which are oriented with (001) at an angle to the main foliation.

The quartzofeldspathic microlithons may be up to about ten millimetres wide and are composed of quartz, albite, ?K-feldspar and minor phyllosilicates. They generally have a subequigranular, granoblastic texture, however within a single thin section, different microlithons commonly have slightly different grainsizes and varying degrees of foliation development. The microlithons commonly contain aggregates of chlorite, ±biotite which are oriented at angles to the foliation.

Other textures. The ratios of the abundance of chlorite/biotite/sericite change considerably even in a single drill-hole over a distance of a few metres. In the area to the west of the sulphide body the rocks contain mainly chlorite and biotite. Further south, biotite is less abundant and the rocks have subequal sericite and chlorite. In crenulated, phyllosilicate-rich folia, throughout the unit, sericite occurs as fine grains which define a crenulation cleavage ($S_2$). In some rocks biotite and chlorite both occur in the phyllosilicate-rich folia however only chlorite occurs in the quartzofeldspathic microlithons.

There are no unequivocal fragmental textures in the rocks although the domainal foliation commonly gives the rocks a fragmental appearance. Fibrous pressure beards are common, especially around pyrite grains, and are composed of quartz, ±biotite, ±chlorite, ±?albite and ±carbonate. Some rocks have fibrous albite in the matrix which is similar to the feldspar-rich hangingwall rocks (Hvf) (6.3.d). In a few rocks which are particularly pyrite- and chlorite-rich there are very few relict phenocrysts of plagioclase.

Veins. The chloritic, pyritic metavolcanic rocks contain veins of:

(i) quartz, K-feldspar and carbonate which cut the $S_1$ foliation and have fibrous microstructures parallel to the $S_1$ foliation;

(ii) very thin carbonate veins which are parallel to $S_1$.

**K-Feldspar-Bearing Metavolcanic Rocks (Fk)**

The K-feldspar bearing metavolcanic rocks (Fk) are characterised by their low chlorite content and the presence of abundant K-feldspar in the matrix. The rocks have a pale-yellow colour and a weak to strong $S_1$ foliation. The rocks are composed of relict phenocrysts of quartz, plagioclase and mafic minerals supported in a matrix of quartz, K-feldspar and ?albite with minor chlorite, biotite, sericite and pyrite with accessory zircon and apatite.
Relict phenocrysts. Relict phenocrysts of quartz, in the least-deformed rocks, have an equant, anhedral to subhedral shape and have primary embayments. Some have rims of fibrous quartz and K-feldspar. In more-deformed rocks the quartz grains have undulose extinction, deformation lamellae and may form lenticular aggregates of grains. Quartz grains commonly have scalloped margins where they are in contact with sericite folia.

The relict phenocrysts of plagioclase (now albite) in the least-deformed rocks are prismatic with an anhedral to subhedral shape and are almost free of inclusions/alteration products. In more deformed rocks the relict plagioclase grains have a very complex extinction pattern and some have abundant inclusions of tiny phyllosilicate grains. There are rare cumulophyric grains.

Aggregates of biotite and sphene are probably relics of mafic phenocrysts (including hornblende?).

Porphyroblasts. Pyrite forms subhedral porphyroblasts. The $S_1$ foliation is truncated by the pyrite porphyroblasts and does not wrap around them. The grains have complex pressure beards composed of quartz, chlorite and biotite commonly with (001) oriented subparallel to the crystal faces on the pyrite grains. Slight variations in the orientation of (001) along the pressure beards indicate that the pyrite grains have been rotated during deformation. In places the $S_1$ foliation is curved in toward the pyrite grains so that it meets the crystal faces at an angle close to 90°. This texture is similar to the texture called "symmetrical foliation microboulinage" by Platt & Vissers (1980).

Matrix. In the least-deformed rocks the matrix has a microcrystalline texture with minor coarser-grained, recrystallized domains. Spherulites are common and chlorite forms randomly oriented flakes. In places there is a trace of disseminated sphalerite in the matrix. Sericite and biotite are aligned to define a mostly continuous $S_1$ foliation although in places sericite grains form tiny folia parallel to the foliation. In more strongly deformed rocks the matrix contains long folia of sericite and/or biotite which wrap around the relict phenocrysts. In places the folia are crenulated and a differentiated crenulation cleavage ($S_2$) has developed. $S_2$ is defined mainly by sericite grains. Pressure beards are composed of chlorite and quartz.

Veins. The K-feldspar-bearing metavolcanic rocks contain veins of quartz, ±feldspar, ±carbonate and ±pyrite which are subparallel to the $S_1$ foliation. In some rocks the pyrite is concentrated in the veins. The veins are deformed.

Coarse-Grained Metavolcanic Unit (Fvo)

Around G.R. 5700N 3600E there is an approximately ten metre thick ?lens of coarse-grained metavolcanic rocks. The unit is composed of coarse (<5 mm) crystals of quartz in a strongly foliated matrix of quartz and sericite with a trace of disseminated limonite after pyrite.

Metasedimentary Rocks

Metasedimentary rocks are an important component of the footwall sequence south of 6300N and are best shown in drill-holes PVD 12 and 4. The sequence in this area consists of a number of interbedded lithologies including chloritic, pyritic, metavolcanic rocks (Fv), metapelites (Fm),
metalimestones (Fl), interbedded metavolcaniclastic rocks and metalimestones (Fvs) and cherty rocks. Most of the units have up to five percent disseminated pyrite.

The metapelites (Fm) commonly appear to be chloritic. The metavolcaniclastic rocks in the bedded metavolcaniclastic rocks and metalimestones (Fvs) contain crystals of quartz in a siliceous, sericitic matrix.

The metalimestones form thin (<6 m) units and are poorly banded with wide (1-10 cm) bands of coarse-grained, polygonal calcite separated by thin folia of chlorite, ±sericite, ±?talc. The phyllosilicate folia commonly have minor disseminated pyrite with rare sphalerite and galena. The limestones contains rare quartz grains and the calcite grains have bent and deformed twins.

North of 6300N metasedimentary rocks are only a minor component of the footwall sequence. There is a thin limestone unit in PVD 15B from 188.7 to 191.3 m in a narrow sequence of pyritic siltstones and sericitic metavolcanic rocks. There are a few outcrops of unbedded, sericitic metasiltstones (Fsm) around G.R. 7050N, 3150E and they contain a trace of disseminated limonite after pyrite.

3 Footwall Mineralization

The footwall rocks west of the massive sulphide lens contain a trace of disseminated pyrite which is concentrated in the phyllosilicate-rich folia in the rocks. In places there are narrow (<5 m) intervals with minor (<5%) pyrite, mainly as disseminations but also in thin (<1 cm) lenses parallel to the foliation.

The footwall rocks to the south of the sulphide lens in the area of drill-holes PVD 4 and 12 have a much higher sulphide content. In PVD 4 there is a trace of disseminated pyrite throughout the footwall but there are two small (<10 m) intersections with from five to ten percent pyrite. It occurs as disseminations mainly, but also forms thin (<1 cm) lenses parallel to the S1 foliation. Chalcopyrite occurs with the pyrite in places. In PVD 12, immediately below the inferred mineralized horizon, there is a metavolcanic unit (34.4-68 m) which contains from five to ten percent sulphide in disseminations and veins. The sulphides are mainly pyrite with lesser sphalerite, chalcopyrite, galena and minor covellite. The veins also contain quartz and chlorite with minor sericite and abundant tiny grains of ?rutile. Quartz occurs as coarse polycrystalline grains. The phyllosilicates occur as randomly oriented flakes, rosettes and as well-foliated masses. Pyrite occurs as subhedral to euhedral grains. Sphalerite, galena and chalcopyrite occur as small inclusions in pyrite and as interstitial masses. Chalcopyrite is commonly rimmed by sphalerite and covellite. Covellite also occurs in fractures in chalcopyrite. Deeper in the hole there is less than one percent pyrite which occurs as disseminations in the metavolcanics. From 97.5 to 103.4 m there is up to five percent disseminated pyrite in a sericitic, siliceous metavolcanic unit.
6.3.c Mineralized horizon

1 Definition

The mineralized horizon is composed of a sequence of sulphidic, sericitic and siliceous fine-grained rocks which occur between the mostly pale-coloured, coarse-grained hangingwall metavolcanics and the mostly medium-grained, green footwall metavolcanics. The maximum true thickness of the horizon in the drill-holes is 25 metres.

2 Facies Present and Their Distribution

The mineralized horizon consists of mainly fine-grained, sericitic, siliceous, pyritic schists (Ms) with minor amounts of a number of facies including massive sulphide, semi-massive sulphide, dark-green, fine-grained, chloritic schist (Mc), gossan (Mg), sericitic, siliceous metavolcanic rocks (Mv), metalimestone (Ml), limonitic, sericitic, siliceous breccia (Mb) and pyritic chert. Other minor lithologies in the horizon include a pyritic black metapelite unit (PVD 15B) and the WMC geologists recorded a "fine grained kaolinitic rock with hair-like septae of sulphides" in PVD 1 (Western Mining Corporation, 1984). The distribution of the facies in the drill-holes is shown in Figure 6.1.

Massive sulphides were intersected in drill-holes PVD 14, 6, 3, 7, 13, and 5 and these intersections appear to be parts of a single massive sulphide lens. Around the sulphide lens there is a reasonably consistent distribution of facies, from bottom to top (west to east):

(i) footwall metavolcanic rocks, commonly more chloritic towards the top;
(ii) dark-green, fine-grained, chloritic schist (Mc); ±fine-grained, sericitic, siliceous, pyritic schists (Ms); ±metalimestone; ±sericitic, siliceous metavolcanic rocks (Mv);
(iii) massive sulphides; ±semi-massive sulphides;
(iv) fine-grained, sericitic, siliceous, pyritic schists (Ms); ±sericitic, siliceous, metavolcanic rocks (Mv);
(v) hangingwall metavolcanic rocks.

South of the massive sulphide lens the mineralized horizon is composed of mainly fine-grained, sericitic, siliceous, pyritic schists (Ms); sericitic, siliceous metavolcanic rocks (Mv) and metalimestones (Ml). Some of the drill-holes south of the massive sulphide lens intersected zones with a high disseminated sulphide content which may represent the marginal zones of the sulphide lens. The intersections were:

(i) PVD 15B (185-187 m), sericitic, siliceous schist with ten percent pyrite and a trace of sphalerite and galena;
(ii) PVD 8 (52-57 m), less than fifteen percent pyrite in a "silicified tuff" (Western Mining Corporation, 1984);
(iii) PVD 9 (56.7-57.1 m), banded sericitic, siliceous schist with five percent limonite after pyrite.

The mineralized horizon can be traced south to PVD 12 at 6,100N. Further south, however, PVD-4 appears to be a section through only footwall rocks and presumably the mineralized
LEGEND

HANGING WALL META VOLCANIC ROCKS

---

MINERALIZED HORIZON

---

FOOTWALL META VOLCANIC ROCKS

---

Note that the intersections have not been corrected to true width.

highly pyritic zone, possibly the extension of the sulphide lens.

Fig. 6.1 Mineralized horizon facies intersected in Peak View diamond-drillholes.
horizon and the hangingwall sequence have been removed in this area due to the fault along the eastern side of the Peak View Outlier.

Lack of outcrop make it difficult to trace the mineralized horizon north of PVD 14 and there is only a small outcrop of fine-grained, sericitic, siliceous, gossanous schist at 7650N.

3 Description of Facies

*Dark-Green, Fine-Grained, Chloritic Schists (Mc)*

The dark-green, fine-grained, chloritic schists occur below the massive sulphide lens. They are composed of fine-grained quartz and chlorite with lesser sericite, biotite and pyrite with minor sphene and rare zircon. No unequivocal bedding was observed in the rocks. Some of the schists have relict microphenocrysts of quartz which may show embayments. In places the schists have relict phenocrysts of plagioclase which mostly contain abundant inclusions of chlorite. Pyrite grains contain inclusions of silicates and some contain tiny grains of sphalerite and galena. Biotite commonly appears to be replacing chlorite. Staining failed to show any K-feldspar in these rocks. The schists show some compositional variation and become very sericitic in places and some rocks contain thin (<2 mm) bands composed of pyrite and quartz with minor sphalerite.

The schists have a fine (<3 mm) domainal foliation ($S_1$) with individual bands/folia of:

(i) chlorite and pyrite,
(ii) quartz and chlorite,
(iii) sericite.

Chlorite grains are either oriented parallel to $S_1$ or randomly oriented. A crenulation cleavage ($S_2$) is developed in places. Sericite grains are parallel to one of the foliations.

The rocks contain broken fragments of veins composed of coarse-grained, quartz, sericite, chlorite, sphalerite, pyrite and a trace of galena and chalcopyrite. Some rocks contain veins of quartz and K-feldspar which have a coarse-grained, subhedral, open-space-filling texture.

*Fine-Grained, Sericitic, Pyritic, Siliceous Schist (Ms)*

The fine-grained, sericitic, siliceous, pyritic schists can be divided into two groups: first, the schists below the sulphide lens, and second those above and south of the sulphide lens. The main difference is that the schists below the sulphide lens are more sulphidic, have less chlorite and are poorly banded compared to the other group.

Fine-grained, sericitic, siliceous, pyritic schists below the sulphide lens. These schists form the footwall to the sulphide lens in PVD 14, 3, 7 and 5. They are composed of relict microphenocrysts of quartz ($±$plagioclase) in a matrix of granoblastic sericite, quartz and pyrite with minor $±$K-feldspar, $±$sphalerite, $±$galena, $±$chalcopyrite, $±$zircon, $±$carbonate, $±$chlorite, $±$apatite. Pyrite commonly occurs as large porphyroblasts. These schists are cherty in places and in PVD 3 they contain thin bands of massive sulphides. The matrix has a microcrystalline, granoblastic texture and sericite grains are aligned to define a continuous foliation ($S_1$). Some rocks have a distinct compositional and grainsize banding parallel to $S_1$ due mainly to the
development of a domainal foliation. The bands are <2 mm wide and staining showed that some of the coarser bands contain K-feldspar.

The fine-grained, sericitic, siliceous, pyritic schists contain veins of:

(i) pyrite, sphalerite, galena and chalcopyrite cutting \( S_1 \);
(ii) quartz, ±sphalerite, ±pyrite, ±sericite parallel to \( S_1 \);
(iii) quartz and sphalerite cut by \( S_1 \);
(iv) coarse-grained quartz, K-feldspar and galena;
(v) coarse-grained quartz, sphalerite, pyrite, chlorite, galena and chalcopyrite.

In PVD 7 there are open vugs with subhedral quartz grains projecting in to them.

Fine-grained, sericitic, siliceous, pyritic schists above and south of the sulphide lens. These schists contain relict microphenocrysts of quartz supported in a well-foliated matrix of quartz, sericite, chlorite, pyrite and ±carbonate. The rocks vary from phyllosilicate-rich rocks to cherty rocks. In one place there is a thin (<1 cm) band of semi-massive sulphides (PVD 6, 49.8 m). The microphenocrysts of quartz have a subrounded to subangular shape and are commonly microboudinaged. Plagioclase microphenocrysts are rare and are extensively altered to phyllosilicates.

The schists are commonly banded on a scale of 1 to 5 mm. Rarely, the banding is due to bedding which appears as variations in the size and abundance of the quartz microphenocrysts. Most banding is due to the domainal \( S_1 \) foliation which has dark-green, phyllosilicate-rich folia alternating with cream-coloured, siliceous microlithons.

The schists contain masses of randomly oriented flakes of chlorite which are cut by the \( S_1 \) foliation. Sericite is aligned parallel to \( S_1 \) and occurs as scattered tiny grains and as thick folia. Carbonate occurs as scattered grains in the matrix and in pressure beards. Pyrite forms sub-euhedral porphyroblasts which occur as disseminations, as lenticular aggregates of grains and rarely as thin (<2 mm) bands. The rocks contain a trace of zircon.

Veins in the schists are composed of:

(i) quartz, chlorite and sericite,
(ii) quartz,
(iii) quartz and feldspar, cutting and parallel to the \( S_1 \) foliation,
(iv) chlorite, ±pyrite in mesh-like networks,
(v) carbonate in extensional microstructures,
(vi) quartz, pyrite, sphalerite, and minor chlorite, sericite and tennantite-tetrahedrite. The sericite occurs as coarse, randomly oriented flakes.

**Metalimestone (MI)**

Metalimestone units were intersected in the mineralized horizon in drill-holes PVD 14, 6, 15B, 2 (and 12?). In PVD 14 and 6 the units occur stratigraphically below the sulphide lens. The units have a maximum true thickness of about 2 m. They are well-banded, with thick carbonate bands (<3 cm) alternating with thin (<3 mm) silicate-rich folia composed of quartz, chlorite and sericite. The carbonate-rich bands are composed of coarse-grained carbonate in a matrix of very
fine-grained carbonate. In places the carbonate bands contain masses of brown siderite. Some of the rocks contain large quartz grains and in places there is a trace of disseminated pyrite. The silicate-rich folia may have a "greasy" feel which suggests the presence of talc. The rocks have a good foliation ($S_1$) which is parallel to the banding and both are microfolded and crenulated.

Limonitic, Sericitic, Siliceous Breccia (Mbx)

The limonitic, sericitic, siliceous breccia is composed of porous limonite (and manganese oxides?) with large grains of coarse-grained sericite and secondary silica partially filling cavities. In PVD 12 the breccia contains fragments of limestone. Some surface samples of the breccia contain randomly oriented fragments of schist.

The Sulphide Lens

The sulphide lens was intersected in drill-holes PVD 14, 6, 3, 7, 13 & 5 and I have examined thin sections from all of these holes except PVD 5 and 13. The gossans on the surface and the drilling show that the lens is about 150 m long and the section through PVD 3, 7 and 13 indicates that it is over 220 m deep. Recent deep geophysical work by WMC indicates that the lens does not extend significantly beyond these limits (WMC staff, pers. comm., 1986). The lens has a maximum true thickness of about 2 m. The drill intersections and estimated true thicknesses of the drill intersections are given in Table 6.1. The description of the massive sulphide lens is hampered by poor drill-core recovery in some intervals, however it is clear that the lens consists of mainly massive sulphides with minor amounts of sulphidic chert and coarse-grained veins of quartz and chalcopyrite. In the thicker intersections the lens is stratigraphically zoned: the upper part of the lens has more sulphidic chert bands and is strongly banded whereas the lower part of the lens is composed of poorly banded, massive sulphide without sulphidic cherts.

Massive sulphides. The massive sulphides are composed of mainly pyrite, sericite and chlorite with lesser sphalerite, galena, chalcopyrite and quartz, with rare tennantite-tetrahedrite and arsenopyrite. There are very rare grains of zircon and pyrrhotite and needles of apatite. The total sulphide content varies up to about seventy percent.

Pyrite tends to have a subhedral to euhedral shape where it is in contact with silicates but it has anhedral, complex interfingerung contacts with other sulphides. The margins of pyrite grains commonly have a caries texture where they are in contact with sphalerite. Similar textures occur with chalcopyrite in places. Pyrite commonly has inclusions of sphalerite, galena and chalcopyrite and in places these are arranged in bands, suggesting a growth zoning in the pyrite. The inclusions may also occur along the cleavages in pyrite grains. In some rocks pyrite grains are commonly fractured and in places pyrite forms lenticular aggregates of tiny grains.

Sphalerite has an interstitial, anhedral texture and in sulphide-rich bands it is commonly the dominant matrix mineral. Chalcopyrite has an interstitial, anhedral texture and in some places it fills fractures in the pyrite grains. In rare cases chalcopyrite grains are rimmed by sphalerite. Galena has an interstitial, anhedral texture and in some sulphide-rich bands it forms large masses in the matrix.
Tennantite-tetrahedrite is rare and it occurs as tiny interstitial grains and inclusions in pyrite. Arsenopyrite was only seen in the section from PVD 14 where it forms large subhedral grains.

Chlorite forms masses of randomly oriented grains and shows incipient conversion to biotite in some rocks. In places chlorite and sericite form complexly intergrown, randomly oriented masses. Sericite is mostly well-foliated but in places the foliated grains cut randomly oriented sericite grains. Quartz occurs in three forms: as subequigranular, polygonal masses; as large, coarse-grained masses; and as fibrous fringes around pyrite grains. In a few rocks the gangue contains a trace of tiny, acicular ?apatite grains.

The massive sulphides have a weak banding which is parallel to the S₁ foliation in the rocks. The banding is due to a number of features:

(i) variations in the overall sulphide/gangue ratio,
(ii) variations in grainsize,
(iii) variations in the composition of the sulphides (particularly the chalcopyrite/sphalerite ratio),
(iv) variations in the sulphide/gangue ratio of the matrix.

Phyllosilicates in the sulphide lens are moderately to very well foliated. The bands of sulphides are commonly fractured and may consist of a series of microboudinaged fragments, parallel to the foliation. It appears that the textures in the broken fragments of sulphide are much less deformed than the surrounding gangue which is strongly foliated.

In sulphide-rich bands the sulphides have a complexly intergrown texture and pyrite is anhedral. In more gangue-rich bands pyrite tends to form large, subhedral "framework" grains. In places sphalerite, galena and chalcopyrite form elongate grains parallel to the foliation. In some rocks sphalerite forms rims on chalcopyrite and elsewhere chalcopyrite forms incomplete rims on pyrite.

Fine-grained pyritic chert. The fine-grained pyritic cherts are composed of pyrite grains in a matrix of microcrystalline quartz and minor sericite with a trace of sphalerite, chalcopyrite and galena. Pyrite forms subhedral to euhedral grains. Chalcopyrite is interstitial to pyrite and is intergrown with it. Although quartz mostly has a microcrystalline texture some coarser-grained domains occur. Sericite occurs as tiny, randomly oriented flakes.

Coarse-grained quartz and chalcopyrite veins. The coarse-grained quartz and chalcopyrite veins in the sulphide lens vary from a few millimetres to several centimetres wide and are composed of coarse-grained quartz, sericite, chalcopyrite and minor chlorite. Coarse grains of quartz and rosettes of sericite are surrounded by a wispy network of interstitial chalcopyrite, pyrite and sphalerite. Some of the quartz grains consist of polycrystalline aggregates of tiny grains. Chlorite occurs as tiny inclusions in large quartz grains. The distribution of the veins is not known in detail, however initial indications are that although small veins occur in many parts of the sulphide lens the largest veins are concentrated in the lower parts of the thickest part of the lens (PVD 3 and 7).

Other veins. The massive sulphide lens also contains veins of:

(i) coarse-grained quartz, carbonate, pyrite, chlorite, sericite, and galena;
(ii) coarse-grained quartz, pyrite, ±chalcopyrite, ±sphalerite which are parallel to the foliation;
(iii) coarse-grained quartz, chalcopyrite and feldspar (plagioclase?).

Geochemistry. The geochemistry of the intersections through the massive sulphide lens is given in Table 6.1. The data are from Western Mining Corporation (1984). The highest copper values come from PVD 3 and 7 where the lens is thickest. At least some of the high copper values are associated with coarse-grained quartz-chalcopyrite veins. The two northern holes, PVD 14 and 6, have low copper, lead and zinc values, but note that PVD 14 has the highest gold value (0.75 ppm) for the whole lens. The analyses of 10 cm intervals in PVD 3 show that the upper part of the lens in this hole, which is more banded and siliceous than the lower part, has lower values.

Semi-massive Sulphides

My only polished thin section of the semi-massive sulphides is from PVD 6 and it suggests that these rocks are a sulphide-poor variant of the massive sulphides. The textures and mineralogy of the two facies are essentially the same.

Sericitic, Siliceous Metavolcanic Rocks (Mv)

The metavolcanic rocks are well-foliated and are composed of deformed, relict phenocrysts of quartz and plagioclase supported in a matrix of sericite and quartz. In places the rocks contain minor disseminated pyrite and sulphide veins.

6.3.d Hangingwall Sequence

1 Introduction.
The hangingwall rocks at Peak View consist of a (<120 m) thick sequence of metavolcanic rocks with very rare metasedimentary units. The metavolcanic rocks are composed of relict phenocrysts of quartz and feldspar supported in a matrix of quartz, feldspar and phyllosilicates. The rocks are banded and the width of individual bands varies from a few millimetres to about thirty metres. The banding is mainly due to variations in the sericite content and the concomitant degree of S1 foliation development. Rocks with very little sericite are massive and poorly foliated and have a fawn to pink colour or a dark-green colour in chloritic bands. Sericitic rocks have a grey to yellow-grey colour and a strong S1 foliation. Unequivocal bedding is very rare in the hangingwall rocks.

2 General Features of the Hangingwall Metavolcanic Rocks

Fragmental textures. The banding and foliation in the rocks makes the recognition of fragmental textures difficult, however structures which may be deformed lithic fragments or altered vitriclasts occur in places and are common in PVD 2 from 40 to 60 m. The structures have a lenticular shape, vary in size up to 1 x 6 cm, are very sericite-rich and contain more crystals than the host rocks.
Table 6.1 Geochemistry of the Peak View massive sulphide lens. Data from Western Mining Corporation (1984).

<table>
<thead>
<tr>
<th>Drill hole &amp; intersection</th>
<th>Length (m)</th>
<th>True thickness (m)</th>
<th>Massive/semimassive</th>
<th>Cu (wt%)</th>
<th>Pb (wt%)</th>
<th>Zn (wt%)</th>
<th>Ag (ppm)</th>
<th>Au (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVD 14 215.4–215.5</td>
<td>0.10</td>
<td>0.09</td>
<td>Massive</td>
<td>0.08</td>
<td>2.6</td>
<td>4.6</td>
<td>90</td>
<td>0.75</td>
</tr>
<tr>
<td>PVD 6 50.6–51.0</td>
<td>0.40</td>
<td>0.38</td>
<td>Massive</td>
<td>0.46</td>
<td>2.9</td>
<td>5.5</td>
<td>150</td>
<td>0.05</td>
</tr>
<tr>
<td>51.0–51.5</td>
<td>0.50</td>
<td>0.47</td>
<td>Semimassive</td>
<td>0.13</td>
<td>1.28</td>
<td>2.3</td>
<td>46</td>
<td>0.10</td>
</tr>
<tr>
<td>PVD 3 32.10–34.2</td>
<td>2.10</td>
<td>1.81</td>
<td>Massive</td>
<td>1.93</td>
<td>5.64</td>
<td>11.65</td>
<td>103</td>
<td>0.15</td>
</tr>
<tr>
<td>32.10–32.20</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>0.93</td>
<td>0.88</td>
<td>1.77</td>
<td>28</td>
<td>0.05</td>
</tr>
<tr>
<td>32.20–32.30</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>3.4</td>
<td>1.39</td>
<td>3.6</td>
<td>90</td>
<td>0.05</td>
</tr>
<tr>
<td>32.30–32.40</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>1.55</td>
<td>1.61</td>
<td>4.5</td>
<td>70</td>
<td>0.05</td>
</tr>
<tr>
<td>32.40–32.50</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>2.3</td>
<td>1.56</td>
<td>4.2</td>
<td>70</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>32.50–32.60</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>1.53</td>
<td>1.83</td>
<td>4.9</td>
<td>80</td>
<td>0.05</td>
</tr>
<tr>
<td>32.60–32.70</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>1.79</td>
<td>3.4</td>
<td>6.9</td>
<td>100</td>
<td>0.10</td>
</tr>
<tr>
<td>32.70–32.80</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>1.76</td>
<td>4.5</td>
<td>10.3</td>
<td>110</td>
<td>0.10</td>
</tr>
<tr>
<td>32.80–32.90</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>2.80</td>
<td>2.2</td>
<td>6.1</td>
<td>140</td>
<td>0.10</td>
</tr>
<tr>
<td>32.90–33.00</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>2.6</td>
<td>5.1</td>
<td>11.2</td>
<td>100</td>
<td>0.10</td>
</tr>
<tr>
<td>33.00–33.10</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>1.02</td>
<td>10.1</td>
<td>18.9</td>
<td>110</td>
<td>0.25</td>
</tr>
<tr>
<td>33.10–33.20</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>0.63</td>
<td>9.5</td>
<td>17.9</td>
<td>110</td>
<td>0.25</td>
</tr>
<tr>
<td>33.20–33.30</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>0.62</td>
<td>10.9</td>
<td>18.2</td>
<td>110</td>
<td>0.20</td>
</tr>
<tr>
<td>33.30–33.40</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>1.06</td>
<td>7.6</td>
<td>15.2</td>
<td>90</td>
<td>0.20</td>
</tr>
<tr>
<td>33.40–33.50</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>1.63</td>
<td>7.9</td>
<td>15.8</td>
<td>100</td>
<td>0.20</td>
</tr>
<tr>
<td>33.50–33.60</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>4.4</td>
<td>6.7</td>
<td>14.5</td>
<td>100</td>
<td>0.25</td>
</tr>
<tr>
<td>33.60–33.70</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>5.6</td>
<td>3.6</td>
<td>7.3</td>
<td>90</td>
<td>0.10</td>
</tr>
<tr>
<td>33.70–33.80</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>1.71</td>
<td>5.6</td>
<td>14.3</td>
<td>70</td>
<td>0.20</td>
</tr>
<tr>
<td>33.80–33.90</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>1.28</td>
<td>4.5</td>
<td>15.4</td>
<td>110</td>
<td>0.15</td>
</tr>
<tr>
<td>33.90–34.00</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>1.39</td>
<td>7.8</td>
<td>22.0</td>
<td>200</td>
<td>0.35</td>
</tr>
<tr>
<td>34.00–34.10</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>1.71</td>
<td>11.9</td>
<td>22.0</td>
<td>190</td>
<td>0.25</td>
</tr>
<tr>
<td>34.10–34.20</td>
<td>0.10</td>
<td>0.08</td>
<td>Massive</td>
<td>0.86</td>
<td>9.2</td>
<td>9.7</td>
<td>100</td>
<td>0.20</td>
</tr>
<tr>
<td>PVD 7 90.95–92.80</td>
<td>1.85</td>
<td>1.65</td>
<td>Massive</td>
<td>4.25</td>
<td>1.23</td>
<td>2.9</td>
<td>60</td>
<td>0.40</td>
</tr>
<tr>
<td>92.80–93.20</td>
<td>0.40</td>
<td>0.35</td>
<td>Massive</td>
<td>0.59</td>
<td>3.7</td>
<td>11.0</td>
<td>40</td>
<td>0.50</td>
</tr>
<tr>
<td>PVD 13 200.05–201.00</td>
<td>0.95</td>
<td>0.75</td>
<td>Semimassive</td>
<td>0.55</td>
<td>1.16</td>
<td>3.2</td>
<td>22</td>
<td>0.05</td>
</tr>
<tr>
<td>201.00–201.5</td>
<td>0.50</td>
<td>0.40</td>
<td>Massive</td>
<td>1.15</td>
<td>3.2</td>
<td>11.2</td>
<td>60</td>
<td>0.10</td>
</tr>
<tr>
<td>201.50–201.85</td>
<td>0.35</td>
<td>0.28</td>
<td>Semimassive</td>
<td>1.44</td>
<td>0.28</td>
<td>1.35</td>
<td>27</td>
<td>0.05</td>
</tr>
<tr>
<td>PVD 5 52.30–52.80</td>
<td>0.50</td>
<td>0.50</td>
<td>Massive</td>
<td>0.92</td>
<td>8.5</td>
<td>15.6</td>
<td>90</td>
<td>0.30</td>
</tr>
</tbody>
</table>

* Note that in PVD 13 the sulphide lens actually starts at 200.00m.

Relict perlites. Structures which may be relict perlites occur in some of the rocks. The structures are up to 0.6 mm in diameter and consist of narrow (0.07 mm), concentric rings of feldspar separated by thinner (0.005 mm) rings and arcs of sericite.

Relict phenocrysts. The hangingwall metavolcanic rocks have from five to twenty five percent relict phenocrysts which range in size up to 3 mm. Narrow intervals in some drill-holes
and all of the hangingwall rocks in PVD 2 have grains up to 5 mm. Size grading of crystals occurs in PVD 15B (152.3 - 159.0 m) and PVD 7 (85.0- 86.7 m) where they fine to the east and in narrow zones in PVD 3 (12.0 m) and PVD 6 (30.0 m) where they fine to the west.

Quartz grains are anhedral to subhedral and rarely have a euhedral β-quartz shape. Embayments are common and these may contain unfoliated matrix material. Most grains have undulose extinction and other deformation textures such as subgrains, deformation lamellae, fractures and microboudinage are common. Grain boundaries with sericite folia commonly have a scalloped appearance.

Plagioclase grains (now albite) have a prismatic shape with an anhedral to subhedral (or rarely euhedral) outline. Cumulophyric grains are common. The grains show varying degrees of alteration to phyllosilicates (sericite, ±chlorite, ±montmorillonite), epidote and calcite. Alteration ranges from a brown dusting of fine alteration phases, through cleavage-controlled flakes, to grains which are almost completely replaced. In deformed, partly altered plagioclase grains the grains are free of alteration products in zones of subgrain development and in areas adjacent to fractures.

Stained thin section off-cuts showed that K-feldspar phenocrysts are rare and subordinate in abundance to plagioclase phenocrysts.

Relicts of mafic phenocrysts occur in most rocks. They are brown, irregularly shaped aggregates of fine-grained epidote, opaques, ±iron oxides, ±sphene, ±chlorite, ±biotite. Only rarely do the aggregates have a prismatic shape. In a few of the aggregates the opaques are aligned in rows, probably due to an original crystallographic direction such as biotite (001). In a few rocks there are aggregates of chlorite, biotite, opaques and zircon which may also be altered mafic phenocrysts.

Porphyroblasts. In most rocks pyrite forms large (<1 mm) porphyroblasts with a euhedral to subhedral shape. The grains are commonly bent or fractured and grain boundaries with sericite folia are scalloped. The S1 foliation abuts and does not wrap around the pyrite grains.

Matrix minerals. In the matrix the shape of quartz grains varies between two endmembers: equant grains with straight margins and elongate grains with a strong crystallographic preferred orientation and sutured boundaries.

The morphology and extinction pattern of matrix feldspar grains is complex. Most grains have an irregular, anhedral outline and adjacent grains have complex interfingering boundaries. The grains have an equant to tabular shape and may poikilitically enclose smaller albite or chlorite grains. Some grains have simple or albite twins. Many grains have curved or fanning, acicular to columnar extinction and other grains have a random patchy extinction pattern. Staining indicates that these grains may be albite or K-feldspar or possibly a mixture of the two. Although the matrix feldspar grains are clear and generally free of inclusions some of them have tiny patches of inclusions similar to the core zones in the relict phenocrysts of plagioclase.

Most relict phenocrysts of plagioclase have a thin rim composed of tiny grains of inclusion-free feldspar. Only small parts of the rim are in optical continuity with the core and the
grains in the rest of the rim have the same irregular, wavy, acicular extinction pattern as the matrix feldspar grains.

Sericite forms small flakes parallel to the foliation and commonly occurs at the boundaries of quartz or feldspar phenocrysts. Sericite also occurs as thin folia composed of masses of small grains with a strong preferred orientation.

Chlorite generally occurs as large randomly oriented aggregates of tiny grains in the matrix of the rocks. It forms relatively larger, well-formed grains in pressure beards, extensional microstructures and in zones of the matrix which have recrystallized to form a mosaic texture. Aggregates and rosettes of chlorite occur in the feldspar-rich rims around relict phenocrysts of plagioclase and in the larger matrix feldspar grains. In sericite folia, chlorite may be interlayered with sericite or form tiny lenses of randomly oriented grains.

Biotite is common only in drill-hole PVD 2 and is rare in all other drill-holes. It occurs only in relatively phyllosilicate-poor (<15%) rocks and in rocks which have chlorite in the matrix. It occurs as aggregates of randomly oriented grains, as rims to chlorite aggregates, and in some sericite folia. Where biotite occurs in the sericite folia it may be concentrated along the margins of the folia.

Carbonate forms anhedral grains and irregularly shaped aggregates of grains. It occurs in the matrix, in pressure shadows, in extensional microstructures and in zones of subgrain development in relict phenocrysts. Epidote occurs as anhedral grains and aggregates of grains and as radiating aggregates of acicular crystals. In some places it is an alteration product of plagioclase and may almost completely replace the grains. Zircon and apatite form subhedral prisms which may be microboudinaged.

Sericite folia are commonly crenulated and some rocks have a crenulation cleavage (S2). In some rocks the microlithons between the sericite folia may have sericite flakes which are aligned at angles to the S1 foliation but are parallel to the crenulation fold axis.

3 Lithological Types in the Hangingwall Metavolcanic Rocks

Attempts to define particular depositional units in the hangingwall metavolcanics by correlating between drill-holes on the basis of grain size and/or possible fragmental textures were unsuccessful. On a macro-scale the rocks are readily subdivided into two types: weakly foliated, phyllosilicate-poor rocks; and strongly foliated, phyllosilicate-rich rocks. Detailed microscopy, staining and XRD work, however, has shown that there are five main lithological types:

(i) massive, phyllosilicate-poor metavolcanic rocks (Hvm);
(ii) feldspar-rich metavolcanic rocks (Hvf);
(iii) sericite-rich metavolcanic rocks with relict phenocrysts of altered feldspar;
(iv) sericite-rich metavolcanic rocks with relict phenocrysts of fresh feldspar;
(v) metavolcanic rocks with carbonate laths (Hvc).

These types are end-members and rocks with intermediate characteristics do occur. In particular, rocks intermediate between types (ii) and (iii) are common.
Massive, phyllosilicate-poor metavolcanic rocks (Hvm). The massive, phyllosilicate-poor metavolcanic rocks are massive and poorly foliated, with a matrix composed of a fine-grained (0.01-0.05 mm) quartz and K-feldspar with minor (<5%) chlorite, albite and sericite. The phyllosilicates generally occur as tiny, randomly oriented flakes, however in recrystallized domains in the matrix, sericite flakes have a strong preferred orientation. Sericite also forms very thin folia around relict phenocrysts. These rocks contain relics after mafic phenocrysts, but the matrix does not have columnar, radiating feldspars. My only samples of this rock type come from PVD 2 (77.4, 85.5 m). These rocks appear to correlate with very similar rocks on the surface around G.R. 6600N, 3485E (Map 6.1).

Feldspar-rich metavolcanic rocks (Hvfl). These rocks have a "siliceous" appearance with a mottled grey, green or pink colour. In the drill-core they form bands from 0.3 to 3 m wide and commonly dominate intervals of up to 25 m. They are composed of relict phenocrysts of quartz, plagioclase, ±mafic relics in a fine- to medium-grained (0.01-0.1 mm) matrix of quartz, feldspar and minor epidote with variable chlorite. In the matrix, feldspar occurs as radiating columnar masses of grains.

The green areas in the rocks have up to fifteen percent chlorite which occurs as anhedral flakes, aggregates of tiny grains and net-like aggregates which enclose other matrix grains. Quartz phenocrysts commonly have scalloped margins which are filled with chlorite. Staining indicates that in most of these rocks the matrix is very rich in albite but in some rocks the chlorite-rich patches have a relatively high K-feldspar content. The pink-coloured rocks generally have very little K-feldspar.

In places the rocks are partly replaced by a network of semi-pervasive, non-dilational quartz veins. In one rock the pink, albitic zones wrap around smaller chloritic patches. The rocks in PVD 14 commonly have K-feldspar in the matrix and probably correlate with the outcrops of pyritic, K-feldspar-rich rocks around G.R. 3260E 7200N (Map 6.1).

As the degree of foliation development and the sericite content increase the textures become more complicated. In pink, albitic bands the minerals have a strong preferred orientation, the grain size is smaller and sericite occurs as tiny subhedral grains and thin folia. Foliated chlorite-rich bands have anastomosing folia of chlorite and sericite. Lozenge-shaped, relatively undeformed microlithons are separated by extensional microstructures filled with fibrous phyllosilicates, quartz and feldspar. The phyllosilicates in the extensional microstructures may be chlorite only, chlorite and sericite or sericite only. Relict phenocrysts commonly have fibrous pressure beards and these beards are commonly zoned with chlorite in the centre and sericite along the margins. Some of the more-foliated rocks have minor K-feldspar in both the albite-rich zones and the chlorite-rich zones.

Sericite-rich metavolcanic rocks with relict phenocrysts of altered feldspar. These rocks occur in intervals up to 5 m thick in the hangingwall and are common immediately above the mineralized horizon. They have abundant sericite in the matrix and the relict phenocrysts of feldspar show extensive alteration to sericite and epidote, ±chlorite, ±green ?montmorillonite. They have a strong domainal S1 foliation with large sericite folia composed of well-aligned sericite
grains and minor brown epidote. The microlithons between the sericite folia are mainly composed of a recrystallized mosaic of quartz and sericite with minor albite and only rare K-feldspar. Sericite in these areas is aligned and contributes to the S\(_1\) foliation. In some rocks there are randomly oriented sericite flakes and felted masses of sericite. The sericite folia wrap around these sericite masses. Pressure beards around phenocrysts are composed of quartz and sericite (and albite?) with no chlorite.

**Sericite-rich metavolcanic rocks with relict phenocrysts of fresh feldspar.** These are uncommon but are widely distributed. They have a very strong domainal foliation which is defined by thick folia of sericite. Small microlithons between the folia have textures which are similar to the rocks in type (i) and (ii). The sericite folia truncate relict phenocrysts and the relict phenocrysts within the folia are elongate parallel to the folia. Relict phenocrysts of plagioclase show little or no alteration.

**Metavolcanic rocks with carbonate laths (Hvc).** At 3325E 7000N and 3275E 7200N there are lenses of sericitic metavolcanic rocks which have numerous, large (<2 x 5 mm), randomly oriented laths of carbonate. The S\(_1\) foliation abuts and is not deflected around the laths. They are composed of a few large grains of carbonate which poikilitically enclose matrix quartz grains. The laths appear to have formed by replacement of the feldspar and sericite in the matrix after the formation of the S\(_1\) foliation. The unit at 7000N can be correlated with the interval from 29.1 to 30.1 m in PVD 7.

### 4 Distribution of the Facies

There is insufficient data to precisely define the distribution and abundance of the facies, particularly the phyllosilicate-poor metavolcanic rocks (Hvm). The feldspar-rich metavolcanic rocks (Hvf) and the sericite-rich metavolcanic rocks with relict phenocrysts of altered feldspar appear to be the dominant rock types in the hangingwall. Within the latter group there is a change to more K-feldspar-rich compositions in the area of PVD 14 and further north. Sericite-rich metavolcanic rocks with relict phenocrysts of altered feldspar are common immediately above the mineralized horizon.

### 5 Metasedimentary Rocks in the Hangingwall

A unit of bedded metavolcaniclastic rocks and metapelites occurs in PVD 15B from 69.2 to 71.4 m.

### 6 Veins in the Hangingwall Rocks

Common vein minerals include quartz, chlorite, albite, carbonate and pyrite with rare occurrences of K-feldspar, arsenopyrite, ?sphalerite and sericite. The veins are up to several centimetres wide and they may be parallel to, or cutting across, the foliation. Some veins are folded. In some massive rocks there are veins filling conjugate fractures. The minerals in most veins show deformation effects such as undulose extinction, microboudinage and deformation
lamellae. In some places where the veins are cut by the foliation, the veins have scalloped resorbed margins where they are in contact with the phyllosilicate-rich folia.

6.3.e Dolerite Dykes

Around 3200E 7250N there are two east-west-trending dolerite dykes. The dykes have a massive, unfoliated subequigranular texture and are composed of plagioclase laths with equant prisms of altered mafic minerals. The ground magnetic surveys (Western Mining Corporation, 1984) show that the dykes are associated with strong magnetic highs.

6.4 STRUCTURE AND METAMORPHISM OF THE PEAK VIEW OUTLIER

The dominant structural feature of the rocks in the Peak View Outlier is the mostly domainal, S₁ foliation. The foliation is subparallel to bedding and surface mapping shows that it dips from 50° to 85° to the east-northeast. Drilling has shown that the sequence dips east-northeast at about 60°. On the foliation there is commonly a down-dip lineation L₁. The structures suggest that the Peak View Outlier consists of a single limb of an isoclinal fold which has been faulted into its present position.

In places the S₁ foliation is deformed by crenulations, microfolds and kinks and rarely a crenulation cleavage (S₂) is developed. In places there are tectonic breccias composed blocks of metavolcanic rocks which have S₁ in random orientation although there are no obvious faults within the outlier.

The metamorphic minerals in the structures related to the first deformational event (D₁) including the phyllosilicate-rich folia, pressure beards and extensional microstructures include sericite, chlorite, biotite, feldspar and carbonate. These minerals suggest that D₁ was at low metamorphic grade (greenschist facies) according to the scheme of Winkler (1979). Sericite crystallized during the formation of the S₂ crenulation cleavage and this suggests that D₂ was at a similar, or slightly lower grade, than D₁.

6.5 INTERPRETATION OF THE PEAK VIEW PROSPECT

6.5.a General

(i) The Peak View deposit occurs in a faulted block of Silurian metavolcanic and metasedimentary rocks.

(ii) Present indications are that the Peak View Outlier contains a continuous, conformable sequence which dips and faces east. It is possible, however, that there is a structural break in the sequence because the blocks of sericitic, siliceous, gossanous breccia (Mbₓ) in the mineralized horizon may be interpreted as a fault breccia. This would imply that there is a fault which is subparallel to bedding, and the foliation (S₁), in the
mineralized horizon. In the absence of more substantial evidence for faulting I will assume that there has not been any significant faulting in the outlier.

(iii) The metamorphic and deformational fabric in the rocks was produced during a single, protracted metamorphic event at greenschist facies with two deformational events.

(iv) The rocks were deposited in a marine volcanic setting.

6.5.b Footwall Rocks

(i) The chloritic, pyritic metavolcanic rocks (Fe) have been partly recrystallized during metamorphism and a domainal foliation has developed. The quartzofeldspathic microlithons, however, preserve randomly oriented chlorite grains which probably predate the metamorphism and may have formed in part of the hydrothermal system which formed the sulphide lens. Features including the disseminated pyrite and the lack of mafic phenocrysts in the rocks are also probably due to the same alteration event. Plagioclase was stable during alteration although the incipient alteration of the grains to chlorite, ±carbonate may be related to this event. Overall, the textures and minerals suggest that the rocks were subjected to a propylitic style of alteration.

(ii) Textures in the K-feldspar-bearing metavolcanic rocks (Fk) such as spherulites and unbroken relict phenocrysts and the matrix-supported nature of the rocks suggest that they were deposited as lavas. Although the preservation of spherulites in these rocks suggests that they are unaltered the presence of chlorite and pyrite and rare disseminated sphalerite suggests that they have been weakly altered.

(iii) The metasedimentary rocks in the footwall appear to represent a shallow-marine sequence which has been weakly altered and mineralized. The limestones were probably biogenic accumulations although no fossils were found. It is not clear whether the sulphidic phyllosilicate-rich bands in the limestones are a metamorphic feature or a deformed alteration structure.

(iv) The sulphide lens at Peak View lies at the top of a broad semi-conformable zone of propylitic alteration with disseminated sulphides. The main zone of footwall mineralization detected so far occurs around drill-holes PVD 4 and 12, which is away from the sulphide lens. The vein style mineralization in PVD 12 is deformed and appears to predate at least the end of the deformation. The age of these veins and the relationship of this zone to the sulphide lens is not clear, however one possibility is that this zone may be part of an original feeder zone which has been displaced from the sulphide lens by strike-slip faulting.

6.5.c Mineralized Horizon

(i) The dark-green, chlorite schists (Mc) represent volcanic rocks and fine volcaniclastic rocks which were altered and metamorphosed. The randomly oriented chlorite in the siliceous microlithons between phyllosilicate-rich folia probably predates the metamorphism and indicates a premetamorphic alteration event. The partial alteration of
plagioclase to chlorite may be related to this event. Because sericite in these rocks is oriented parallel to a foliation it is probably a metamorphic mineral. The absence of K-feldspar from the rocks implies that potassium was introduced into the rocks via the metamorphic fluid. The age of the veins in the rocks is not clear and they may have formed at the time of mineralization or during metamorphism. Overall, the rocks appear to have been altered to a propylitic assemblage of quartz, chlorite, pyrite, ±other sulphides prior to metamorphism.

(ii) The fine-grained, sericitic, siliceous, pyritic schists (Ms) below the sulphide lens probably represent fine-grained volcaniclastic rocks which were altered during the mineralizing event and have been metamorphosed. It is not clear whether the veins in the rocks were produced during the mineralizing event or metamorphism. Sericite in these rocks has a metamorphic texture which suggests that it formed during the metamorphism.

(iii) The fine-grained, sericitic, siliceous, pyritic schists (Ms) above and south of the sulphide lens probably represent fine-grained volcaniclastic (epiclastic and/or pyroclastic?) deposits which were altered and later metamorphosed. The randomly oriented chlorite grains in the rocks probably predate the metamorphism. Sericite in the rocks is parallel to $S_1$ and was probably formed during the metamorphism. The K-feldspar in the rocks and the scattered small flakes of sericite in the siliceous microlithons indicate that potassium was present in the rocks prior to metamorphism. Overall, the observations suggest that prior to metamorphism the rocks were altered to chlorite, pyrite, quartz and a potassium mineral (K-feldspar?). Any plagioclase in the rocks was destroyed.

(iv) The origin of the metalimestones (Ml) is not clear. They may be either altered and metamorphosed biogenic accumulations or metamorphosed exhalative deposits similar to the carbonate bodies associated with the Rosebery deposit in Tasmania. (Brathwaite, 1974). A biogenic origin might imply a shallow depth of seawater at the time of mineralization. The carbonate in the rocks is dominated by deformational/metamorphic textures. The silicate-rich folia appear to be a domainal metamorphic foliation, however such an origin would require the introduction of components into the carbonates to form the silicates. Alternatively the silicate folia may represent either an original sedimentary or volcaniclastic component in the rocks, and/or an alteration feature.

(v) The limonitic, sericitic, siliceous breccia (Mbx) appears to represent a weathered breccia which initially contained abundant metalimestone fragments. It is not clear whether the rock is a tectonic breccia or a karst breccia. If it is a tectonic breccia then it postdates the metamorphism and suggests the presence of a fault along the mineralized horizon.

(vi) The sulphide lens probably represents a metamorphosed and deformed lens of massive sulphides which formed as a sedimentary exhalative accumulation on the sea floor. The
compositional banding in the lens is probably a primary depositional feature which has been accentuated by the metamorphic foliation. The observation that some of the chlorite and sericite grains in the lens have a randomly oriented texture which is cut by the foliation suggests that these minerals predate the metamorphism and are likely to have formed during the mineralizing event. The gangue minerals probably also formed as exhalative minerals in the manner described by McLeod & Stanton (1984). The presence of zircon and ?apatite in the gangue suggests that there is some volcaniclastic component in the lens although Windrim et al. (1984) have argued that zircon can be a hydrothermal mineral in volcanic-associated deposits.

(vii) The coarse-grained quartz which forms part of the gangue in the massive sulphide lens is similar to the quartz in the coarse-grained quartz-chalcopyrite veins and so it is likely that it represents disrupted fragments of thick veins. During deformation the originally large grains have formed polycrystalline aggregates.

(viii) During deformation pyrite in the sulphide lens has deformed in a brittle fashion and chalcopyrite has deformed by ductile flow to fill fractures in the pyrite grains. Aggregates of sulphides have also been fractured in a brittle fashion, however the lenticular shape of some grains of chalcopyrite, sphalerite and galena suggest that they have also deformed by ductile flow. Sulphide textures such as the poorly formed nature of the pyrite grains, the caries textures and the numerous inclusions of sulphides in pyrite, together with the absence of annealed "triple-junction" textures suggest that there has been very little recrystallization and annealing of the sulphides.

(ix) During metamorphism and deformation the phyllosilicates in the sulphide lens have formed a strong foliation. While it is possible that minerals such as sericite and chlorite have formed during diagenesis or metamorphism from precursors (McLeod & Stanton, 1984) the only obviously new metamorphic mineral in the sulphide lens is biotite, which appears to be replacing chlorite.

(x) The fine-grained pyritic cherts appear to represent a siliceous compositional variant in the exhalative deposits.

(xi) The coarse-grained, quartz-chalcopyrite veins postdate the enclosing sulphides bands and probably formed during the mineralizing event. They may be analogous to the pyrite, chalcopyrite, quartz veins in Kuroko deposits which form the siliceous (keiko) ore (Sato, 1974). They also have similarities with the marginal zones of the copper mounds at Woodlawn (McKay & Hazeldene, 1987; see their Fig. 17 point 3 and Fig. 12 part E and F).

(xii) The other veins in the sulphide lens may have formed either at the time of mineralization, possibly as a compositional variation on the coarse-grained quartz-chalcopyrite veins, or during metamorphism.

(xiii) The metavolcanic rocks in the mineralized zone are similar to the hangingwall metavolcanic rocks.
6.5.d Hangingwall Rocks

(i) The possible lithic structures in the hangingwall rocks may be either deformed lithic fragments, altered vitriclasts or parts of very large sericite folia formed during metamorphism.

(ii) Perlites form by the slow, progressive hydration of glass (Best, 1982). A study of the Oligocene volcanic sediments in Trans-Peco, Texas (Walton, 1975) showed that original glass shards had been coated by montmorillonite and replaced by analcite. The process had considerably lowered the $K_2O$ content of the rocks. A similar process may explain the preservation of the perlitic cracks in the Peak View rocks. It is possible that the cracks may have been filled by a clay mineral which is now sericite and the glass devitrified to form zeolites which are now mainly albite.

(iii) The aggregates of epidote, opaques, ±iron oxides, ±sphene, ±chlorite, ±biotite are interpreted as altered relicts of mafic phenocrysts. The timing of the alteration is not clear and could have occurred during magmatism and/or synvolcanic alteration and/or during metamorphism.

(iv) The complex, interfingering, fanning shapes of the feldspar grains in the matrix of the hangingwall metavolcanic rocks do not have a spherulitic texture. Instead it is possible that the grains have formed by the replacement of precursor minerals such as analcite, natrolite or stilbite.

(v) Before deformation the hangingwall rocks were composed of well-formed, unbroken phenocrysts of embayed quartz, plagioclase, rare K-feldspar, minor cumulophyric feldspar grains and minor mafic phenocrysts supported in a ?glassy matrix. In places the rocks had perlitic cracks. Overall, these features suggests that the rocks were deposited as lavas.

(vi) The massive phyllosilicate-poor metavolcanic rocks (Hvm) have a matrix which is rich in quartz, K-feldspar and albite. These minerals probably formed due to devitrification although there are no unequivocal devitrification structures such as spherulites or axiolites.

(vii) The feldspar-rich metavolcanic rocks (Hvf) have the same phenocrysts as the massive, phyllosilicate-poor metavolcanic rocks (Hvm) but have less K-feldspar, fewer mafic relicts and much more albite in the matrix. The textures suggest that these rocks were originally similar to the massive, phyllosilicate-poor rocks but were altered. The alteration first produced the green, chloritic zones and later produced the pink albitic zones. Coombs (1953) describes albite-rich rocks in Triassic tuffs and greywackes in New Zealand. Authigenic albite forms clear overgrowths on plagioclase grains and felted masses in the matrix. The albite formed during low-grade metamorphism by replacement of analcime which had formed by interaction of glass with saline brines. Around the Kuroko deposits of Japan there is a zone of analcime plus calcite alteration which envelopes the sericite plus chlorite and montmorillonite plus mixed-layer clay alteration zones (Iijima, 1974; Utada et al., 1974). The analcime
forms radiating, fibrous fan-like aggregates, rounded crystals and cryptocrystalline aggregates. The largest crystals are up to 0.2 mm long and the textures form by the pseudomorphic replacement of the early zeolite, mordenite. In places the original vitriclastic textures are preserved. The rocks of this zone have less potassium and magnesium and higher sodium and calcium compared to the clay zones. The analcime is thought to have formed by the interaction of the hydrothermal fluids with the pre-existing regional zeolite zones. The fluids leached sodium and calcium from the clay zones and this was then used to produce sodium- and calcium-rich zeolites. These observations suggest that the feldspar-rich rocks at Peak View may have formed by the interaction of hydrothermal fluids, produced during the waning phases of the system responsible for the mineralization, with the hangingwall volcanic rocks. The hydrothermal alteration produced abundant zeolites which were subsequently replaced by feldspar during metamorphism.

(viii) The sericite-rich rocks in the hangingwall are dominated by metamorphic fabrics, however the presence of randomly oriented sericite flakes suggests that the rocks may be deformed altered rocks. This texture is probably due to crystallization before the deformation although it may be related to the crenulation folding which produces variations in the orientation of the sericite grains.

(ix) In the sericite-rich metavolcanic rocks with relict phenocrysts of altered feldspar the alteration of the phenocrysts probably occurred during the synvolcanic hydrothermal alteration event.

(x) The sericite-rich metavolcanic rocks with relict phenocrysts of fresh plagioclase appear to represent rocks which began as either the massive, phyllosilicate-poor metavolcanic rocks (Hvm) or the feldspar-rich metavolcanic rocks (Hvf). During metamorphism the rocks have undergone very intense foliation development so that they are now dominated by very thick phyllosilicate-rich folia which were produced during the metamorphism. The intervening quartzofeldspathic microlithons have been reduced in size to the extent that they are now only vestiges of originally broad microlithons.

(xi) The rocks with textures intermediate between the sericite-rich metavolcanic rocks and the feldspar-rich metavolcanic rocks appear to represent zones in which the feldspar-rich rocks were only party altered to the sericite-rich rocks.

(xii) Overall, the textures in the hangingwall rocks suggest that the rocks were altered to form chloritic zones, then zones of zeolites, and later, zones of sericite (with partial plagioclase destruction).

(xiii) The hangingwall rocks have been strongly deformed. The deformation involved:

1. plastic deformation, fracturing and microboudinage of relict phenocrysts;
2. growth of quartz, chlorite and later sericite in extensional microstructures;
(3) partial recrystallization of the matrix to form a mosaic texture and crystallization of sericite flakes (with only partial destruction of early, randomly oriented feldspar and phyllosilicate fabrics);

(4) formation of sericite folia by pressure solution processes.

(xiv) The extensional microstructures in the feldspar-rich metavolcanic rocks (Hvf) in the hangingwall indicate that there has been considerable elongation during metamorphism. Chlorite was the stable phyllosilicate at an early stage of the metamorphism and and sericite became stable later.

(xv) Veins in the hangingwall may have formed either during metamorphism or the mineralizing event.

6.5.e Dolerite Dykes

The unfoliated nature of the dolerite dykes suggests that they postdate the regional deformation which probably occurred during the latest Silurian to Early Devonian in this area.

6.5.f Summary of the Interpreted Depositional History

The sequence at Peak View records the following depositional history:

(i) The footwall rocks were deposited in a shallow-marine environment and the volcanic rocks were probably deposited as pyroclastics and lavas. In the south volcaniclastic sediments and biogenic limestones were deposited between periods of volcanic deposition.

(ii) The mineralized horizon represents widespread, fine-grained, ?epiclastic, volcaniclastic sedimentation in a marine environment with local accumulation of volcanic deposits and exhalative sulphides (and carbonate?).

(iii) The mineralized horizon was buried by a thick sequence of volcanics, at least part of which were deposited as lavas. Deposition was apparently too rapid to allow any accumulation of sedimentary rocks.
CHAPTER 7

GEOCHEMISTRY

7.1 INTRODUCTION

This chapter is in three parts. The first part presents the results of a whole-rock geochemical study of the metavolcanic rocks from the Bredbo-Bunyan and Peak View study areas. The second part is a rare-earth element study of the metavolcanic rocks from the Bredbo-Bunyan study area. The third part gives the results of a sulphur isotope study of the sulphides and barite from the Bredbo-Bunyan area.

7.2 GEOCHEMISTRY OF THE METAVOLCANIC ROCKS

7.2.a Introduction

1 Processes Contributing to the Present Composition of the Metavolcanic Rocks

The present composition of the metavolcanic rocks in the two study areas is likely to be the result of many different processes including:

(i) Primary compositional variation. Owen and Wyborn (1979) showed that the volcanic rocks in the Canberra region, like the granites, can be divided into those derived from igneous source rocks (I-types) and sedimentary source rocks (S-types). Further subdivision is possible and Wyborn et al. (1981) showed that three groups of S-type volcanics were derived from different source compositions.

(ii) Magmatic effects. Within comagmatic volcanic units there may be variations due to magmatic processes such as fractionational crystallization (Wyborn and Chappell, 1986; Wyborn et al., 1987) and restite unmixing (Wyborn and Chappell, 1986). Hildreth (1979) has documented systematic variations in phenocryst type and chemical composition in ignimbrites which indicate compositional zoning in high-level magma chambers.

(iii) Eruptional and depositional processes. The composition of pyroclastic volcanics can be modified during eruptional and depositional by processes such as fractionation of the vitric dust in the eruption column to form separate crystal-rich and vitric-rich deposits (Sparks and Walker, 1977). The possible presence of accidental lithic fragments and/or xenoliths in the rocks is a problem in rocks where a strong metamorphic fabric may disguise these features.

(iv) Postdepositional alteration. This may include a number of processes. During the welding and compaction of pyroclastic deposits the vapour phase can redistribute Na, K, and Si leading to crystallization of alkali feldspars, tridymite and cristobalite in pore
spaces (Best, 1982). During the devitrification of metastable glass, ground water can leach elements including Na, K and cause oxidation of ferrous iron (Scott, 1971; Noble, 1967). Synvolcanic hydrothermal alteration by fluids derived from groundwater and/or seawater and/or magmatic water, may lead to a range of different compositions: from subtle changes in large volumes of rock which had low fluid/rock ratios to profound changes in zones with a high fluid/rock ratio (eg. Franklin et al., 1981).

(v) Metamorphic processes. Wybom et al. (1981) showed that during low-grade metamorphism of volcanic rocks in the Canberra area Na, K, Al, Si and Ca were mobile, phenocrysts were altered and the matrix was recrystallized although there was little textural change. In low-grade metamorphic rocks which have a strong metamorphic fabric it is likely that there has been some redistribution of elements. Pressure solution processes lead to dissolution of soluble minerals, transport of elements in a mobile fluid phase and precipitation of minerals in phyllosilicate-rich folia, pressure beards, extensional microstructures. Metamorphism of Ordovician metasedimentary rocks in Victoria involved the production of a strong foliation which was accompanied by addition of K and loss of Na, Ca, Mn and Si (Stephens et al., 1979). Kerrich et al. (1977) documented chemical changes in basalts which occurred during the development of a metamorphic cleavage by pressure solution processes.

(vi) Weathering. This includes present day weathering and synvolcanic submarine or subaerial weathering.

2 The Whole-Rock Geochemical Study

The geochemical study was devised and the samples submitted for analysis at an early stage of the work. The study was intended as a reconnaissance and the aims were to:

(i) compare the compositions of altered and unaltered rocks,

(ii) attempt to decide whether Units A to D have a significantly different composition to those of Units E and F which might reflect the presence of two different volcanic suites in the area.

The samples were not selected to test hypotheses arising from the detailed petrographic work and do not include samples from all of the zones of alteration. Furthermore, no attempt has been made to assess the effects of metamorphism on the composition of the rocks. The Peak View samples are divided into footwall and hangingwall samples and I have not done the detailed petrography on the samples which would allow further subdivision.

Note that the samples from the drill-core contain no obvious signs of weathering. The surface samples of Units E and F appear to be fresh, however the more strongly foliated surface samples from Units B and C are very slightly weathered.
7.2.b The Samples

Twenty eight samples from the Bredbo-Bunyan study area and 12 samples from the Peak View area were chosen for major and trace element analysis. Sample locations are given in Appendix 3.

1 Samples from the Bredbo-Bunyan Area

Unit B. Samples WDP 5, 6, 7, 9, 10 and 11 are from the metavolcanic rocks (Bv). WDP 5, 6 and 7 come from outcrops west of the gossans at the Gamma-Delta Prospect. WDP 9, 10 and 11 come from the Gillans Prospect drill-holes (BRYG 001 and 002). WDP 5 and 6 are more strongly foliated than the other samples and WDP 7, 8 and 10 contain prominent, large, white relict phenocrysts of plagioclase. WDP 11 is from a very pale, siliceous unit in drill-hole BRYG 002.

Unit C. Samples WDP 1 and 4 are from the coarse-grained metaporphry (Cp). The analysis of sample ER 72 which is included in the following discussion is from Reid (1980). WDP 4 is more foliated and contains less plagioclase than the other samples. WDP 1 and ER 72 come from two outcrops which are quite close together in the centre of the thickest part of Unit C and should be regarded as two samples from the same compositional domain.

Unit D. Samples WDP 15 to 25 are from Unit D. Samples WDP 15, 16, 17 and 18 are from the mineralized, K-feldspar-rich metavolcanic rocks (Dkb) intersected in Billilingra Prospect drill-hole DDH-BL 1. WDP 15 and 16 are typical of the facies whereas WDP 17 and 18 are from the sericite-rich zone along the western side of the facies. None of the samples contain any obvious mineralized veins. WDP 19, 23, 20, 21, 22, 24 and 25 are from the dark-green metavolcanic rocks (Dv) intersected in the Harnett Prospect drill-hole DDH-H3. The samples in the order presented are from the west to the east. WDP 24 is from the small fine-grained, sericitic, siliceous, pyritic interval from 223.8 to 237.0m.

Unit E. Samples WDP 26, 27, 28, 13, 12, 14, 2 and 3 are from Unit E. WDP 26 and 27 are from metavolcanic units in the mineralized, sericitic, siliceous metasedimentary and metavolcanic rocks (Es) in DDH-H3 at the Harnett Prospect. WDP 26 is composed of quartz and sericite. WDP 27 is sericitic but still retains many primary textures including plagioclase phenocrysts. WDP 2 and 3 are from the massive hornblende-bearing metavolcanic rocks (Ehv). They are massive, unfoliated and appear to be unweathered. WDP 28 is from the western side of the massive hornblende-bearing metavolcanic rocks (Ehv) intersected in the bottom of DDH-H3 and is more sericitic and foliated than the rest of the facies. WDP 12, 13 and 14 are from the interbedded metavolcanic and metasedimentary rocks (Evs) intersected in the Stonehenge prospect drill-holes. WDP 13 is from a sericitic unit in BRYZ 002.

Unit F. WDP 8 is from the hornblende-bearing metavolcanic rocks (Fhv) and is a massive, unfoliated and very fresh rock.
2 Samples from the Peak View Area

All samples are from drill-core. WDP 33, 34, 35, 36, 38 and 39 are from the hangingwall and WDP 29, 30, 31, 32, 37 and 40 are from the footwall.

7.2.c Results

The analyses are presented in Appendix 4 with an analysis of facies Cp, ER 72, which is from Reid (1980). The analytical techniques are given in Appendix 5.

1 Immobile Elements.

Elements such as Ti, Zr, Y, Nb and the rare-earth elements (REE) are generally considered to be immobile during weathering and low-grade alteration and are used to indicate the primary geochemical characteristics of rocks (Winchester and Floyd, 1977; Pearce and Cann, 1973). The Zr vs TiO₂ plot (Fig. 7.1.a) suggests that there are five compositional groups in the samples:

(i) the largest group includes the Peak View footwall rocks, rocks from Unit E and F, facies Dv, WDP 15 and 16 from facies Dkb and most of facies Bv,
(ii) the Peak View hangingwall rocks (low Ti~),
(iii) the coarse-grained metaporphry (Cp) (high Zr and TiO₂),
(iv) WDP 17 and 18 from facies Dkb (high Zr),
(v) WDP 11 from facies Bv (low TiO₂ and Zr).

The first three groups plot in approximately linear clusters which trend toward the origin. The Zr/Y plot (Fig. 7.1.b) shows that most samples plot in a broad group with no clear subdivisions.

The Y vs TiO₂ plot (Fig. 7.1.c) shows a much wider scatter of Y values. The Peak View footwall rocks, the rocks from Unit E and F, facies Dv, and most of facies Bv plot as a coherent group which trends toward the origin. The Peak View hangingwall samples have a considerable range of Y values and the group does not trend toward the origin. Three samples of facies Dkb (WDP 16, 17 and 18) plot on the low TiO₂ side of the main group. WDP 15 (Dkb) and 26 (Es) have very low Y values.

2 TiO₂ Variation Diagrams

In Figure 7.2 the geochemical data are plotted against TiO₂. TiO₂ was chosen because it has probably been immobile in the rocks. In general the samples of facies Bv, Ehv, Evs and Fhv plot in a relatively coherent group. These rocks can be inferred to be the least-altered samples and provide a basis for comparison.

SiO₂. In the SiO₂ plot (Fig. 7.2.a) there is a single, well-defined linear cluster, with a negative slope, composed of most of the samples from facies Ehv, Evs, Dv, Bv and Dkb. The cluster presumably reflects the primary variation in the rocks. Samples from facies Dkb plot as a group on the low TiO₂-high SiO₂ end of the group suggesting that it may be a more fractionated unit. Above the main group the samples WDP 24 (Dv), 5 (Bv) and 26 (Es) have high SiO₂ and TiO₂ values which may indicate loss of some major components during alteration. Below the main group there are two samples from facies Evs (WDP 12 and 14) and two samples from facies Dv.
**Fig. 7.1.a** Zr vs TiO₂.

**Fig. 7.1.b** Zr vs Y.

**Fig. 7.1** Immobile element plots. (For legend see p. 199).
Fig. 7.1.c  Y vs TiO₂

Fig. 7.1  Immobile element plots. Continued. (For legend see p. 199).
(WDP 19 and 23) which plot as a line parallel to the main group. There are no obvious reasons why this group should plot separately and presumably this pattern is a result of the low sample size, however it is possible that the two samples from facies Dv have low Si due to depletion during alteration. The footwall samples from Peak View have lower SiO₂ (54 to 66%) than the hangingwall samples (71 to 81%) and both groups tend to scatter considerably.

Al₂O₃. Al₂O₃ (Fig. 7.2.b) has a moderate scatter with no obvious difference between the altered and fresh samples except WDP 26 (Es) which has a very high Al₂O₃ content (19.73%).

Total Fe as Fe₂O₃. Fe₂O₃ (Fig. 7.2.c) values are scattered but most of facies Bv, Ehv, Evs and Fhv plot as a coherent group. The samples from facies Dv with green biotite (WDP 19, 20, 21, 22 and 23) plot above this group and the more sericitic samples (WDP 24 and 25) plot below this group. Facies Es also plots below the group. Facies Dkb plots as a coherent group with low values. The Peak View footwall samples have higher Fe₂O₃ than the hangingwall samples.

MnO. The MnO plot (Fig. 7.2.d) has a broad scatter with no obvious trends.

MgO. On the MgO plot (Fig. 7.2.e) facies Bv, Evs, Ehv and Fhv plot as a small coherent group. Facies Dv scatters above and below this group but note that the sericitic samples WDP 24 and 25 plot below the group. Facies Es samples have low MgO values. Facies Dkb plots as a coherent group with low values. Peak View footwall samples generally have higher MgO values than the hangingwall.

CaO. The CaO plot (Fig. 7.2.f) has a wide scatter. The samples of facies Bv, Ehv, Evs and Fhv plot in a broad group with high CaO values. The scatter in this group presumably reflects the mobility of Ca during albitisation and varying degrees of incorporation of Ca into carbonate and epidote. The samples from facies Dv and the sericitic rocks Es have scattered and lower CaO values. The Peak View footwall samples have a wide range of values and the hangingwall samples have a restricted range, generally < 1%.

Na₂O. Most of the samples from facies Bv, Ehv, Evs and Fhv plot as a reasonably coherent group with from 1.5 to 4% Na₂O (Fig. 7.2.g). Most of facies Dv plots below this group except WDP 19 (Dv) which plots above the group (4.32%). Facies Dkb also has low Na values. The sericitic samples, including facies Es, WDP 24 (Dv) and WDP 28 (Ehv), have very low Na content. Peak View samples from the footwall and the hangingwall scatter widely.

K₂O. Most of the samples of facies Bv, Ehv, Evs and Fhv plot in a group with a restricted range of from 1.5 to 3.5% K₂O (Fig. 7.2.h). Samples from facies Dkb, Dv (except WDP 19), Es and the sericitic samples from facies Evs (WDP 13) and Ehv (WDP 28) plot above this group. The Peak View samples are widely scattered.

P₂O₅. All samples except for WDP 26 (Es) plot as a coherent linear trend converging on the origin (Fig. 7.2.i). This suggests that P has been an immobile element in these rocks. WDP 26 plots below the trend.

Ba. The rocks which came from zones of mineralization, WDP 15 and 16 (Dkb) and WDP 27 (Es), have very high Ba contents (Fig. 7.2.j).

Rb. Samples from facies Dkb, Dv, Es and the other two sericitic samples from Unit E, WDP 28 (Ehv) and WDP 13 (Evs) have high Rb values (Fig. 7.2.k).
Fig. 7.2.a  SiO$_2$ vs TiO$_2$.

Fig. 7.2.b  Al$_2$O$_3$ vs TiO$_2$.

Fig. 7.2  TiO$_2$ variation diagrams.  (For legend see p. 199).
Fig. 7.2.c  Total Fe as Fe$_2$O$_3$ vs TiO$_2$.

Fig. 7.2.d  MnO vs TiO$_2$.

Fig. 7.2 TiO$_2$ variation diagrams. Continued    (For legend see p. 199).
Fig. 7.2.e  MgO vs TiO₂.

Fig. 7.2.f  CaO vs TiO₂.

Fig. 7.2 TiO₂ variation diagrams. Continued  (For legend see p. 199).
Fig. 7.2.g Na$_2$O vs TiO$_2$.

Fig. 7.2.h K$_2$O vs TiO$_2$.

Fig. 7.2 TiO$_2$ variation diagrams. Continued (For legend see p. 199).
Fig. 7.2.i  P₂O₅ vs TiO₂.

Fig. 7.2  TiO₂ variation diagrams. Continued  (For legend see p. 199).
Fig. 7.2.j  Ba vs TiO₂.

Fig. 7.2.k  Rb vs TiO₂.

Fig. 7.2  TiO₂ variation diagrams. Continued  (For legend see p. 199).
Fig. 7.2.1 Sr vs TiO₂.

Fig. 7.2.m Pb vs TiO₂.

Fig. 7.2 TiO₂ variation diagrams. Continued (For legend see p. 199).
Fig. 7.2.n  Th vs TiO$_2$.

Fig. 7.2.o  U vs TiO$_2$.

Fig. 7.2  TiO$_2$ variation diagrams. *Continued*  (For legend see p. 199).
Fig. 7.2.p  Ce vs TiO$_2$.

Fig. 7.2.q  V vs TiO$_2$.

Fig. 7.2  TiO$_2$ variation diagrams. Continued  (For legend see p. 199).
Fig. 7.2.r Cr vs TiO₂.

Fig. 7.2.s Ga vs TiO₂.

Fig. 7.2  TiO₂ variation diagrams. Continued  (For legend see p. 199).
Fig. 7.2.t Cu vs TiO$_2$.

Fig. 7.2.u Zn vs TiO$_2$.

Fig. 7.2 TiO$_2$ variation diagrams. Continued (For legend see p. 199).
Sr. Most of the samples from facies Bv, Ehv, Evs and Fhv plot above those from facies Dkb, Es and Dv. WDP 5 and 6 (Bv) and the other two sericitic samples from Unit E, WDP 28 (Ehv) and WDP 13 (Evs) also plot in the low-Sr group (Fig. 7.2.1).

Pb. The Pb plot has a very scattered distribution with no obvious trends (Fig. 7.2.m).

Th. Most samples from the Bredbo-Bunyan area plot in a narrow range with from 12 to 21ppm (Fig. 7.2.n).

U. Most samples from the Bredbo-Bunyan area plot in a narrow range with from 2 to 4ppm U (Fig. 7.2.o). WDP 24 and 25 from facies Dv, and WDP 15 and 16 from facies Dkb have slightly higher values.

Ce. Most of the samples from facies Bv, Dv, Ehv, Evs and Fhv plot in an elongate flat group (Fig. 7.2.p). Samples from facies Dkb and WDP 26 (Es) have higher values. The Peak View samples are widely scattered.

V and Cr. Most samples from the Bredbo-Bunyan area plot as a broad group (Fig. 7.2.q & r). Facies Dkb has low V and Cr content. The Peak View hangingwall samples have very low values compared to the footwall samples.

Ga. WDP 24, from the small sericitic interval in facies Dv, has very high Ga (32.5ppm). The rest of the samples plot (Fig. 7.2.s) as a flat group generally with from 13 to 19ppm Ga.

Cu and Zn. Cu and Zn are generally widely scattered (Fig. 7.2.t & u).

3 P2O5 vs Zr Plot

The P2O5/Zr graph (Fig. 7.3) shows that most of facies Bv, Dv, Ehv, Evs and Fhv plot as a small elongate group which trends toward the origin. Facies Cp rocks have high Zr and P2O5 contents and also plot in a linear group which trends toward the origin. WDP 11 (Bv), WDP 15, 17 and 18 (Dkb) and WDP 26 (Es) plot away from the main group. The Peak View footwall and hangingwall samples plot in different groups and the footwall samples have a wide scatter.

7.2.d Discussion

(i) Overall the "immobile" element plots suggest that:

1. The Peak View footwall rocks are petrogenetically different to the hangingwall rocks.
2. In the Bredbo-Bunyan area there is no obvious difference between the rocks of Units B, D and E (and F).
3. The Ti/Zr ratio in most of the samples has remained constant except for the mineralized, K-feldspar-rich metavolcanic rocks (Dkb).
4. Y has probably been immobile in the rocks except in the mineralized, K-feldspar-rich metavolcanic rocks (Dkb), the Peak View hangingwall and the mineralized, sericitic, siliceous metasedimentary and metavolcanic rocks (Es).
5. The Peak View footwall rocks are similar to the main group in the Bredbo-Bunyan area. This may reflect the fact that all are probably I-type.
Fig. 7.3  $\text{P}_2\text{O}_5$ vs Zr plot. (For legend see p. 199).
(ii) The TiO₂/P₂O₅ plot indicates that the TiO₂/P₂O₅ ratio has not changed in most of the rocks. This implies that on the TiO₂/Zr plot, WDP 17 and 18 (Dkb) do not plot near the main linear group because they have gained Zr and the restricted range of TiO₂ values for all of the facies Dkb rocks is a primary feature.

(iii) Facies Cp has very high Zr, Y, P₂O₅ and TiO₂ values compared to the other facies and it probably has a different primary composition.

(iv) Within facies Bv, WDP 11 has a very different composition from the other samples with higher SiO₂, Na₂O and Th, and lower TiO₂, total Fe, MnO, MgO, K₂O, Ba, P₂O₅, Rb, Zr, V, Cr and Zn. It is probable that this rock has a different primary composition.

(v) Within facies Bv the two more foliated samples, WDP 5 and 6, have low Sr values which suggests that there may have been some destruction of plagioclase in these rocks.

(vi) Interpreting the mineralized, K-feldspar-rich metavolcanic rocks (Dkb) is difficult. Compared to the group of unaltered rocks from facies Bv, Ehv, Evs and Fhv, the rocks from facies Dkb have: higher Si, K, Rb and Ce; lower Ti, Fe, Mg, Ca, Na, P, Sr, V and Cr; and similar Al, Mn, Ga, Zr. It is possible that the composition is due to primary fractionation because, on the variation diagrams which show trends, facies Dkb rocks tend to plot toward more fractionated compositions (eg. higher Si and lower Ti, Fe, Mg and P). On the other hand, the rocks come from a mineralized zone and the high K₂O and Ba values in WDP 15 and 16 and the very high Pb, Zn, and Cu values in WDP 15 are probably related to alteration and mineralization. The wide range of Zr (and Y) values is puzzling and may be due to alteration. Overall, the present composition of facies Dkb appears to reflect the effects of alteration and possibly a primary composition which was different to the other rocks in the area.

(vii) Within the dark-green metavolcanic rocks (Dv) WDP 23 has very high CaO and Sr, and low CO₂ which suggests that Ca is not in carbonate and may be in calcic plagioclase. Compared to the other samples from facies Dv the sericitic sample, WDP 24, has higher Si, S, CO₂, Ga, Pb and lower Al, total Fe, Mn, Mg, Ca, Na, Sr and Zn. This reflects the mineralization and the alteration, involving destruction of feldspar, in this interval.

(viii) The samples from Unit E and F can be divided into two groups. First, the sericitic samples, including the mineralized, sericitic, siliceous metasedimentary and metavolcanic rocks (Es), WDP 28 from the massive, hornblende-bearing metavolcanic rocks (Ehv), and WDP 13 from the interbedded metavolcanic and metasedimentary rocks (Evs). The second group includes the unaltered rocks from facies Ehv, Evs and the hornblende-bearing metavolcanic rocks (Fhv). Compared to the unaltered rocks the sericitic rocks have: higher K₂O; generally higher Ba and Rb; and lower Na₂O, CaO, MnO, MgO, Sr, Cu and Zn. Note that within the sericitic samples, WDP 27 has high S, and WDP 26 has low total Fe.
(ix) WDP 26 from the mineralized, sericitic, siliceous metasedimentary and metavolcanic rocks (Es) has high Zr and TiO₂, and low P₂O₅ contents compared to other samples. On the plot of TiO₂ vs Zr (Fig. 7.1) it plots at the high end of the main trend which suggests that the rock has preserved its original Zr/Ti ratio but the values have increased due to subtraction of major components from the rock. On the TiO₂ vs P₂O₅ and P₂O₅ vs Zr (Fig. 7.2 and 7.3) the rock plots away from the inferred primary trend toward the low P₂O₅ side. One explanation is that the rock may have lost P during alteration but note that there is no evidence to suggest that P has been mobile in the other sericitic rocks. Another possibility is that WDP 26 may have originally been an immature, epiclastic, volcaniclastic deposit which had a low detrital apatite content.

(x) The Peak View hangingwall rocks have higher SiO₂, Th and lower TiO₂, total Fe, MnO, MgO, P₂O₅, Cr, V than the footwall samples. Na, K, Ba and Rb tend to vary greatly.

(xi) Assuming that most of facies Bv, Dv, Es, Ehv, Evs and Fhv had very similar primary geochemistry then it is possible to characterise the geochemical effects of alteration. The sericitic zones (facies Es, WDP 24 [Dv], WDP 28 [Ehv] and WDP 13 [Evs]) have gained K and Rb, and lost Fe, Mg, Ca, Na, Sr and show sporadic gains of Si compared to the fresh rocks. The rocks of facies Dv (except WDP 24) which are characterised by the presence of green biotite, chlorite and minor sercite have gained Fe, Mg, K, Rb and V, and lost Ca, Na, Sr, with possible sporadic loss of Si.

7.3 RARE-EARTH ELEMENT STUDY

7.3.a Introduction

1 Background

The rare-earth elements (REE) are commonly used in petrogenetic studies to indicate magmatic processes (Hanson, 1980) because they are generally considered to be immobile during weathering, low grade alteration and low grade metamorphism (Herrmann et al., 1974). It is becoming clear, however, that the REE may be mobilised and fractionated during processes such as seafloor weathering (Ludden and Thompson, 1979), spilitization (Hellman and Henderson, 1977), zeolite facies metamorphism (Wood et al., 1976) and prehnite-pumpellyite facies metamorphism (Hellman et al., 1977). Recent studies of massive sulphide deposits (Graf, 1977), porphyry copper deposits (Taylor and Fryer, 1980), gold mineralization (Kerrich and Fryer, 1979), and uranium deposits (McLennan and Taylor, 1979) have shown that the REE are mobile in zones of alteration and can be used to understand the alteration process. A REE study of three Canadian massive sulphide deposits by Campbell et al. (1984) showed that the REE were depleted in the intensely altered pipes below the deposits but were immobile in the low grade alteration zones which surround the deposits. At Kidd Creek the REE were concentrated in a chlorite
alteration zone just below the sulphide body. In general the degree of REE mobility increased as the size of the deposit increased.

Another line of research has focussed on the observation that Archaean felsic volcanic rocks associated with massive sulphide mineralization have unusual REE patterns. Studies in the Canadian Shield (Thurston, 1981; Campbell et al., 1982; Lesher et al., 1985) have shown that volcanic horizons which contain massive sulphide deposits typically have "flat" chondrite-normalised REE patterns with prominent, negative Eu anomalies. Non-mineralized volcanic sequences generally have patterns with a steeper negative slope and Eu anomalies, if present, may be weakly negative or positive.

These observations have great potential in mineral exploration (Mannard, 1982), however the applicability of the technique is not clear. Preliminary data from mineralized and unmineralized volcanics at a number of deposits including the Golden Grove deposit (Western Australia) and a Kuroko deposit (Japan), supported the REE trends (Campbell et al., 1982). A detailed study of the Ordovician volcanics associated with the Buchans, Newfoundland, massive sulphide deposits, however, failed to show similar trends (Strong, 1984). At Buchans the mafic volcanic rocks throughout the sequence have similar steep REE patterns with variable Eu anomalies. Unmineralized felsic volcanics deep in the footwall have flat REE patterns with negative Eu anomalies. All of the other felsic units, including the ore horizon volcanics, have steep patterns with variable Eu anomalies.

The "flat" REE patterns were considered by Campbell et al. (1981, 1982) and Lesher et al., (1985) to be due to fractionation in magma chambers at shallow depths in the crust. These shallow magma chambers would also provide the heat required for convective circulation of fluids which form the massive sulphide deposits. The steep negative patterns are considered to have been produced by fractionation in magma chambers deeper in the crust. Strong (1984) suggested that there was no need to explain the patterns in terms of primary magmatic processes because they could be produced by alteration associated with the mineralization.

2 The Present Study

The overall aim on the present study was to attempt to apply the findings of the other REE studies to the Bredbo-Bunyan area. The study was devised at a time when it appeared that the mineralization and alteration in the area was of the massive sulphide style. The main aim was to see if the metavolcanics from the main mineralized horizon (Unit D) have a distinct REE pattern compared to the underlying metavolcanics (Unit B) and the younger metavolcanics (Unit E and F). The second aim was to compare altered and unaltered metavolcanic rocks from each unit to attempt to determine the mobility of the REE in different alteration zones. The third aim was to determine the effects of metamorphism on the REE by comparing the least altered rocks from different metamorphic zones and comparing foliated and unfoliated rocks.

The main problem with the study was that it was impossible to select a group of samples which would clearly distinguish between magmatic, alteration and metamorphic effects. In general, the degree of metamorphic foliation development increases with the inferred degree of alteration.
and all unaltered rocks from units B and D have a metamorphic foliation. The Peak View prospect was not included in the study because there are no obvious unaltered rocks at the prospect.

3 Samples

Fourteen of the samples which were used for whole-rock analysis were chosen for REE analysis. The samples and the reasons for their selection were:

(i) WDP 7; weakly foliated, least-altered facies Bv rock;
(ii) WDP 5 and 6; moderately foliated, possibly weakly altered facies Bv rocks;
(iii) WDP 15, 16, 17 and 18; progressively less altered samples from facies Dkb;
(iv) WDP 19, 22 and 25; facies Dv, possibly a zone of footwall alteration, strongly foliated;
(v) WDP 26 and 27; facies Es, a sericite alteration zone, strongly foliated;
(vi) WDP 2 and 8; fresh samples of facies Ehv and Fhv respectively, unaltered and unfoliated.

7.3.b Results

The REE results are included in Appendix 4 and plots of chondrite-normalised abundances for the samples are given in Figure 7.4. The data were normalised using the abundances of Evensen et al. (1978) multiplied by 1.8. The chondrite-normalised REE patterns for all samples (Fig. 7.4.a) are very similar except for WDP 26 (Es). From La to Ho the pattern has a steep negative slope with a prominent negative Eu anomaly. From Ho to Lu it flattens and for some samples this part has a slightly positive slope. WDP 27 (Es) has the lowest La, Ce and Nd ratios and WDP 18 (Dkb) and 26 (Es) have consistently high La, Ce and Nd ratios. The pattern of WDP 26 (Es) has a sigmoidal shape. From La to Sm the pattern is essentially the same as those of the other samples. From Eu to Lu it diverges from the range of the other samples to much lower ratios. The rock has a very-slight, negative Eu anomaly.

There are a few subtle features in the patterns for each facies. The samples of facies Bv (Fig. 7.4.b) have slightly larger Eu anomalies and facies Dkb samples have smaller Eu anomalies than the other samples. Within facies Bv WDP 5 has consistently higher values than the other two samples for all REE except for Eu. In facies Dkb (Fig. 7.4.c) WDP 18 has higher La, Ce and Nd values than the other samples. Within facies Dv (Fig. 7.4.d) WDP 22 has slightly higher middle REE (MREE) and heavy REE (HREE) values than the other samples.

7.3.c Discussion

1 Factors Affecting the Distribution and Abundance of the REE in the Metavolcanic Rocks

The present distribution and abundance of REE in the metavolcanic rocks in the Bredbo-Bunyan area is the result of the modification of the primary abundance and distribution by synvolcanic alteration and metamorphism. The changes during synvolcanic alteration and metamorphism would be controlled by the concentration of REE in the hydrothermal fluid, the
Fig. 7.4.a  Chondrite-normalised REE patterns for all samples.
Fig. 7.4.b  Chondrite-normalised REE patterns for the metavolcanic rocks from facies Bv.
Fig. 7.4.c  Chondrite-normalised REE patterns for the mineralized, K-feldspar-rich metavolcanic rocks (Dkb).
Fig. 7.4.d  Chondrite-normalised REE patterns for the dark-green metavolcanic rocks (Dv).
Fig. 7.4.e Chondrite-normalised REE patterns for the hornblende-bearing metavolcanic rocks (Ehv, WDP 2; Fhv, WDP 8) and volcanic units in the mineralized, sericitic, siliceous metasedimentary and metavolcanic rocks (Es, WDP 26 & 27).
distribution coefficients between the fluid and pre-existing minerals (and glass), the stability of pre-existing minerals, the stability of any new minerals, the partitioning of REE into new minerals, the capacity of the fluid to transport the REE out of the rocks, and finally, the fluid rock/ratio.

2 The Primary Distribution of REE in the Rocks

The volcanic rocks at the time of deposition were most likely composed of glass with crystals of quartz, plagioclase, hornblende and/or biotite, magnetite, apatite and zircon. In magmatic systems the crystal/melt distribution coefficient \(K_D\) for REE of quartz is generally considered to be very low (Buma et al., 1971). Henderson (1984) has summarised the distribution coefficients for the REE in dacitic and rhyolitic rocks. Magnetite has very low \(K_D\) for all REE. Plagioclase has a low \(K_D\) for all REE except Eu \((K_D > 1)\). Hornblende, zircon and apatite all have high \(K_D\) values \((>>1)\). Hornblende would tend to concentrate the MREE and HREE and zircon would concentrate the HREE. Apatite will contain all REE equally, however in a system which is crystallizing hornblende and zircon it is probable that the melt would be depleted in the HREE and so apatite would become enriched in the LREE.

Sphene and allanite, which have very high \(K_D\) values and can be the dominant REE site in granites (Sawka, 1985; Gromet and Silver, 1983) do not appear to have been primary phases in the Bredbo-Bunyan rocks. Sphene is a secondary phase in the rocks and has formed by alteration of mafic phenocrysts. Although some epidote grains in facies Bv may have cores of allanite it is not clear whether it is primary or secondary.

The actual proportion of REE contained in the minerals and the glass is difficult to ascertain. The high \(K_D\) values suggest that most of the REE would have been in the minerals with only small amounts in the glass.

3 The Effect of Metamorphism and Synvolcanic Alteration

Secondary minerals in the rocks, formed during synvolcanic alteration, diagenesis or metamorphism, include albite from plagioclase; chlorite, sphene, epidote and opaques after mafic phenocrysts; quartz, K-feldspar, chlorite, sericite, biotite, hematite, sphene, epidote and allanite from glass.

From Fig. 7.4.a it is clear that all of the samples have essentially the same REE pattern (except WDP 26 from facies Es). This suggests that all of the rocks had very similar initial abundances and that during alteration and metamorphism the abundances have been preserved. This is probably due to the stability of minerals such as apatite, zircon and plagioclase (despite conversion to albite) and the stabilization of the REE in secondary minerals. Sphene and allanite have very high \(K_D\) for REE (Henderson, 1984) and sphene is potentially a site for much of the REE released by the alteration of the mafic phenocrysts. Analyses of chlorites from sea floor basalts (Copeland et al., 1971) and chlorites produced by the experimental alteration of glassy tholeites (Menzies et al., 1979) show that chlorite has the capacity to take up considerable REE and even preserve primary REE patterns (Ludden and Thompson, 1979). Biotite and muscovite in
some granites have high (>>1) $K_D$ values (Buma et al., 1971; Alderton et al., 1980) and can concentrate the REE in metamorphic rocks due to surface adsorption (Raoldset, 1975).

Eu is probably concentrated in matrix albite and K-feldspar produced during devitrification. The slightly higher Eu values of the facies Dkb rocks may be due to some primary variation or it may indicate some gain of Eu by these rocks during alteration. The slightly larger Eu anomalies in the facies Bv samples suggests that these rocks may have lost Eu due to the conversion of the matrix to minerals other than feldspar during either metamorphism or alteration.

Epídote and carbonates in the rocks presumably have some capacity to take up REE into the Ca site.

4 Sample WDP 26

WDP 26 is a very sericitic metavolcanic rock from the zone of interbedded metasedimentary and metavolcanic rocks at the Harnett Prospect. I do not have a thin section of it, however XRD confirms that it is composed of mainly quartz and sericite. The hand specimen also contains some unidentified, tiny black grains. Compared to the other Bredbo-Bunyan rocks it has a slightly higher $Zr$ and lower $P$ content.

The REE pattern from La to Eu is essentially the same as that of the other samples and the simplest explanation is that the rock still has the primary abundances for these elements. This suggests that the REE abundances from Gd to Lu are not primary values and that they have been depleted. The depletion may be due to the destruction of a HREE-bearing phase, probably either zircon and/or hornblende, and removal of those HREE from the system in the absence of secondary minerals capable of taking up the REE. It is tempting to relate the low HREE to the low $P_2O_5$ (and therefore apatite?) content of the rock, however as explained above it is unlikely that apatite contained significant HREE. The most likely mineral is hornblende because the high $Zr$ content (223 ppm) of the rock suggests that zircon has not been destroyed. Rocks similar to WDP 26 from the same drill-hole do not contain any obvious relicts after mafic phenocrysts.

The alteration process has not significantly affected the LREE content of the rock compared to the other samples. This requires that either the hornblende had very low LREE abundances or that any LREE released in the process were fixed in the rock (in sericite?). It also suggests that if apatite in the rocks has been destroyed then the LREE in apatite have been fixed in the rock.

The Eu content in WDP 26 is only slightly lower than that of the other rocks. The rock presumably had feldspar in it originally and this might be expected to be lost during alteration. Destruction of hornblende should not effect the Eu abundance because it has very low $K_D$ values for Eu. The Eu in the rock is presumably contained in sericite and/or $Eu^{2+}SO_4$ (Graf, 1977).

5 Other Points

It is not clear whether the fact that the La, Ce and Nd ratios of WDP 18 (Dkb) and 26 (Es) plot on the top side of the group is significant. There is a discrepancy between Ce values measured by XRF and INAA (Appendix 4), however the results suggest that WDP 26 and 18 have a slightly higher values for these LREE. Whether this is due to primary variation or alteration is not clear. In
the case of WDP 26 this result is enigmatic because the rock has a comparatively low $P_2O_5$ (and therefore apatite?) content.

The consistently low ratios for WDP 27 (Es) may indicate that the REE abundances in the rock have been diluted by the addition of sulphide and carbonate. The rock has 2.8% S and 3.72% CO$_2$.

6 Implications of the Primary Abundances

The observation that the rocks have similar REE patterns suggests that all of the felsic volcanic rocks in the study area have very similar magmatic history and may be comagmatic. In terms of the regional stratigraphy this suggests that there is no significant compositional difference between the stratigraphically lower metavolcanic rocks (Units B and D), which are thought to be part of the Colinton Volcanics, and the overlying metavolcanics (Units E and F) of the Rothlyn Formation.

Compared to the Archaean REE patterns of Campbell *et al.* (1981, 1982) and Lesher *et al.*, 1985) the Bredbo-Bunyan rocks are most similar to the patterns from the unmineralized sequences. The main mineralized horizon, Unit D, does not have a distinct REE signature and the sericitic rock in the altered zone has an even steeper REE pattern.

7.3.d Summary of Conclusions from the Rare-Earth Element Study

The REE study of the felsic metavolcanics in the Bredbo-Bunyan area indicates that:

(i) all units had virtually identical REE patterns and are therefore probably comagmatic,
(ii) the main mineralized horizon does not have a flat REE pattern,
(iii) during metamorphism and low-grade alteration the rocks preserved their primary REE patterns,
(iv) in a zone of intense alteration marked by sericite development the HREE have been lost due to destruction of hornblende.

7.4 SULPHUR ISOTOPE STUDY

7.4.a Introduction

The aim of the sulphur isotope study was to do a reconnaissance investigation of the sulphur isotopic composition of the sulphides and barite in the main zones of mineralization in the Bredbo-Bunyan area. In order to keep the study fairly simple it was decided to analyse mainly pyrite because it occurs in most zones and could easily be hand-picked from the drill-core or percussion-drillchips. Samples of pyrrhotite and barite were also analysed. A few pairs of coexisting pyrite and barite grains were submitted for analysis in order to try geothermometry, however results were obtained for only one pair. The analyses were done by Dr Shensu Sun of the Bureau of Mineral Resources in Canberra.
7.4.b Results

The results are presented as a histogram in Figure 7.5 and details of the locations and the mineral assemblages in the samples are given in Appendix 6. The analytical precision for most samples is ±0.1‰ except for one sample which did not duplicate well which has a poorer precision (at most ±2‰). The pyrite-barite pair from the Billilingra Prospect gives a temperature of 255 ±10°C using the geothermometer of Ohmoto and Rye (1979).

7.4.c Initial Discussion of Results

A full discussion of the sulphur isotope results will be given in Chapter 8, but note three important features of the data:

(i) the narrow range of values around 5‰ for the samples of pyrite and pyrrhite from the Gillans and Picasso Prospects (zones of mineralization below the main mineralized horizon).

(ii) the very broad range of values for pyrite from the Billilingra, Driscolls Hill and Harnett Prospects (the main mineralized horizon).

(iii) the samples of barite have δ34S values which are close to and below the value for Silurian seawater which is 26‰ (Claypool et al., 1980).

The calculated temperature from the barite-pyrite pair is only meaningful if three conditions are met:

(i) the minerals formed in equilibrium.

(ii) the minerals have preserved their isotopic composition during subsequent events such as metamorphism.

(iii) the samples used for the analysis were pure.

Studies of natural systems (Ohmoto and Rye, 1979) and experimental work (Ohmoto and Lasaga, 1984) indicate that sulphate-sulphide equilibrium was generally not attained during coprecipitation of sulphides and sulphates at temperatures below ≤350°C. Equilibrium is more likely in systems which cooled slowly and have a high total sulphur content. I am unable to assess these parameters for the present system and it is not clear if the result is meaningful or not.
Fig. 7.5 Sulphur isotope histograms for all samples and for individual prospects. Results are expressed as $\delta^{34}S^\circ_{CDT}$. 

- Pyrite
- Pyrrhotite
- Barite
Chapter 8

DISCUSSION

8.1 THE PROBLEM OF METAMORPHIC VS ALTERATION MINERAL ASSEMBLAGES

The problem of the equivalence of low-grade metamorphic mineral assemblages and hydrothermal alteration assemblages has been pointed out by Hedenquist and Reid (1984) and Kristmannsdottir (1979). Studies of mineralization in metamorphosed terrains are fraught with the problems of distinguishing zones of alteration and determining the original mineralogy of the zones.

In both detailed study areas most rocks have a strong, commonly domainal, S₁ metamorphic foliation which is defined by phyllosilicates and phyllosilicate-rich folia composed of sericite, chlorite, ± biotite. In most rocks there are microlithons which preserve premetamorphic textures such as those which:

(i) contain randomly oriented minerals (including sericite, chlorite and rarely biotite),
(ii) have a very fine grainsize in contrast to the more granoblastic texture elsewhere in the rock,
(iii) preserve delicate primary structures such as spherulites or acicular feldspar grains.

Metamorphism and foliation development in these rocks has not completely destroyed the premetamorphic minerals and textures.

The minerals in the microlithons with premetamorphic textures cannot necessarily be interpreted as relict primary (or alteration) minerals. McLeod and Stanton (1984) and Stanton (1982) suggest that the minerals in and around some metamorphosed sulphide bodies have formed from early precursors such as clays, zeolites, Fe- and Al-oxides, and related diagenetic/authigenic minerals. The process involves the substantial preservation of original textures and involves:

(i) the direct transformation of sedimentary and diagenetic minerals,
  (eg. kaolinite/halloysite → sillimanite; nontronite → chlorite),
(ii) the combination and retexturing of small precursor domains of detrital, authigenic or diagenetic constituents
  (eg. kaolinite/montmorillonite clay → illite/hydromica → sericite/muscovite),
(iii) the retexturing of existing sedimentary minerals.

It is not clear whether these processes have occurred in the two detailed study areas, particularly whether tiny domains in the rocks have behaved isochemically. The broader principle is probably valid and it is clear that biotite in some microlithons appears to have replaced chlorite and it is possible that the pyrophyllite in the rocks may be a metamorphic mineral formed from kaolinite and quartz.
Overall, in attempting to recognise alteration zones in the rocks from the two study areas, it is clear that the microlithons with random textures offer the best chance of indicating alteration minerals. For the present I will assume that these minerals are premetamorphic but acknowledge the possibility that some may have grown from precursors with little or no obvious textural change.

8.2 THE PEAK VIEW DEPOSIT

8.2.a General

The regional stratigraphic position of the Peak View Outlier is not clear but on lithological grounds it correlates with the Late Silurian sequences. The immobile element plots suggest that the Peak View footwall rocks may have similarities with the rocks of the Bredbo-Bunyan area which are inferred to be least altered. This suggests that the Peak View rocks are I-types.

8.2.b The origin of the Peak View Mineralization

1 Introduction

Features of the Peak View deposit including the volcanic rocks in the host sequence, the stratiform lens of massive sulphides, the vein and disseminated mineralization in the footwall, and the submarine setting, indicate that the deposit fits into the group of deposits called volcanic associated massive sulphide deposits by Franklin et al. (1981). These deposits are generally considered to have formed at or near the discharge sites of subseafloor hydrothermal convection cells (Solomon, 1976; Franklin et al., 1981; Ohmoto et al., 1983). In the Canberra region the deposit is clearly analogous with the Captains Flat deposit (Davis, 1974) and the Woodlawn deposit (McKay and Hazeldene, 1987).

2 Environment of Deposition.

The footwall rocks at Peak View consist of volcanic rocks (at least partly deposited as lavas) interbedded with volcaniclastic rocks and biogenic carbonates. The facies suggest a shallow-marine environment. The mineralized horizon, apart from the sulphides, consists of a thin sequence of mainly fine-grained volcaniclastic material (possibly with some biogenic carbonate bodies). The mineralized horizon was buried by a rapidly deposited, thick sequence of volcanic rocks including at least some lavas.

The primary geochemistry of the hangingwall volcanics appears to be very different to that of the footwall volcanics but the significance of this to the mineralization is not clear. It may mean nothing but it suggests that the mineralization occurred at the onset of a new volcanic regime and this has implications for heat sources to drive convection and structural controls for the hydrothermal system.
3 Source of Components.

The source of the sulphur in the Peak View deposit can be inferred by comparison with the well-studied Woodlawn deposit. Ayres et al. (1979) considered that the sulphur isotopic composition of the Woodlawn deposit was consistent with most of the sulphur being derived from Silurian seawater sulphate. The sulphides had either formed by partial reduction of seawater sulphate at high temperatures (near 300°C) or by mixing of oceanic sulphate with lighter sulphur from a volcanic source. If the sulphur is derived from seawater then most of the fluid was probably originally seawater. Lead isotope ratios for the Woodlawn and Captains Flat deposits are essentially identical (Gulson, 1979) and the same as those at the Briars Mine (Bird, 1983). These results suggest a common source for the lead in all these deposits. Gulson (1979) was unable to resolve whether the lead at Woodlawn had come from leaching of the sequences below the deposit or if it had come from a magmatic fluid. A lead isotope study of Kuroko deposits and the underlying rocks by Fehn et al., (1983) showed that the ratios from the deposits have a narrow range and were consistent with having been derived from hydrothermal leaching of both the underlying volcanics and the basement rocks. By analogy it can be assumed that the lead and other metals in the Peak View deposit were derived by leaching of the rocks beneath the deposit, the Silurian volcanosedimentary sequences and the inferred basement (the Ordovician metasedimentary rocks).

4 The Plumbing System and Alteration.

There are no obvious conduits, such as faults, in the footwall at Peak View which might have served to focus the discharge at that particular site. The fluid caused a large zone of semi-conformable propylitic alteration in the footwall rocks which appears to have been associated with some sulphide veining. Within this zone no obvious pipe-like feeder zone has been found although it is possible that the zone of sulphide veining in PVD 12 represents part of a feeder zone.

The fine-grained volcanioclastic sediments of the mineralized horizon were altered to quartz, chlorite, pyrite, ±a potassium-bearing phase (K-feldspar?).

Alteration in the hangingwall rocks, presumably by the continuation of the hydrothermal system responsible for the mineralization, produced a zone of intense sericite development immediately above the sulphide lens. Alteration higher in the hangingwall involved development of chlorite initially, then Na-zeolites and finally sericitic zones.

5 Deposition of the Sulphide Body.

The stratiform nature of sulphide lens suggests that it was precipitated directly onto the seafloor, probably due to interaction of the hydrothermal plume with seawater (Sato, 1972; Large, 1977; Solomon and Walshe, 1979). Modelling of hydrothermal plumes by Turner and Gustafson (1978) have shown that plumes may pulsate due to buoyancy reversals so that sulphide deposition is episodic and this may lead to banding in the sulphide deposit. The fine banding in the Peak View deposit may have formed in this way. The larger scale zoning in the sulphide lens at Peak View, with siliceous, well-banded sulphides (mainly pyrite) on top of poorly banded, polymetallic
Ch. 8 DISCUSSION

sulphides, may be due to the temporal evolution of the system although it is possible that the early formed parts of the deposit were modified as later fluids passed through them in a manner similar to that proposed for the Kuroko deposits by Eldridge et al. (1983).

Copper-rich zones commonly occur in the lower parts of volcanic associated massive sulphide deposits (Franklin et al., 1981) and Eldridge et al. (1983) showed that in the Kuroko deposits copper deposition occurred during the hottest stage of a thermally intensifying, and then waning, hydrothermal system. No comparable copper-rich zone has been found in the Peak View deposit and the only copper-rich parts of the deposit are the quartz-chalcopyrite veins which occur mainly in the lower part of the thickest part of the deposit. Although it is possible that these veins occur along the margins of an undetected copper-rich zone it is also possible that no such zone exists. Studies of massive sulphide districts in Canada (Sangster and Scott, 1984; Spence and de Rosen-Spence, 1975) and Japan (Ohmoto et al., 1983) show that not all deposits have copper-rich zones and that in these districts the copper-rich deposits occur closer to the hottest parts of the system whereas copper deficient deposits occur in cooler parts. Overall, it appears that at Peak View the hydrothermal system was never hot enough to deposit significant amounts of copper and that the thermal peak of the system may be represented by some quartz-chalcopyrite veining in the sulphide body.

Apart from the massive sulphide lens the hydrothermal system produced semi-massive sulphides, pyritic cherts and possibly the carbonate bodies

8.2.c The Effects of Metamorphism and Deformation

Deformation and metamorphism probably during the latest Silurian and earliest Devonian involved folding, the production of a very strong domainal foliation ($S_1$).

8.3 THE BREDBO-BUNYAN AREA

8.3.a General geological setting

In terms of the Bredbo Block stratigraphy the Bredbo-Bunyan area appears to include part of the Cappanana Formation, the Colinton Volcanics, Rothlyn Formation and the intrusive porphyries. The area faces east and records a depositional history involving deposition of:

(i) muds and minor carbonates in a shallow-marine environment (Unit A),
(ii) thick, mainly terrestrial volcanics including lavas and pyroclastics (Unit B, facies Cv and Cm, and Unit D),
(iii) a transgressive, shallow marine sequence with volcanic rocks (Unit E),
(iv) deep-water muds with volcanic rocks (Unit F).

The Bullanamang Porphyry intruded after the deposition of the Late Silurian sequence.

The geochemistry of the metavolcanic rocks suggests that there is no significant difference between the composition of the least-altered rocks throughout the sequence. If this is true then it suggests that the volcanics from Units A, B, C, and D are I-type, like the volcanics of Units E and F. The whole extrusive volcanic sequence may be comagmatic with the lower parts being
deposited in a mainly subaerial setting and the higher parts deposited in a submarine setting. The deep-water setting can be related to regional subsidence which created a trough extending through the Bredbo, Captains Flat and Rocky Pic Blocks.

8.3.b Initial Statement of Possible Models for the Formation of Mineralization

Theories for the origin of the mineralization in the Bredbo-Bunyan area fall into three groups:

(i) Volcanic-associated massive sulphide model. The mineralization may be of the synvolcanic volcanic-associated massive sulphide style and has been metamorphosed and deformed. Gilligan et al. (1979) considered that the mineralization at Harnett was of this style and that the lack of a stratiform body was due to dilution of the mineralizing fluids by deposition of pyroclastics.

(ii) Epithermal model. The mineralization may be of synvolcanic, epithermal style which has been metamorphosed and deformed. The nature of the mineralization, stratabound disseminations and veins of sulphide and barite associated with propylitic, sericitic and advanced-argillic alteration zones close to the top of a terrestrial volcanic sequence, are features consistent with epithermal deposits (eg. Henley, 1985; Hayba et al., 1985).

(iii) Metamorphic model. The mineralization may have formed during the metamorphism in structurally controlled sites with precipitation of minerals and alteration by metamorphic fluids in a manner similar to that described by Fyfe and Henley (1973). Mel Jones (Gold Fields Exploration Pty Ltd, pers comm., 1987) suggested that the Harnett Prospect may have formed in a way which is similar to that proposed by some workers for the Hemlo gold deposit in Canada. Burk et al. (1986), Walford et al. (1986) and Ferreira and Fyfe (1986) consider that the Hemlo mineralization formed in a zone of retrograde metamorphism where the flow of metamorphic fluids was focussed due to structurally enhanced permeability. The wall rocks in the zone may have had enhanced chemical reactivity.

For the two synvolcanic models the Bullanamang Porphyry cannot be considered as a heater because it was intruded after the mineralization formed.

8.3.c Subdivision of the Mineralization and Alteration

The mineralization in the Bredbo-Bunyan area can be divided into four groups:

(i) the main mineralized horizon which occurs along the top of the subaerially deposited metavolcanics (Unit D) and in the transgressive sequence (Unit E). This group includes the mineralized zones in the Cosgrove Hill area and at the Billilingra-Barite, Driscolls Hill, Harnett and Stonehenge Prospects.

(ii) mineralization below the main horizon in the basal sedimentary sequence and the metavolcanic rocks of Units A and B and facies Cv and Cm. This group includes the Gillans, Picasso, Gamma-Delta Prospects and the western part of the Driscolls Hill Prospect as well as numerous small zones.
(iii) mineralization above the main horizon. This group includes the small jasper zones in Unit E northeast of Cosgrove Hill and the chert unit (Fch) at the Harnett Prospect.

(iv) mineralization in the Bullanamang Porphyry (Cp).

The Bullanamang Porphyry intruded after the deposition of the Late Silurian sequence (4.5.b). The mineralization in the porphyry probably formed by pyrometasomatic processes, possibly involving some redistribution of mineralization in the volcanics, and will not be considered any further.

8.3.d Timing of the Mineralization and Alteration

There are four lines of direct evidence for the age of the mineralization:

(i) Virtually all of the mineralization in the area is deformed and so it must predate at least the end of the last deformational event (probably D2).

(ii) In all of the zones of mineralization and alteration where I have done detailed petrography there are random phyllosilicate textures in the microlithons between the phyllosilicate-rich, foliation-defining folia. These random textures are considered to be relics of premetamorphic textures.

(iii) There is only one unequivocal exhalite in the area: the sulphidic chert (Fch) in the eastern part of the Harnett Prospect. It is reasonable to infer that the formation of the chert was associated with some alteration of the rocks beneath it, so that at least some of the alteration and mineralization at the Harnett Prospect formed at this time.

(iv) The framework-supported metavolcanic rocks (Ef) contain clasts of massive pyrite and fragments similar to the massive, white, K-feldspar-rich metavolcanics rocks (Dk). This suggests that these rocks were partly derived (by explosive fragmentation or erosion?) from subaerial? zones of mineralization and alteration in the region.

These observations strongly suggest that the mineralization and alteration formed at the time of volcanism and sedimentation during the late Silurian. The absence of mineralization from the sequence above the base of Unit F suggests that mineralizing process had ceased by this time.

8.3.e The Original Nature of the Mineralization and Alteration

1 The Main Mineralized Horizon

The mineralization and alteration along the main horizon occurs in four groups,

(i) The Cosgrove Hill area. The host rocks to the mineralization and alteration in the Cosgrove Hill area are a thick unit of mainly lavas deposited in a subaerial environment. Mineralization and alteration processes produced:

1. zones of K-feldspar, chlorite, pyrite and quartz alteration,
2. zones of sericite, quartz and pyrite alteration surrounded by propylitic alteration,
3. a zone of what is now pyrophyllite, ±kaolinite, ±alunite, ±quartz, ±pyrite in a thin zone of sedimentary rocks at the top of the subaerial volcanics,
4. a zone of what is now pyrophyllite, ±kaolinite at a deeper level in the sequence, below the lavas.
(ii) The Billilingra and Barite Prospects. In a sequence of subaerially deposited lavas with minor volcaniclastic rocks a central zone was altered to K-feldspar, sericite, quartz, pyrite, barite. The central zone contained minor propylitic alteration zones and had marginal zones of sericitic alteration. Veins of gold-rich, sulphidic barite with carbonate, quartz, and sericite formed in the central zone.

(iii) The Driscolls Hill Prospect. A small zone of sericite, quartz, pyrite, ±K-feldspar, alteration was produced in the volcanic rocks at the top of the subaerial volcanic sequence and in the transgressive sedimentary sequence. The zone was underlain by propylitic alteration in the volcanics.

(iv) The Harnett and Stonehenge Prospects. At Harnett the main zone of mineralization formed in the transgressive sedimentary sequence. The mineralization consisted of disseminated sulphides and veins composed of varying amounts of quartz, pyrite, ±sericite, ±K-feldspar, ±barite, ±minor base metal sulphides. The alteration produced very sericitic and siliceous rocks, small zones of intense silicification and a single marginal stratiform zone of pyrophyllite, kaolinite, sericite, hematite and quartz. The mineralized zone was underlain by a broad zone of propylitic alteration and overlain by sericitic alteration. The Stonehenge Prospect appears to be the weakly mineralized, marginal part of the Harnett zone. At Stonehenge zones of intense silicification in a sericitic, siliceous, gossanous interval at the top of the thick subaerially deposited volcanics were produced.

2 Mineralization Below the Main Mineralized Horizon

In the basal sedimentary sequence in the metapelites there are sericitic pyritic zones surrounded by propylitic zones. The propylitic zones contained disseminated pyrite and pyrrhotite and veins of coarse-grained quartz, chlorite, pyrrhotite, plagioclase and amphibole. In the volcanic rocks, in narrow zones parallel to strike, there were zones with intense sericite, kaolinite, ±siderite alteration with minor pyrite mineralization. These were surrounded by pyritic, chloritic zones which graded out into broad zones of weak propylitic alteration. In places there were thick veins of quartz and pyrite.

3 Mineralization Above the Main Mineralized Horizon

Mineralization above the main mineralized horizon is restricted to a few jasper bands in the rocks and a few zones of hematite and epidote development in the volcanic unit immediately above the main mineralized horizon. At the Harnett Prospect a small chert body, possibly associated with some sulphides, formed above this volcanic unit at the base of the deep marine sequence.

8.3.f Interpreted Depositional Environments and Timing of the Mineralization

Determining the environment of deposition of the mineralization and the timing of the system with respect to the deposition of the host rocks has been difficult for two main reasons. First, the mineralization occurs in rocks deposited around the time of a marine transgression, which might be
associated with a complex range of rapidly changing, subaerial and submarine sedimentary environments. Second, there are problems in distinguishing zones of subsurface alteration and mineralization from surface discharge zones.

In the Cosgrove Hill area the presence of zones of hematite and epidote alteration and jasper veins in the massive, hornblende-bearing metavolcanics (Ehv) immediately above the altered zones in Unit E suggests that the hydrothermal system was operating after the deposition of facies Ehv. The narrow units of hematitic, sericitic metasedimentary rocks (Ehs) and the bedded pyrophyllite, kaolinite, alunite, quartz, ?pyrite (Eaa) occur along the same palaeosurface immediately on top of Unit D and along the base of Unit E. One interpretation is that these zones represent subsurface zones of alteration along permeable horizons below an aquitard (the thick metavolcanics of facies Ehv). Alternatively, the pyrophyllite-bearing unit (Eaa) may be a metamorphosed boiling mud pool deposit, similar to deposits described in the Taupo Volcanic Zone in New Zealand by Hedenquist (1985). By inference, the sericitic, hematitic rocks (Ehs) may also be some type of surface discharge. An important point about the Cosgrove Hill area is that the sedimentary rocks below the hornblende-bearing metavolcanics (Ehv) are very thin and the thicker quartz arenites higher in facies Ehv suggest that in this area the marine transgression occurred after deposition of at least part of facies Ehv.

In the Billilingra-Barite area the presence of sericitic alteration and small barite veins in the lower parts of the massive, hornblende-bearing metavolcanics (Ehv) indicate that the hydrothermal system was operating after the deposition of this unit.

In the Driscolls Hill area the mineralization occurs in the metasediments of Unit E which include a small limestone lens. This suggests that mineralization in this area occurred after the establishment of marine conditions.

The exhalative chert at the Harnett Prospect indicates that hydrothermal system was operating after the marine conditions were established. One problem with this interpretation is the metapelite composed of pyrophyllite, sericite, kaolinite, hematite and quartz and gossanous chert (Dm) at the northern end of the Prospect which may be interpreted as a near-surface alteration zone or possibly even a boiling mud pool. This zone may have been a surface discharge site at an early stage of the hydrothermal system which was subsequently buried.

Overall the observations suggest two basically opposite interpretations, neither of which satisfy all of the conditions:

(i) The mineralization developed in a subaerial setting with the small chert at Harnett deposited in the waning stages of the mineralizing event after a rapid change to deep marine conditions. This model would require a small regression at the time of mineralization to expose the shallow marine facies in Unit E. It would also allow any advanced argillic zones to have been eroded prior to the deposition of later units.

(ii) Mineralization occurred after the deposition of Unit Ehv and the establishment of the deep submarine environment. All of the mineralization and alteration except the chert at Harnett formed in permeable zones below the sea-floor. The volcanic unit (Ehv) possibly acted as an aquitard.
A third possibility is that the mineralization (except for the chert at Harnett) formed in a mostly shallow-marine environment prior to the deposition of the volcanic unit (Ehv). During the waning stages of the system the volcanic unit (Ehv) buried the mineralized zone and was then weakly altered. In this model the main mineralized horizon at the Harnett and Driscolls Hill (and Barite?) Prospects formed at, and immediately below, the sea floor at a site where the hydrothermal system discharged into the sea, the main mineralized zone at Billilingra formed at a deeper level below the seafloor and the Cosgrove Hill area was subaerial discharge zone. The shoreline was somewhere in the area between the Barite Prospect and the Cosgrove Hill Prospects.

8.3.g Flow Patterns in the System

The main mineralized horizon is interpreted to have been produced by near-surface zones of fluid flow in a number of hydrothermal systems. For the present I will assume that there were four separate hydrothermal systems (the Cosgrove Hill area, Billilingra-Barite area, Driscolls Hill area and the Harnett-Stonehenge area) although I acknowledge that at least some of these could be interpreted as part of a single system. In parts of the main mineralized horizon there is a strong lithological control on the location of the mineralization (the sedimentary rocks of Unit E) however the reason for the fluid flow in the lavas of facies Dkb is not clear. In the Harnett-Stonehenge and Billilingra-Barite areas the shape of the mineralized zones suggests that there was a strong lateral flow in the system. If the analogy with subaerial epithermal systems is correct then the high As values at the Barite Prospect suggest that in this area fluid flow was from north (Billilingra Prospect) to south (Barite Prospect).

The zones of mineralization and alteration below the main horizon are interpreted to be deeper levels in the hydrothermal system responsible for the main horizon. Although I have found no obvious control on the location of these zones they presumably were originally permeable volcanic units, possibly unwelded fragmental rocks. The present distribution of these zones suggests that there might be some link between them and specific zones in the main mineralized horizon: the Gillans, Picasso and Gamma-Delta zones may be related to the Harnett-Stonehenge zone; the Riversdale Gossans to the Driscolls Hill zone and the gossans in the Mt Oak area may be related to the Cosgrove Hill system.

There are no obvious large-scale structures in the rocks below the main horizon such as faults which might have controlled the location of the zones of mineralization.

8.3.h Hydrothermal Fluid Properties and Alteration

Some properties of the hot hydrothermal fluid in the deeper part of the system can be estimated from the mineralization and alteration in the Gillans and Picasso Prospects. Based on the occurrence of amphibole in modern hydrothermal systems the hydrothermal amphibole at Gillans Prospect suggests a temperature of $\geq 300-350^\circ$C (Henley and Ellis, 1983). The presence of sericite, ±kaolinite and the absence of K-feldspar in the main zones of alteration suggests a low to moderate pH. The presence of pyrrhotite at Gillans suggests a very low $f_o^2$ and $f_s^2$ but this is probably partly due to the reduced nature of the pelites.
In the main mineralized horizon the zones of K-feldspar-rich rocks may have been produced by boiling. Studies of modern geothermal systems show that the assemblage K-feldspar is characteristic of zones of boiling (Henley and Ellis, 1983; Hedenquist and Reid, 1984). The K-feldspar is produced due to the increase in pH in the fluid which occurs as volatiles such as CO₂ and H₂S are fractionated into the steam phase as the fluid boils.

The zones of quartz, ±pyrophyllite, ±kaolinite, ±alunite, ±pyrite may have been produced in four different ways:

(i) oxidation of H₂S separated from fluids by boiling. In the geothermal systems in the Taupo Volcanic Zone (Hedenquist, 1985) the steam rising from the boiling hydrothermal fluid may condense into near-surface oxygenated groundwater. This causes the H₂S from the steam to be oxidised to sulphate and forms the "steam-heated acid sulphate fluid" which has pH=2-3 and relatively cool temperatures 100-130°C. The acid nature of the fluid causes intense leaching of the rocks with the development of advanced-argillic alteration assemblages with kaolinite, dickite, alunite, cristobalite, native sulphur, pyrite and hematite. If the steam-heated acid-sulphate fluid drains back into the system and mixes with the ascending hydrothermal fluid then deep zones of advanced-argillic and argillic alteration assemblages are developed. This fluid is called the "mixed acid-sulphate fluid" and has pH=2-5 and temperatures 100-180°C.

(ii) disproportionation of magmatic SO₂. In some modern geothermal systems advanced argillic assemblages occur at considerable depths and these are thought to have formed by introduction of deep (magmatic?) SO₂ into the fluids (Henley and Ellis, 1983). Pyrophyllite is characteristic of the hotter parts of these zones.

(iii) oxidation of reduced sulphur due to mixing with oxygenated fluids. In the Kuroko deposits of Japan kaolin and small amounts of pyrophyllite occur in the narrow zone of alteration which envelopes the sulphide ore bodies (Shirozu, 1974). Urabe et al. (1983) noted kaolinite in alteration zones around the margins of the main alteration zones at the Uwamuki deposits. They considered that the kaolinite-bearing zones formed by the oxidation of reduced sulphur in the fluid to sulphuric acid due to mixing with seawater.

(iv) supergene oxidation of sulphides.

My present interpretation of the alteration zones is that:

(i) The deep zones of sericite, ±kaolinite and quartz formed due to the acid nature of the ascending fluids. The symmetrical nature of these alteration zones with the surrounding chloritic zones suggests that the zones formed synchronously and that there has not been any overprinting by a later event. The chloritic alteration zones appear to reflect zones of less-intense alteration and were probably at less-acid conditions. The low pH in the fluid may have been controlled by precipitation of carbonates in a manner similar to that proposed by Pisutha-Arnond and Ohmoto (1983) for the Kuroko fluids.
(ii) The K-feldspar alteration zones may have formed where the ascending fluid boiled.

(iii) The stratigraphically high zones of advanced argillic alteration, which contain alunite, formed due to mixing of the hydrothermal fluids with oxygenated seawater immediately below the sediment-seawater interface. These zones appear to occur at the margins of the main areas of alteration and may represent zones of lateral flow of the hydrothermal fluids along permeable horizons.

8.3.i Sources of Metals

According to Matti Vaasjoki (CSIRO, Division of Mineralogy, North Ryde, Sydney, pers. comm., 1984) the lead isotope composition of the Harnett prospect is essentially identical to that of the Woodlawn deposit. Gulson (1979) showed that the Woodlawn and Captains Flat deposits have the same isotopic composition but was unable to distinguish whether the lead had come from a magmatic source or leaching of the Silurian and Ordovician sequences. All of these deposits appear to share a similar source for lead, probably a mixture of lead from the Silurian volcanics and the Ordovician sequence. Present indications are that the alteration in the Bredbo-Bunyan area can be traced into the basal sedimentary sequence which is presumably originally unconformable on the Ordovician (and/or Lower Silurian sequence). It is reasonable to infer that the hydrothermal system(s) extended into these older sequences.

8.3.j The Sulphur Isotope Results

1 Possible Sources for Sulphur in the Mineralizing Fluids and Their Isotopic Composition

There are a number of possible sources for the sulphur in the mineralization:

(i) Silurian seawater. Sulphur in Silurian seawater occurred dominantly as sulphate and had an isotopic composition of about $+26\%$ (Claypool et al., 1980).

(ii) Magmatic fluids. The volcanics in the Bredbo-Bunyan area appear to be mainly I-types and any granitic magma bodies below the sequence during the Late Silurian were probably also I-type. I-type magmas probably have sulphur isotopic compositions which are similar to the average for mantle-derived felsic igneous rocks which is $0\pm3\%$ (Ohmoto and Rye, 1979). Sulphur in magmatic fluids derived from these magmas might be expected to have a similar isotopic composition although some fractionation of sulphur species in the melt may occur leading to a range from $-3$ to $+7\%$ (Ohmoto and Rye, 1979).

(iii) Sulphur in minerals and connate fluids in Ordovician and Silurian rocks. Sulphur in volcanic minerals in the Late Silurian volcanic rocks is expected have approximately magmatic $\delta^{34}S$ values. Sulphur in any Silurian seawater which penetrated the volcanic pile should have seawater $\delta^{34}S$ values. Any diagenetic sulphates in the rocks should also have $\delta^{34}S$ values close to seawater values. Gulson (1976) reports $\delta^{34}S$ values of 0 to $14\%$ for pyrite in Ordovician and Silurian black shales near the Woodlawn deposit. Ayres (1979) reports $\delta^{34}S$ values of $+12.9$ and $+4.4\%$ for pyrite in Ordovician black
shales near Woodlawn. Late Ordovician seawater had $\delta^{34}$S value of $\approx +28\%$ (Claypool et al., 1980). (Note that it is possible that these sulphur values, taken from the Woodlawn area, are in fact hydrothermal values produced in the hydrothermal system responsible for the Woodlawn deposit).

(iv) Meteoric water. Meteoric water might be expected to have very low sulphur content and the sulphur will depend on the isotopic composition of the sulphur in any rocks it passes through.

2 Processes Which May Change the Sulphur Isotopic Composition of the Mineralizing Fluid

There are a number of processes which may change the sulphur isotopic composition of the mineralizing fluid:

(i) Dissolution of wallrock minerals (e.g. pyrite in black shales).
(ii) Precipitation of minerals.
(iii) Boiling of the fluid and removal of H$_2$S. In a boiling system the H$_2$S in the vapour would be expected to be enriched in $^{32}$S leaving the residual fluid enriched in $^{34}$S. The effect of boiling on the system depends on whether the H$_2$S in the vapour escapes from the system or recondenses back into it.
(iv) Mixing of fluids from different sources.

3 Sulphur Species in the Fluids and Their Isotopic Composition

In hydrothermal systems at low temperatures ($<350^\circ$C) and pressures the two dominant sulphur species are H$_2$S and SO$_4^{2-}$ (Ohmoto and Rye, 1979). The distribution of sulphur isotopes between these species is a function of a number of factors including temperature, pH, fO$_2$ and the total sulphur content of the fluid. These factors influence the H$_2$S / SO$_4^{2-}$ ratio in the fluid and the temperature mainly controls the isotopic fractionation factors between sulphur species (Ohmoto and Rye, 1979). The H$_2$S / SO$_4^{2-}$ ratio might increase, for example, due to reduction of sulphate in the fluid by either Fe$^{2+}$ in ferromagnesinan minerals or reduced carbon, in the wallrocks (Ohmoto and Rye, 1979).

4 Interpretation of the Sulphur Isotopes in the Deep Footwall Zones

At low fO$_2$ and pH the $\delta^{34}$S$_{\text{fluid}}$ becomes close to that of the associated sulphides (Ohmoto and Rye, 1979). At the Gillans Prospect the presence of pyrrhotite indicates very low fO$_2$ and at the estimated temperature ($\geq 300-350^\circ$C) equilibrium between the sulphur species and isotopes is to be expected. The presence of sericite and kaolinite in the alteration zones indicate a low to moderate pH. The $\delta^{34}$S values of these prospects suggest that the $\delta^{34}$S$_{\text{fluid}}$ was about $5\%$. This is very different from Silurian seawater sulphate ($26\%$) but it does overlap the magmatic values ($-3$ to $+7\%$) and the apparent range for Ordovician and Silurian sedimentary pyrite ($0-14\%$).
5 Interpretation of the Sulphur Isotopes from the Main Mineralized Horizon

The broad range of $\delta^{34}S$ values for pyrite in the main mineralized horizon can be explained by varying degrees of oxidation of the fluid and equilibrium fractionation of $^{34}S$ into sulphate. Assuming an equilibrium fractionation factor of 23‰ (the value obtained from the barite-pyrite pair from Billilingra) and $\delta^{34}S_{\text{fluid}} = 5$‰ then the following isotopic compositions for $\text{H}_2\text{S}$ and $\text{SO}_4^{2-}$ result for different ratios of $\text{H}_2\text{S} / \text{SO}_4^{2-}$:

\[
\begin{array}{ccc}
\text{H}_2\text{S} / \text{SO}_4^{2-} & \delta^{34}S_{\text{H}_2\text{S}} \text{‰} & \delta^{34}S_{\text{SO}_4^{2-}} \text{‰} \\
9 / 1 & 2.7 & 25.7 \\
1 / 1 & -6.5 & 16.5 \\
1 / 9 & -15.7 & 7.3 \\
\end{array}
\]

Ohmoto and Lasaga (1984) showed that equilibrium between coprecipitated sulphide and sulphates is commonly not achieved in experimental and natural systems and the observed fractionation is lower than the equilibrium value. In the present study the observed $\delta^{34}S$ values for pyrite strongly suggest that at least partial equilibrium was attained and that oxidation occurred in conditions which favour equilibrium such as low pH, low flow rates and high temperatures (Ohmoto and Lasaga, 1984). Nonequilibrium oxidation of $\text{H}_2\text{S}$ in the fluid would produce $\text{SO}_4^{2-}$ with a range of $\delta^{34}S$ values but would preserve the restricted range of $\delta^{34}S_{\text{H}_2\text{S}}$ values (Ohmoto and Rye, 1979).

An alternative interpretation of the barite data is that the barite formed from seawater sulphate because one of the $\delta^{34}S_{\text{barite}}$ values at the Billilingra Prospect is identical to Silurian seawater sulphate values (26‰). This interpretation would require that the hydrothermal fluid had $\delta^{34}S_{\text{ sulphate}} = 26$‰ and that barite had formed directly from seawater or if the hot hydrothermal fluid was originally a seawater fluid it had somehow maintained its sulphate composition. Partial reduction of seawater sulphate should produce very light (<<26‰) $\text{H}_2\text{S}$ and heavier (>26‰) sulphate in the fluid. The slightly lighter values for the other barite sample (+20.5 to +23.9‰) suggests that there was a component of lighter sulphate in the fluid and might require mixing of two fluids such as seawater and hot hydrothermal fluid (with light sulphate) to produce the barite results. This process still requires some mechanism for producing the light sulphide values. Bacterial reduction of sulphate does produce a wide spread of light sulphide values but this mechanism seems unreasonable in the present environment.

Equilibrium oxidation of the fluid can produce the observed $\delta^{34}S$ values. There are a number of ways in which the oxidation could have taken place:

(i) interaction with oxidised rocks,
(ii) interaction with oxidised meteoric groundwaters,
(iii) as a result of boiling due to the loss of reduced gases such as $\text{H}_2$ into the steam,
(iv) interaction with oxygenated seawater.

Unaltered rocks in the Bredbo-Bunyan area contain magnetite and altered zones contain hematite. The fluids have oxidised the rocks and not vice versa. Interaction with oxidised meteoric groundwater is a viable mechanism only if the supply of groundwater is continuously replenished. The degree to which the loss of $\text{H}_2$ during boiling causes oxidation is not clear (Hedenquist and
Reid, 1984). The most likely mechanism is mixing with seawater and this is confirmed, perhaps, by the oxidised nature of the alteration at the Harnett Prospect which is interpreted to be at the seafloor.

There are two consequences for the sulphur isotope compositions of the minerals due to mixing with cold seawater:

(i) the process would add heavy sulphur to the system so that $\delta^{34}S_{\text{fluid}}$ increases.

(ii) mixing would lower the temperature of the fluid making equilibrium less likely.

Equilibrium mixing would involve both oxidation of $\text{H}_2\text{S}$ in the hydrothermal fluid and reduction of seawater sulphate but the overall effect in the present system would be to produce heavier sulphur species in the fluid. Disequilibrium mixing of the $\text{H}_2\text{S}$-rich hydrothermal fluid with seawater would produce a range of $\delta^{34}S_{\text{sulphate}}$ values and a restricted range of $\delta^{34}S_{\text{H}_2\text{S}}$ values because the oxidation of $\text{H}_2\text{S}$ is more rapid than the reduction of sulphate at low temperatures (Ohmoto and Rye, 1979). The fluid would preserve higher temperature equilibrium $\delta^{34}S_{\text{H}_2\text{S},\text{composition}}$ but would not produce light $\text{H}_2\text{S}$. The $\delta^{34}S_{\text{sulphate}}$ values would be the result of the mixture of the higher temperature hydrothermal fluid value, the seawater sulphate value and the value of the sulphate produced by oxidation of $\text{H}_2\text{S}$ in the hydrothermal fluid. Both equilibrium oxidation and nonequilibrium mixing may have occurred in the Bredbo-Bunyan system. Equilibrium oxidation is required to produce the light sulphide and probably occurred in the upflow part of the system where the hot fluid first mixed with small amounts of seawater. Nonequilibrium mixing with seawater is geologically reasonable in the areas of the system which were closer to the seafloor.

The sulphur isotope data for the main mineralized horizon show some variation in space. Although the number of results is small the average $\delta^{34}S$ values for pyrite and barite are lighter to the south:

<table>
<thead>
<tr>
<th></th>
<th>$\delta^{34}S_{\text{pyrite}}$%</th>
<th>$\delta^{34}S_{\text{barite}}$%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Billilingra</td>
<td>+2.2</td>
<td>+24.9</td>
</tr>
<tr>
<td>Driscolls Hill</td>
<td>−1.8</td>
<td>+21.2</td>
</tr>
<tr>
<td>Harnett</td>
<td>−6.2</td>
<td></td>
</tr>
</tbody>
</table>

Although the variation may be due to different systems having different sulphur isotopic compositions it may reflect different degrees of oxidation of the hydrothermal fluid. The equilibrium oxidation model suggests that sulphides and barite from more oxidised zones should be lighter than those from less oxidised zones. At the Harnett Prospect the abundant hematite in the dark-green metavolcanic rocks (Bv) beneath the mineralized zone suggests a more oxidised environment than the Billilingra Prospect where there is much less hematite. This is consistent with the interpreted geology: Billilingra appears to be a deeper footwall zone whereas the main mineralized zone at Harnett appears to be a seafloor discharge zone. The near surface zones such as Harnett and Driscolls Hill might be expected to have more mixing with seawater. If this interpretation is correct then it implies that hydrothermal fluid/seawater ratio at the deposits was generally high. Low fluid/seawater ratios would produce barites with isotopic compositions close to that of seawater sulphate.
6 The Source of the Sulphur

The barite compositions argue against seawater sulphur being the only source of sulphur in the hydrothermal fluid because the observed barite values are too light. Reduction of seawater sulphate should produce light $\text{H}_2\text{S}$ and heavier residual $\text{SO}_4^{2-}$ with $\delta^{34}\text{S}_{\text{Sulphate}} > 26\%$. The $\delta^{34}\text{S}_{\text{Fluid}} = 5\%$ obtained from the lower alteration zones is not diagnostic of any single source and suggests that the sulphur came from a combination of sources involving a significant contribution of light sulphide from the volcanics and/or the sedimentary rocks.

8.3.k Source of the Hydrothermal Fluid

From the interpreted geological framework at the time of mineralization it is possible to infer that three types of fluid were present during the mineralizing event: the hot hydrothermal fluid, cold seawater and pore water in the rocks. The pore water might be a mixture of residual meteoric water in the subaerially deposited volcanics of Unit D and seawater moving down into the rocks. It is also possible that the rocks contained meteoric water flowing from any adjacent subaerial zones in a manner analogous to the meteoric fluids encountered in the Seikan Undersea Tunnel in Japan (Mizukami and Ohmoto, 1983).

The ultimate source of the hydrothermal fluid in the Bredbo-Bunyan area might be seawater, meteoric water, magmatic fluid, or a mixture of any of these. At present I have no direct evidence to distinguish between these possibilities. My bias is to interpret the sulphur isotope value of $\delta^{34}\text{S}_{\text{Fluid}} = 5\%$ to have resulting from leaching of sulphides in Silurian and Ordovician rocks by a meteoric fluid.

8.3.l Precipitation of Sulphides, Barite and Gold

Mixing of different hydrothermal fluids and boiling are both important mechanisms for deposition of sulphides, gold and barite in the epithermal environment (Hayba et al., 1985). In the Bredbo-Bunyan area the association of gold with barite suggests that gold, probably carried as bisulphide complexes (Henley and Ellis, 1983), was deposited due to changes in the $\text{H}_2\text{S}/\text{SO}_4^{2-}$ ratio in the fluid during oxidation of the fluid (Ripley and Ohmoto, 1985).

8.3.m Genetic Models

From the information presented so far it is clear that the mineralization in the Bredbo-Bunyan area did not form during the metamorphic event although it has been modified by it. The mineralization fits neither the volcanic-associated massive sulphide model or an epithermal model directly. Instead it appears to be either a volcanic-associated massive sulphide system which has entered a shallow-water environment and boiled or an epithermal system developed in a partly marine environment. Overall the observations are more consistent with an epithermal system.

A schematic diagram showing the main features of the hydrothermal system responsible for the Bredbo-Bunyan mineralization is shown in Figure 8.1. It is based on the models for modern
geothermal systems in silicic volcanic terranes by Henley and Ellis (1983). The important components in the model are:

(i) a tectonically active environment (eventually forming a deep basin) which allows meteoric water to penetrate the volcanics and the basement,
(ii) heating of the waters (by shallow magma bodies?),
(iii) leaching of sulphur and metals from the country rocks,
(iv) production of a low pH, reduced fluid,
(v) the possible addition of material from the magma (metals and/or sulphur?),
(vi) focussing of the fluid into narrow zones as it rises, producing central zones of intense sericitic alteration and surrounding weaker propylitic alteration,
(vii) at high levels, boiling of the fluid to produce K-feldspar alteration zones, and mixing with cold seawater in the rocks below the seafloor, causing deposition of sulphides and barite,
(viii) production of advanced argillic assemblages in small zones close to the seafloor due to mixing with oxygenated seawater,
(ix) venting of the fluid into cold seawater.

One of the main differences between the Bredbo-Bunyan area and the modern geothermal systems is the lack of extensive and deep, near-surface advanced argillic alteration zones. The fluid was presumably too buoyant to concentrate near the sea floor and rose up into the seawater.

8.3.n Regional Implications

The main mineralized horizon in the Bredbo-Bunyan study area may be traced to other parts of the Bredbo Block (3.2.f)(Fig. 8.2). To the south of the study area it is represented by the Bushy Hill (and Black Rock Barite?) deposits. Northeast of the study area, it may correlate with the Birchams-Colinton North (and Ponderose-Michelago Copper?) horizon. The mineralized horizon in the northeastern area is succeeded by mainly subaerially deposited volcanics. This is consistent with the interpretation (4.5.a) that the volcanic centre for the Bredbo-Bunyan area lay to the north. This mainly subaerial setting may have been the source for the meteoric water in the Bredbo-Bunyan zones.

Elsewhere in the Bredbo Block there is mineralization in the Rothlyn Formation at the Dartmoor and Skidmore and the Square Range prospects. The mineralization and alteration in these areas is superficially very similar to the mineralization in the Cosgrove Hill-Stonehenge horizon. Perhaps the zones in the Rothlyn Formation represent parts of this same mineralized horizon.

There are a number of implications for gold exploration in the Bredo Block arising from the present work. The observation that the mineralization in the Bredbo-Bunyan area defines a mineralized horizon provides a focus for exploration activity. Within the Bredbo-Bunyan study area the northern end of the mineralized horizon, the Cosgrove Hill area, remains essentially unexplored. The extensions of the horizon to the north and south of the Bredbo-Bunyan study area are also potential targets, in particular the Black Rock Barite deposit and possibly the Bushy
Hill area west of Cooma. On a regional scale the inferred extensions of this horizon must also be targets.

The association of gold with barite in the Bredbo-Bunyan area makes the other occurrences of barite in the block targets; in particular the Black Rock Barite, Bredbo Barite, C249, Birchams, Colinton Silver and C252 prospects; Baczynski's West gossan and the Dartmoor and Skidmore areas.

8.4 REGIONAL PATTERNS OF MINERALIZATION

8.4.a Mineralization and Palaeogeography

On a regional scale the Peak View deposit is one of a series of massive sulphide deposits including the Captains Flat and Woodlawn deposits which occur in a meridional belt in the Rocky Pic and Captains Flat Blocks. This belt probably extends north to include the group of small deposits around Peelwood (Gilligan et al., 1979) and Sunny Corner (Seccombe et al., 1984). The deposits in the Canberra region apparently formed in a deep marine trough with shallow-marine and/or terrestrial environments along both sides. The sequences along both sides of the trough contain only small vein-style deposits and there are large unmineralized areas. The trough sequences contain the only mafic volcanic rocks in the region, all of the stratiform mineralization and most of the stratabound mineralization. The Bredbo-Bunyan zones of mineralization occur in a subaerial volcanic sequence and transgressive shallow marine sequence below the trough sequence and formed during the initial stages of the subsidence which formed the regional trough.

The trough sequences presently occur immediately to the east of the I-S line (Lambert, 1979). The I-S line for much of its length occurs along major regional faults, however there is no direct evidence to suggest that the faults were operative during the Silurian. These observations suggest that during the late Silurian the eastern edge of the Proterozoic layer in the lower crust controlled the formation of the deepwater trough. The presence of the bulk of the regional mineralization along this structure is consistent with the theory that zones of crustal weakness, especially dilatant features, become conduits for magmas and hydrothermal systems (eg. Cathles et al., 1983). Present indications are that both meteoric and seawater fluids used these favourable circumstances to produce hydrothermal deposits.

8.4.b The Deeper Parts of the Hydrothermal Systems

It can reasonably be inferred that the deeper parts of the hydrothermal systems responsible for the volcanic-associated massive sulphide mineralization and the epithermal mineralization were in the Ordovician rocks which formed the basement to the Late Silurian sequences. The recognition of alteration zones in the Ordovician rocks is probably very difficult because even before the metamorphism they were probably very subtle features. I would like to draw attention to the Cullarin Block, because it has a number of features which may relate to this problem. First, the present structural position of the block, with parts of the trough sequence on both sides, suggests that the block might expose the basement of the Late Silurian trough. Second, the block contains
Fig. 8.2 The inferred distribution of the mineralized horizon in the Bredbo Block.

The northern part of the block is not shown.
granites which are the right age to have been heaters for hydrothermal systems (eg. the Late Silurian Koolambah Granodiorite (=419Ma; Hayden, 1980). Third, the contact between the Bredbo Blocks and the Cullarin Block is at least partly unconformable (and not faulted) so that this area at least has the potential to preserve an uninterrupted section through the hydrothermal system responsible for the mineralization along the eastern side of the Bredbo Block. The part of the Cullarin Block to the east of Cooma may also be a shallow level section through the block because there are no granites in the area. Finally, the mineralization in the block, especially the gold and sulphide mineralization at the Cowarra Prospect (cf. McQueen et al., 1984) may be related to the Late Silurian hydrothermal systems. Elsewhere in the region small gold deposits are common in the Ordovician rocks (Felton, 1977; Gilligan, 1975b) but the age and origin of these deposits is unclear.

8.5 SUGGESTIONS FOR FUTURE WORK

During my study it became clear that there are many aspects of the geology and mineralization in the Canberra region which require further work. In particular:

(i) the depositional environments of the Late Silurian sequences,
(ii) the stratigraphic correlations between separate structural blocks,
(iii) the timing and effects of the deformational and metamorphic events,
(iv) the Late Silurian regional tectonic setting,
(v) the nature of the hydrothermal systems which produced the mineralization.

At a more basic level there is the need for good descriptions of many of the zones of mineralization in the region. My work has been a contribution toward understanding some of these problems and I hope that it will be of use to future workers.
References


REFERENCES


REFERENCES 252


COX S.F. & ETHERIDGE M.A. (in prep.) Cleavage development during high fluid pressure deformation of low grade metamorphosed silicic volcanics at Mount Lyell, Tasmania. (Submitted to J. Struct. Geol.).


GLASSON K.R. 1957. The regional geology and structure of an area around Captains Flat, N.S.W. M.Sc. thesis. Sydney Univ. (unpubl.).


HARPER L.F. 1909. The geology of the Murrumbidgee district near Yass, N.S.W. Geol. Surv. N.S.W., Rec. 9, 1–54.


HORSLEY M.R. 1972. Geology and economic potential of the Coopers Creek area, N.S.W. B.Sc.(Hons) thesis. Sydney Univ. (unpubl.).


JODODEX AUSTRALIA PTY LTD STAFF. 1979b. Jododex Australia Pty Ltd. P.L.A's 89, 90, 91 at Boro. Report to the N.S.W. Department of Mineral Resources & Development on


REFERENCES 259


McKAY W.J. & HAZELDENE R.K. 1987. Woodlawn Zn–Pb–Cu sulphide deposit, New South Wales, Australia: An interpretation of ore formation from field observations and metal zoning. Econ. Geol. 82, 141–64.


REFERENCES


MANNARD G.W. 1982. A critical appraisal of the applicability of recently developed data and theories to the search for volcanogenic massive sulphide deposits. Geosc. Can. 9, 76–79.


O’GRADY I. 1980. Part I. The geology of the Kybeyan area, N.S.W. BSc (Hons) project report
Univ. Melb. (unpubl).

OHMOTO H. & LASAGA A.C. 1984. Kinetics of reactions between aqueous sulfates and sulfides in

York.

OHMOTO H., MIZUKAMI, M., DRUMMOND S.E., ELDRIDGE C.S., PISUTHA–ARNOND V. &
LENAGH T.C. 1983. Chemical processes of Kuroko formation. Econ. Geol. Mon. 5,
570–604.

OLDERSHAW W. 1965. Geological and geochemical survey of the Captains Flat area, New South

Univ. Canberra (unpubl.).


OWEN M. & WYBORN D. 1979. Geology and geochemistry of the Tantangara and Brindabella
Miner. Resour. Geol. Geophys., Bull. 204

Newmont Holdings P/L under joint agreement with ICI Australia Ltd and Aberfoyle

PACKHAM G.H. 1960. Sedimentary history of part of the Tasman Geosyncline in southeastern


PEARCE J.A. & CANN J.R. 1973. Tectonic setting of basic volcanic rocks determined using trace

1975/236.

PETRerson M.D. & LAMBERT I.B. 1979. Mineralogical and chemical zonation around the
26, 169–186.

29, 264p.

PIllANS B. 1974. Surficial geology of the Murrumbidgee–Bredbo interfluve, NSW. BSc. (Hons)

PISUTHA–ARNOND V. & OHMOTO H. 1983. Thermal history, and chemical and isotopic
compositions of the ore–forming fluids responsible for the Kuroko massive sulphide
deposits in the Hokuroko district of Japan. Econ. Geol. Mon. 5, 523–558.


REFERENCES


VERNON R.H. & HOBBS B.E. (Undated) Field guide for the Cooma Metamorphic Complex and nearby granitic bodies. (unpubl.).


Appendix 1  Features of the mineralization in the Canberra region

Notes and abbreviations used in the table.
1. In the Prospect column: P = prospect, M = mine and works = workings.

2. Metall. No. refers to the number of the prospect on the 1:250,000 Metallogenic Sheets:
   C = Canberra, G = Goulburn, W = Wagga Wagga and B = Bega Sheet.

3. In the Host Rocks column, lithology refers to the immediate host rocks to the deposit:
   - volc ........ volcanics
   - mst ........ mudstone
   - sh .......... shale
   - gran ........ granite
   - ch .......... chert
   - phy ........ phyllite
   - dior ........ diorite
   - lst .......... limestone
   - c-s .......... calc-silicate rocks
   - sst .......... sandstone
   - bas .......... basalt

4. Structure refers to any structural features such as faults, folds or joints:
   - F/Sz .......... fault or shear zone
   - cl .......... good cleavage

5. The style of the mineralization:
   - Sb D ............... stratabound disseminations,
   - Sb D/Sw .......... stratabound disseminations and stockwork,
   - Sb D/Sw/Sm ....... stratabound disseminations, stockwork and semimassive bodies,
   - Sb M/Sm .......... stratabound massive and semimassive,
   - Sb Sw/MSm ....... stratabound stockwork with massive and semimassive bodies,
   - S M ............... stratiform massive body.

6. Any reported alteration is referred to as:
   - chl .......... chlorite
   - sil .......... silica
   - CO3 .......... carbonate
   - AA .......... pyrophyllite, kaolinite, alunite
   - ser .......... sericite
   - dol .......... dolomite
   - K .......... K-feldspar
   - kaol .......... kaolinite

7. Ore minerals:
   - Py .......... pyrite
   - Mt .......... magnetite
   - Cp .......... chalcopyrite
   - Gn .......... galena
   - Ba .......... barite
   - As .......... arsenopyrite
   - Wt .......... wittichenite
   - Po .......... pyrrhotite
   - Hm .......... hematite
   - Sp .......... sphalerite
   - Au .......... gold
   - TT .......... tennantite–tetrahedrite
   - Bo .......... bornite
   - Ma .......... marcasite
Mk ....... mackinawite  Mal........ malachite
Bi .......... bismuthinite  Pyrol...... pyrolusite
Ilm ......... ilmenite  Stan........ Stannite
Cs .......... cassiterite  A g......... native silver
Co .......... covellite  Goe....... goethite
Di ............ digenite  El......... electrum
Ch .......... chalcocite

Some indication of the relative abundance of ore minerals is shown where possible thus:

- .......... major mineral  (+) .......... minor mineral

8. Gangue minerals include:

- Qt........ quartz  Se........ sericite
- Cl .......... chlorite  Co.......... carbonate
- Ht .......... host rock  Zr .......... zircon
- Lu .......... leucoxene  Sp.......... sphene
- Ac .......... actinolite  Ep......... epidote
- Fl .......... fluorite  Ka.......... kaolinite
- Tr .......... tremolite  Gt.......... garnet
- Ta .......... talc

9. References:

R 1 Gilligan (1975b)  R 20 Jododex Australia Pty Ltd Staff (1979a)
R 2 Felton (1975)  R 21 Cooke (1977)
R 3 Herzberger and Barnes (1978)  R 22 Glasson (1979)
R 6 Ashley and Creelman (1976)  R 25 Besley (1973a)
R 7 Owen and Wyborn (1979)  R 26 Rabone (1977)
R 8 Bagnall (1981)  R 27 Beams (1984a,b)
R 10 Nisbet (1979)  R 27 Beams (1984a,b)
R 13 Roberts (1976)  R 31 Perriam et al. (1975)
R 15 Larsen and O'Connor (1972)  R 33 Dolanski (1976)
<table>
<thead>
<tr>
<th>R 38</th>
<th>Davis (1974)</th>
<th>R 55</th>
<th>Jododex Australia Pty Ltd Staff, (1979b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R 41</td>
<td>Oldershaw (1965)</td>
<td>R 58</td>
<td>McInnes (1979)</td>
</tr>
<tr>
<td>R 43</td>
<td>Wright-Smith (1972)</td>
<td>R 60</td>
<td>Nethery (1980)</td>
</tr>
<tr>
<td>R 45</td>
<td>Gilligan (1974b)</td>
<td>R 62</td>
<td>Besley (1972)</td>
</tr>
<tr>
<td>R 46</td>
<td>Kratos Uranium N.L. (1971)</td>
<td>R 63</td>
<td>Gilligan (1975c)</td>
</tr>
<tr>
<td>R 47</td>
<td>Gilligan, Felton and Olgers (1979)</td>
<td>R 64</td>
<td>Cottle (1970)</td>
</tr>
<tr>
<td>R 48</td>
<td>Malone (1979)</td>
<td>R 65</td>
<td>My work.</td>
</tr>
<tr>
<td>R 49</td>
<td>Ayres (1979)</td>
<td>R 66</td>
<td>Rabone and Richardson (1979)</td>
</tr>
<tr>
<td>R 53</td>
<td>Kamezys, et. al., (1979)</td>
<td>R 70</td>
<td>Besley (1973b)</td>
</tr>
</tbody>
</table>
Appendix 1 Features of the mineralization in the Canberra region.

<table>
<thead>
<tr>
<th>PROSPECT</th>
<th>METALL. No.</th>
<th>HOST ROCKS</th>
<th>STYLE</th>
<th>ALTERATION</th>
<th>REFERENCES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Li</td>
<td>Structure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GOOBARRAGANDRA BLOCK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Glen Copper P.</td>
<td>C 4</td>
<td>Volc</td>
<td>Stockwork</td>
<td>Sil, chl</td>
<td>R 1, 4, 69</td>
</tr>
<tr>
<td>Nottingham Copper P.</td>
<td>C 5</td>
<td>Volc</td>
<td>Stockwork</td>
<td>Sil</td>
<td>R 1, 4, 69</td>
</tr>
<tr>
<td>Wyora Copper Prospect</td>
<td>C 87</td>
<td>Volc</td>
<td>Vein</td>
<td></td>
<td>R 1</td>
</tr>
<tr>
<td>Broken Cart Gold Mine</td>
<td>C 85</td>
<td>Volc, dior</td>
<td>Vein</td>
<td></td>
<td>R 1</td>
</tr>
<tr>
<td>Murphy’s Reef</td>
<td>W 172</td>
<td>Volc</td>
<td>Vein</td>
<td></td>
<td>R 5</td>
</tr>
<tr>
<td>Stokes Reef</td>
<td>W 174</td>
<td>Volc</td>
<td>Vein</td>
<td></td>
<td>R 5</td>
</tr>
<tr>
<td><strong>TANTANGARA BLOCK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mount Black Mine</td>
<td>C 159</td>
<td>Lst</td>
<td>Joints</td>
<td>Breccia fill, Dol?</td>
<td>R 1, 6, 7</td>
</tr>
<tr>
<td>Hancox’s Mine</td>
<td>C 158</td>
<td>Lst, sh</td>
<td>Breccia fill</td>
<td>Sil</td>
<td>R 1</td>
</tr>
<tr>
<td>Wvora Prospect</td>
<td>C 241</td>
<td>Volc</td>
<td>Vein</td>
<td></td>
<td>R 7</td>
</tr>
<tr>
<td><strong>COTTER BLOCK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Congwarra Copper Lode</td>
<td>C 91</td>
<td>Lst, volc, gran</td>
<td>Fault fill</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paddy’s River Iron Dep.</td>
<td>C 92</td>
<td>Lst, volc, gran</td>
<td>Contact</td>
<td></td>
<td>R 1, 7</td>
</tr>
<tr>
<td><strong>CANBERRA BLOCK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glenesk Gossan</td>
<td>C 14</td>
<td>Lst, volc</td>
<td>Sh D/Sw</td>
<td></td>
<td>R 1, 8</td>
</tr>
<tr>
<td>Westmead Park P.</td>
<td>C 156</td>
<td>Mst</td>
<td>Fault</td>
<td>Sh D/Sw</td>
<td>R 8, 9</td>
</tr>
<tr>
<td>Westmead Park Grid</td>
<td>C 157</td>
<td>Sh, volc</td>
<td>Fault</td>
<td>Sh D/Sw</td>
<td>R 10</td>
</tr>
<tr>
<td>Oak Hill Prospect</td>
<td></td>
<td>Volc, sh</td>
<td>Sh D/Sw</td>
<td></td>
<td>R 10</td>
</tr>
<tr>
<td>Murrumbateman Creek P</td>
<td></td>
<td>Sst, sh</td>
<td></td>
<td></td>
<td>R 10</td>
</tr>
<tr>
<td>Kingfisher Prospect</td>
<td></td>
<td>Mst, volc, c-s</td>
<td>Sh D/Sw</td>
<td></td>
<td>R 11</td>
</tr>
<tr>
<td>Esso Location B 11</td>
<td></td>
<td>Mst</td>
<td>Fault</td>
<td>Breccia fill</td>
<td>R 12</td>
</tr>
<tr>
<td>Hardwicke Prospect</td>
<td></td>
<td>Volc, sh</td>
<td>Vein</td>
<td></td>
<td>R 12</td>
</tr>
<tr>
<td>Bedulluck Prospect</td>
<td></td>
<td>Vein</td>
<td></td>
<td></td>
<td>R 8</td>
</tr>
<tr>
<td>Deacon Prospect</td>
<td></td>
<td>Mst, volc</td>
<td>Fault</td>
<td></td>
<td>R 12</td>
</tr>
<tr>
<td>Spion Kop</td>
<td></td>
<td>Volc</td>
<td>F/Sz</td>
<td>Vein, Clay, chl</td>
<td>R 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Volc</td>
<td></td>
<td>Vein</td>
<td>R 2</td>
</tr>
<tr>
<td>Bachelors Reef</td>
<td></td>
<td>Volc</td>
<td>F/Sz</td>
<td>Vein, Sil</td>
<td>R 2</td>
</tr>
<tr>
<td>Mayfield</td>
<td></td>
<td>Volc</td>
<td></td>
<td>Vein, Chl?</td>
<td>R 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Volc</td>
<td></td>
<td></td>
<td>R 2</td>
</tr>
<tr>
<td>Everton Silver Mine</td>
<td></td>
<td>Volc</td>
<td></td>
<td></td>
<td>R 2</td>
</tr>
<tr>
<td>Reys Prospect</td>
<td></td>
<td>Volc</td>
<td></td>
<td></td>
<td>R 2</td>
</tr>
<tr>
<td>Wallah Wallah Copper M.</td>
<td>G 119</td>
<td>Volc</td>
<td>F/Sz</td>
<td>Vein</td>
<td>R 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Volc</td>
<td></td>
<td>Vein</td>
<td>R 2</td>
</tr>
<tr>
<td>Marie Corelli</td>
<td></td>
<td>Volc</td>
<td>F/Sz</td>
<td>Vein</td>
<td>R 2</td>
</tr>
<tr>
<td>Old Kangiara</td>
<td></td>
<td>Volc</td>
<td></td>
<td>Vein</td>
<td>R 2</td>
</tr>
<tr>
<td>Mammoth Lode</td>
<td></td>
<td>Volc</td>
<td></td>
<td>Vein</td>
<td>R 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Volc</td>
<td>F/Sz</td>
<td>Vein</td>
<td>R 2</td>
</tr>
<tr>
<td>White Flag</td>
<td></td>
<td>Volc</td>
<td></td>
<td>Vein, Sil</td>
<td>R 2</td>
</tr>
<tr>
<td>Clan McKenzie Mine</td>
<td></td>
<td>Volc</td>
<td></td>
<td>Vein</td>
<td>R 2</td>
</tr>
<tr>
<td>Democrat Mine</td>
<td></td>
<td>Volc</td>
<td></td>
<td>Vein</td>
<td>R 2</td>
</tr>
<tr>
<td>Triangle Mine</td>
<td></td>
<td>Volc</td>
<td></td>
<td>Vein</td>
<td>R 2</td>
</tr>
<tr>
<td>Kangiara Copper Mine</td>
<td></td>
<td>Volc</td>
<td>F/Sz</td>
<td>Vein, Sil, chl, epi</td>
<td>R 2, 13, 67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Volc</td>
<td></td>
<td>Vein</td>
<td>R 2</td>
</tr>
<tr>
<td>Langs Creek Mine</td>
<td></td>
<td>Volc</td>
<td></td>
<td>Vein</td>
<td>R 2</td>
</tr>
<tr>
<td>Eclipse Mine</td>
<td></td>
<td>Volc</td>
<td></td>
<td>Vein</td>
<td>R 2</td>
</tr>
<tr>
<td>The Victory</td>
<td></td>
<td>Volc</td>
<td></td>
<td>Vein, Sil, chl</td>
<td>R 2</td>
</tr>
<tr>
<td>Belconon Gold Mine</td>
<td></td>
<td>Volc</td>
<td>F/Sz</td>
<td>Vein</td>
<td>R 1</td>
</tr>
<tr>
<td>McDonalds Mine</td>
<td></td>
<td>Volc</td>
<td></td>
<td>Vein?</td>
<td>R 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Volc</td>
<td>F/Sz</td>
<td>Vein</td>
<td>R 1</td>
</tr>
<tr>
<td>Boder Vale Lead Mine</td>
<td></td>
<td>Volc</td>
<td></td>
<td>Vein</td>
<td>R 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sh, lst</td>
<td></td>
<td></td>
<td>R 2</td>
</tr>
<tr>
<td>Belle Vale Silver Mine</td>
<td></td>
<td>Sh, lst</td>
<td>Vein</td>
<td></td>
<td>R 2</td>
</tr>
<tr>
<td>Humewood Base Metal P.</td>
<td></td>
<td>Lst, sh</td>
<td>Joints</td>
<td>Stockwork</td>
<td>R 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Volc</td>
<td></td>
<td>Vein</td>
<td>R 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Volc</td>
<td></td>
<td>Vein</td>
<td>R 2</td>
</tr>
</tbody>
</table>
Appendix 1  Features of the mineralization in the Canberra region. Continued.

<table>
<thead>
<tr>
<th>PROSPECT</th>
<th>ORE MINERALS</th>
<th>GANGUE</th>
<th></th>
<th></th>
<th></th>
<th>Other</th>
<th>Qt</th>
<th>Sr</th>
<th>Cl</th>
<th>Co</th>
<th>Ht</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Px</td>
<td>Po</td>
<td>Mt</td>
<td>Hm</td>
<td>Cp</td>
<td>Sp</td>
<td>Gn</td>
<td>Au</td>
<td>Hg</td>
<td>As</td>
<td>Other</td>
<td>Qt</td>
</tr>
<tr>
<td><strong>GOOBARRAGANDRA BLOCK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Glen Copper P.</td>
<td>(+)</td>
<td>(+)</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>Bo, (wt)</td>
</tr>
<tr>
<td>Nottingham Copper P.</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>Bo, (wt)</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wyora Copper Prospect</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>Mal</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broken Cart Gold Mine</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Murphy's Reef</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Stokes Reef</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td><strong>TANTANGARA BLOCK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mount Black Mine</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>(Ma,Co,Mk)</td>
<td>(+)</td>
<td>*</td>
<td>Zr,Lu,Sp</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Hancox's Mine</td>
<td>*</td>
<td>(+)</td>
<td>(+)</td>
<td>(Bo)</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mount Black Fault Dep.</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>Ma</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>COTTER BLOCK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Congwarra Copper Lode</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>Paddy's River Iron Dep.</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td><strong>CANBERRA BLOCK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Westmead Park P.</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Westmead Park Grid</td>
<td>*</td>
<td>*</td>
<td>(+)</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Oak Hill Prospect</td>
<td>*</td>
<td>*</td>
<td>(+)</td>
<td>(+)</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Murrumbateman Creek P.</td>
<td>*</td>
<td>*</td>
<td>(+)</td>
<td>(+)</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Kingfisher Prospect</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Esso Location B 11</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Hardwicke Prospect</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Beduluck Prospect</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Deacon Prospect</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Spion Kop</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Bachelor's Reef</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Mayfield</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Everton Silver Mine</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Rays Prospect</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Wallah Wallah Copper M.</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Marie Corelli</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Mammoth Lode</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>White Flag</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Clan McKenzie Mine</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Democrat Mine</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Triangle Mine</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Kangiara Copper Mine</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Langs Creek Mine</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Eclipse Mine</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>The Victory</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Belcomon Gold Mine</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>(+)</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>McDonalds Mine</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Bedev Vale Lead Mine</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Belle Vale Silver Mine</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Humewood Base Metal P.</td>
<td>(+)</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>
Appendix 1 Features of the mineralization in the Canberra region. Continued.

<table>
<thead>
<tr>
<th>PROSPECT</th>
<th>METALL. Host Rocks</th>
<th>STYLE</th>
<th>ALTERATION</th>
<th>REFERENCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edith May Mine</td>
<td>G 242</td>
<td>Sh Vein?</td>
<td>R 2</td>
<td></td>
</tr>
<tr>
<td>Caledon Mine</td>
<td>G 243</td>
<td>Sh Vein</td>
<td>R 2</td>
<td></td>
</tr>
<tr>
<td>Gooda Creek</td>
<td>C 11</td>
<td>Vole Stockwork</td>
<td>R 1</td>
<td></td>
</tr>
<tr>
<td>Hall Copper Prospect</td>
<td>C 12</td>
<td>Vole Vein</td>
<td>R 1</td>
<td></td>
</tr>
<tr>
<td>Gold Creek Gold</td>
<td>C 13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Murrunbateman Creek</td>
<td>C 17</td>
<td>Mst Vein</td>
<td>R 1</td>
<td></td>
</tr>
<tr>
<td>Frank Winters Lead P.</td>
<td>G 244</td>
<td>Sst Vein</td>
<td>R 2</td>
<td></td>
</tr>
<tr>
<td>Nanima Creek Gold W.</td>
<td>G 247</td>
<td>Sst, mst, ch F/Sz Vein Sil</td>
<td>R 2</td>
<td></td>
</tr>
<tr>
<td>Remington and Jordans</td>
<td>G 248</td>
<td>Mst F/Sz Vein</td>
<td>R 2</td>
<td></td>
</tr>
<tr>
<td>Crocker and Butts</td>
<td>G 249</td>
<td>Mst F/Sz Vein Sil</td>
<td>R 2</td>
<td></td>
</tr>
<tr>
<td>Wvelba Base Metal P.</td>
<td>G 236</td>
<td>Vole F/Sz Vein Sil</td>
<td>R 2, 6</td>
<td></td>
</tr>
<tr>
<td>Wvelba Barite Deposit</td>
<td>G 237</td>
<td>Vole Vein</td>
<td>R 2, 6</td>
<td></td>
</tr>
<tr>
<td>Red Hill Copper Mine</td>
<td>G 173</td>
<td>Lat, volc F/Sz</td>
<td>R 2, 67</td>
<td></td>
</tr>
</tbody>
</table>

**BREDBO BLOCK**

| Valley Creek Mine             | C 100             | Vole, sh?, lst?, Faults Vein | R 1, 14 |            |
| London Bridge Mine            | C 174             | Lst, sh, volc Sb D/Sw Dol, skarn | R 1, 15, 61 | |
| Michelago Iron Quarries       | C 163             | Vole, sh, mst Ct Sb D | R 1, 63 |            |
| Ingelara Prospect             |                   | Sh, mst                             | R 16    |            |
| Colinton Silver Mine          | C 259             | Lst Vein                           | R 1, 17, 18 |           |
| Cappanna Prospect             |                   | Sst, sh Faults                      | R 19, 18 |            |
| Woolshed Prospect             | C 258             | Lst, sh, volc Sb D/Sw              | R 20, 1 |            |
| Glenfergus Prospect           |                   | Sh, sst, lst Sb D/Sw               | R 18    |            |
| Cappawidgee (Bransby) P       | C 260             | Vole, lst Stockwork                | R 1, 17, 18 | |
| Gillans Prospect              |                   | Mst, c-s Fault Sb D/Sw             | R 27, 65 |            |
| Gurubang Prospect             |                   | Mst, lst Fault Sb D/Sw             | R 21, 22, 23 |       |
| Burra Silver–Lead Mine        | C 173             | Sh, lst, mst Stockwork             | R 1, 18, 24 |            |
| Mount Allen Prospect          |                   | Sst, sh Fault Sb D/Sw              | R 16    |            |
| Yarradon Prospect             | C 172             | Sst, lst Fault                      | R 1, 61 |            |
| Michelago Copper P. (E)       | C 164             | Sst, sh Fault Bx fill, vein Chl    | R 25, 1, 62, 64 | |
| Spring Valley Prospect        | C 170             | Vole, sh Fault Sb M/Sm              | R 18, 1 |            |
| Cosgrove Hill Prospect        |                   | Vole Ct Sb D/Sw Ser, sil, AA, K    | R 27, 65 |            |
| Billiltinga Prospect          |                   | Vole Ct Sb D/Sw K, ser             | R 27, 65 |            |
| Barite Prospect               | B 13              | Vole, mst Ct Sb D/Sw K, ser, sil   | R 27, 3, 65 |       |
| Driscoll’s Hill Prospect      |                   | Vole, mst Ct Sb D/Sw Sil, ser, K   | R 27, 65 |            |
| Harnett Prospect              | B 15              | Vole, mst, Ct Sb D/Sw Sil, K, chl  | R363,65,64,18,66 | |
| Stonehenge Prospect           |                   | Vole, mst Ct Sb D/Sw Sil, ser, chl | R 65, 27 |            |
| Riversdale Prospect           |                   | Vole Ct Sb D/Sw Ser, sil            | R 27, 65 |            |
| Picasso Prospect              |                   | Vole Ct Sb D/Sw Ser                 | R 65, 27 |            |
| Gamma–Delta Prospect          |                   | Vole Ct Sb D/Sw Ser, sil            | R 65, 18, 27 |       |
| Bushy Hill Prospects          | B 17-22           | Vole Ct Sb D/Sw                      | R 3     |            |
| Michelago Copper (West)       | C 164             | Sh, molar Ct Sb Sw/MSm Chl, sil    | R1,25,18,62,64 |       |
| Ponderose Prospect            |                   | Sh, vole Ctt Sb D/Sw Chl            | R 16    |            |
| C 249                         |                   | Vole Ctt                              | R 1, 18 |            |
| Colinton North Prospect       |                   | Vole, sh Sb D/Sw                     | R 18, 26, 62 |       |
| Colinton Silver Prospect      | C 250             | Vole, sh Sb D/Sw Chl                | R 1, 18, 32, 62 | |
| Baalgammon Mine               | C 253             | Vole, lst Sw Sil                     | R 1, 17, 27 | |
| Reed and Party                | C 254             | Vole, lst? Vein                      | R 1, 27 |            |
| Baczynski’s East Gossan       | C 255-7           | Vole Sb D/Sw                          | R 18, 27, 1 |       |
| Apple Tree Prospect           |                   |                                     | R 18    |            |
| Baczynski’s West Gossan       |                   |                                     | R 28, 27 |            |
| Bircham’s Prospect            | B 14              | Vole, sh, ch Sb D/Sw/Sm Ser          | R 3, 27 |            |
| Bredbo Barite Prospect        | C 251             | Vole, ch? Fault Vein                | R 1, 30 |            |
| C 252                         |                   | Vole                                  | R 1, 30 |            |
| Gungoandra Prospect           |                   | Vole                                  | R 18    |            |
| Googong Prospect              |                   | Sh, lst, mst Sb D/Sw Dol             | R 31, 14, 68 |       |
| Michelago Gold Prospect       | C 160             | Phy Ctt Stockwork                    | R 1, 16 |            |
| Kyries Gold Prospect          | C 245-6           | Vole                                  | R 1     |            |
| Collington Gold Prospect      | C 248             | Vole                                  | R 1     |            |
Appendix 1  Features of the mineralization in the Canberra region.  *Continued.*

<table>
<thead>
<tr>
<th>PROSPECT</th>
<th>ORE MINERALS</th>
<th>GANGUE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Py</td>
<td>Po</td>
</tr>
<tr>
<td>Edith May Mine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caledon Mine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gooda Creek</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Hall Copper Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gold Creek Gold</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Murrumbateman Creek</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>Frank Winters Lead P.</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>Namia Creek Gold W.</td>
<td>*</td>
<td>(+)</td>
</tr>
<tr>
<td>Remington and Jordans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crocker and Butts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wyelba Base Metal P.</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>Wyelba Barite Deposit?</td>
<td></td>
<td>(+)</td>
</tr>
<tr>
<td>Red Hill Copper Mine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BREDBO BLOCK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valley Creek Mine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>London Bridge Mine</td>
<td>*</td>
<td>(+)</td>
</tr>
<tr>
<td>Michelago Iron Quarries (+)</td>
<td>(+)</td>
<td></td>
</tr>
<tr>
<td>Ingelara Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colinton Silver Mine</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Michelago Adit Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mount Allen Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Michelago Copper P. (E) (+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>Spring Valley Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cogrove Hill Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Billinglea Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Battery Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driscoll's Hill Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harnett Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stonehenge Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riversdale Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Picasso Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamma-Delta Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bushy Hill Prospects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Michelago Copper (W) (+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>Ponderose Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colinton North Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colinton Silver Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baa12arnmon Mine</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reed and Party</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baczynski's East Gossan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apple Tree Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baczynski's West Gossan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bircham's Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bredbo Barite Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gungoandra Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Googong Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Michelago Gold Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kyries Gold Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collington Gold Prospect?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Appendix 1  Features of the mineralization in the Canberra region.  *Continued.*
## Appendix 1 Features of the mineralization in the Canberra region. Continued.

<table>
<thead>
<tr>
<th>PROSPECT</th>
<th>METALL.</th>
<th>HOST ROCKS</th>
<th>STYLE</th>
<th>ALTERATION</th>
<th>REFERENCES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>Lithology</td>
<td>Structure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gate (Britten and Party) P.</td>
<td>C 247</td>
<td>Volc</td>
<td>Vein</td>
<td>R 1</td>
<td></td>
</tr>
<tr>
<td>Dartmoor Mine</td>
<td>B 25</td>
<td>Volc</td>
<td>Vein</td>
<td>R 18</td>
<td></td>
</tr>
<tr>
<td>Dartmoor East Mine</td>
<td>B 26</td>
<td>Sh, volc</td>
<td>Sb D/Sw</td>
<td>R 3, 30, 17, 18</td>
<td></td>
</tr>
<tr>
<td>Rock Flat Prospect</td>
<td>B 27</td>
<td>Volc, sh</td>
<td>Fault</td>
<td>Sb D/Sw</td>
<td>R 3, 17, 18</td>
</tr>
<tr>
<td>Black Rock Barite Prospect</td>
<td>Volc</td>
<td>Cl</td>
<td>Vein</td>
<td>R 30, 18</td>
<td></td>
</tr>
<tr>
<td>Alpha Prospect</td>
<td>Volc</td>
<td>Cl</td>
<td>Vein</td>
<td>R 18</td>
<td></td>
</tr>
<tr>
<td>Cooma Creek Prospect</td>
<td>Volc, sh</td>
<td></td>
<td>C247</td>
<td>R 18</td>
<td></td>
</tr>
<tr>
<td>Bunyan Prospect</td>
<td>Sh, volc</td>
<td>Sb D</td>
<td>R 18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caves Prospect</td>
<td>Volc</td>
<td>Cl</td>
<td>Vein</td>
<td>R 18</td>
<td></td>
</tr>
<tr>
<td>Bend Prospect</td>
<td>Sst, bas</td>
<td></td>
<td>R 18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coornartha (Rosebank) P.</td>
<td>B 16</td>
<td>Sh</td>
<td>R 17, 18, 3, 27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skidmore North</td>
<td>Volc, sh</td>
<td>Sb D/Sw</td>
<td>Sil</td>
<td>R 27, 19, 18</td>
<td></td>
</tr>
<tr>
<td>Skidmore (ESSO) Prospect</td>
<td>Volc, sh</td>
<td>Sb D/Sw</td>
<td>R 65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skidmore Copper Mine</td>
<td>B 28</td>
<td>Volc, sh</td>
<td>Sb D/Sw</td>
<td>R 19, 30, 18</td>
<td></td>
</tr>
<tr>
<td>Square Range Prospect</td>
<td>Volc, ist</td>
<td>Sb D/Sw</td>
<td>Sil, ser</td>
<td>R 3, 30, 18</td>
<td></td>
</tr>
</tbody>
</table>

### CULLARIN BLOCK

| Two Eagles Prospect              | Volc, mast | Cl | Sb D/Sw | Ser, chl | R 35 |
| Caves Gossan                     | Volc, Cl   | Sb D/Sw | Sil, chl | R 36 |

### SOUTHERN ROCKY PIC BLOCK

| Narangba Gossan                  | C 176    | Lat, sh |                  | R 1    |
| Anembo Gossan                    | C 261-2  | Sh, lat |                  | R 1    |
| Calabash Gossan                  | C 264    | Volc, lat | Cl |                  | R 1    |
| Jerangle Barite Prospect         | C 263    | Volc, gran | Fault |                  | R 1    |
| Peak View Deposit                | Volc, Sh | SM Sb D/Sw | Chl |                  | R 70   |

### CAPTAINS FLAT BLOCK

| Lake George Mine                 | C 177    | Volc, sh | Cl | Sb D/Sw | Ser, sil, chl? | R 1, 37, 38 |
| Olley's Chert                    | C 181    | Volc, sh, lat | Sb D | Sil | R 39 |
| Federal Mine                     | C 179    | Sh | Fault | Sb D/Sw | R 1 |
| Foxlow Gossans                   | C 182    | Sh, volc, sst | Stockwork | R 40, 1 |
| Bollard Prospect                 | C 180    | Sh, volc, sst | Sb D/Sw | R 1, 41 |
| Woodlands Prospect               | C 105    | Sst | Cl | Vein | R 1 |
| Foxlow Gold Prospect             | C 178    | Sh | Fault | Vein | R 1 |
| Briars Mine                      | C 103    | Volc | Sb D/Sw | R 42, 1 |
| Clare Prospect                   | C 47     | Volc, sh, lat, c-s | Fault | Skarn | R 1, 59 |

### NORTHERN ROCKY PIC BLOCK

| Clare Vale Barite                | G 261    | Sh, mast | Folded | SM | Ser, sil, chl? | R 2, 43, 44 |
| Gurunda Barite                   | G 199    | Sh, mast, volc | Cl | SM | R 2, 44, 45 |
| G 192                            | Sh, ist | R 2    |
| G 198                            | R 2     |
| Lucky Hit Prospect               | G 202    | Mst, sst, volc, sh | Cl, fault | Sb, D/Sw | R 44, 2 |
| Merilla Prospect                 | G 196    | Sh | Cl | Sb D/Sw | R 44, 4 |
| Chisholm's Freehold              | G 197    | Sh | Cl | Sb D/Sw | R 44, 4 |
| Tamton's Mine                    | G 201    | Cl | Sb D/Sw | R 2, 44 |
| Heffron's Creek                  | G 200    | Sh | Vein | R 2 |
| Hannan's Flat                    | Sh, mst | Folds, sst | Sb D/Sw | R 44 |
| Mulloon Prospects                | C107-12  | Mst, volc, sh | Cl, faults? | Stockwork | R 46, 1 |
| Tarago Barite Deposit            | C 51     | Sst, volc | Vein | R 1 |
| C 49                             | Lat | R 1    |
| Woodlawn Mine                    | C 48     | Sh, volc | Cl, faults | SM Sb D/Sw | Chl, sil, ser | R 47, 48, 49 |
| Breadalbene No. 1                | G 257-8  | Volc | Fault | SM | R 44 |
| Breadalbene No. 2                | G 259    | Volc, sst | Cl | SM | R 44 |
| Currowang Mine                   | G 262    | Bas, sh | Cl | Chl, talc, K, sil | R 45, 50, 44 |
| Currowang East                    | Bas | Cl | Chl, talc, K, sil | R 50, 51, 52 |
| The Glen Prospect                 | Mst, volc, sh | Vein | R 53 |
| Sweetwoodlea Prospect            | R 67     |
| Mountain Ash Gold P.             | G 260    | Sh, sst | R 2 |
Appendix 1 Features of the mineralization in the Canberra region. *Continued.*

<table>
<thead>
<tr>
<th>PROSPECT</th>
<th>ORE MINERALS</th>
<th>GANGUE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Py</td>
<td>Po</td>
</tr>
<tr>
<td>Gate (Britten and Party) P.</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Dartmoor Mine</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Dartmoor East Mine</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Rock Flat Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Black Rock Barite Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Alpha Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Cooma Creek Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Bunyan Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Caves Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Bend Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Coomartha (Rosebank) P.</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Skidmore North</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Skidmore (ESSO) Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Skidmore Copper Mine</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Square Range Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>CULLARIN BLOCK</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Two Eagles Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Caves Gossan</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>SOUTHERN ROCKY PIC BLOCK</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Narango Gossan</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Anembo Gossan</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Calabash Gossan</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Jerangle Barite Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Peak View Deposit</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>CAPTAINS FLAT BLOCK</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Lake George Mine</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Olley's Chert</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Federal Mine</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Dam Shaft</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Foxlow Gossans</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Bollard Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Woodlands Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Foxlow Gold Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Briars Mine</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Clare Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>NORTHERN ROCKY PIC BLOCK</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Clare Vale Barite</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Gurrunda Barite</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Lucky Hit Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Merilla Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Chisholm's Freehold</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Taunton's Mine</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Heffron's Creek</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Hannan's Flat</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Mulloon Prospects</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Targo Barite Deposit</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Woodlawn Mine</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Breadalbene No 1</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Breadalbene No 2</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Currongw Mine</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Currongw East</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>The Glen Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Sweetwoodlea Prospect</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Mountain Ash Gold P.</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>
Appendix 1  Features of the mineralization in the Canberra region.  *Continued.*

<table>
<thead>
<tr>
<th>PROSPECT</th>
<th>METALL. No.</th>
<th>HOST ROCKS</th>
<th>STYLE</th>
<th>ALTERATION</th>
<th>REFERENCES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lithology</td>
<td>Structure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOMBAY BLOCK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boro Silver-Lead Mine</td>
<td>C 57</td>
<td>Volc, mst, c-s</td>
<td>Cl</td>
<td>Stockwork</td>
<td>Sil, kaol</td>
</tr>
<tr>
<td>Glenrossal Prospect</td>
<td>C 58</td>
<td>C-s,gran,mst,volc</td>
<td></td>
<td></td>
<td>R 1,56</td>
</tr>
<tr>
<td>Hanging Rock Prospect</td>
<td>C 59</td>
<td>Skarn</td>
<td></td>
<td></td>
<td>R 1</td>
</tr>
<tr>
<td>Ennisclare Prospect</td>
<td>C 60</td>
<td>Sst, sh, c-s</td>
<td></td>
<td></td>
<td>R 1</td>
</tr>
<tr>
<td>Limekiln's Prospect</td>
<td>C 124</td>
<td>Mst, volc, gran</td>
<td>Sb D/Sw</td>
<td></td>
<td>R 56,1</td>
</tr>
<tr>
<td>Wyanbene Prospect</td>
<td>C 269</td>
<td>Lst, sh</td>
<td>Fault?</td>
<td>Vein?</td>
<td>R 1</td>
</tr>
<tr>
<td>Mayfield Gold Prospect</td>
<td>C 125</td>
<td>Volc, c-s, gran</td>
<td>Sb D/Sw?</td>
<td>Chl, sil</td>
<td>R 1,56</td>
</tr>
<tr>
<td>Reedy Creek Barite</td>
<td>C 119</td>
<td>Phy</td>
<td>Fault?</td>
<td>Vein</td>
<td>R 1</td>
</tr>
<tr>
<td>Little Bombay Barite</td>
<td>C 115-6</td>
<td>Volc, gran</td>
<td></td>
<td>Vein</td>
<td>R 1</td>
</tr>
<tr>
<td>Bombay Barite</td>
<td>C 118</td>
<td>Volc, sst</td>
<td></td>
<td>Vein</td>
<td>R 1</td>
</tr>
<tr>
<td>Krawaree Prospect</td>
<td>C 185</td>
<td>Volc, phy</td>
<td>Sb D?</td>
<td>Chl, kaol</td>
<td>R 57,1</td>
</tr>
<tr>
<td>Gundillion's Reef</td>
<td>C 268</td>
<td>Sst, volc?</td>
<td>Fault</td>
<td>Vein</td>
<td>R 1</td>
</tr>
</tbody>
</table>
Appendix 1  Features of the mineralization in the Canberra region.  *Continued.*

<table>
<thead>
<tr>
<th>PROSPECT</th>
<th>ORE MINERALS</th>
<th>GANGUE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Py</td>
<td>Po</td>
</tr>
<tr>
<td>BOMBAY BLOCK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boro Silver-Lead Mine</td>
<td>(+)</td>
<td></td>
</tr>
<tr>
<td>Glenrossal Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hanging Rock Prospect</td>
<td>(+)</td>
<td></td>
</tr>
<tr>
<td>Emmsclare Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limekiln's Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wyambene Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mayfield Gold Prospect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reedy Creek Barite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Little Bombay Barite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bombay Barite</td>
<td>(+)</td>
<td></td>
</tr>
<tr>
<td>Krawaroe Prospect</td>
<td>(+)</td>
<td></td>
</tr>
<tr>
<td>Gundillion's Reef</td>
<td>(+)</td>
<td></td>
</tr>
</tbody>
</table>
Appendix 2 The location of prospects from Chapter 3 which are not shown on the regional Metallogenic Sheets.

<table>
<thead>
<tr>
<th>Prospect</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alpha Prospect</strong></td>
<td>966833 (Cooma)</td>
</tr>
<tr>
<td><strong>Apple Tree Prospect</strong></td>
<td>970152 (Michelago)</td>
</tr>
<tr>
<td><strong>Baczynski's West Gossan</strong></td>
<td>965197 (Michelago)</td>
</tr>
<tr>
<td><strong>Bedulluck Prospect</strong></td>
<td>930110 to 950200 (Canberra)</td>
</tr>
<tr>
<td><strong>Bend Prospect</strong></td>
<td>988927 (Cooma)</td>
</tr>
<tr>
<td><strong>Billilingra Prospect</strong></td>
<td>945120 (Cooma)</td>
</tr>
<tr>
<td><strong>Black Rock Barite Prospect</strong></td>
<td>954873 (Cooma)</td>
</tr>
<tr>
<td><strong>Bunyan Prospect</strong></td>
<td>977976 (Cooma)</td>
</tr>
<tr>
<td><strong>Cappanana Prospect</strong></td>
<td>991206 (Michelago)</td>
</tr>
<tr>
<td><strong>Caves Gossan</strong></td>
<td>120786 (Cooma)</td>
</tr>
<tr>
<td><strong>Caves Prospect</strong></td>
<td>974966 (Cooma)</td>
</tr>
<tr>
<td><strong>Colinton North Prospect</strong></td>
<td>972330 (Michelago)</td>
</tr>
<tr>
<td><strong>Cooma Creek Prospect</strong></td>
<td>970975 (Cooma)</td>
</tr>
<tr>
<td><strong>Cosgrove Hill Prospect</strong></td>
<td>940140 (Michelago)</td>
</tr>
<tr>
<td><strong>Currowang East Prospect</strong></td>
<td>300m east of Currowang</td>
</tr>
<tr>
<td><strong>Deacon Prospect</strong></td>
<td>021138 (Canberra)</td>
</tr>
<tr>
<td><strong>Driscolls Hill Prospect</strong></td>
<td>944084 (Cooma)</td>
</tr>
<tr>
<td><strong>ESSO Location B11</strong></td>
<td>015135 (Canberra) (Around the old quarry)</td>
</tr>
<tr>
<td><strong>Gamma–Delta Prospect</strong></td>
<td>942975 (Cooma)</td>
</tr>
<tr>
<td><strong>Gate (Britten and Party) Prospect</strong></td>
<td>985896 (Cooma)</td>
</tr>
<tr>
<td><strong>Gillans Prospect</strong></td>
<td>925024 (Cooma)</td>
</tr>
<tr>
<td><strong>Glenfergus Prospect</strong></td>
<td>024902 (Cooma)</td>
</tr>
<tr>
<td><strong>Googong Prospect</strong></td>
<td>023776 (Canberra)</td>
</tr>
<tr>
<td><strong>Gungoandra Prospect</strong></td>
<td>955225 (Michelago)</td>
</tr>
<tr>
<td><strong>Gurubang Prospect</strong></td>
<td>068825 (Cooma)</td>
</tr>
<tr>
<td><strong>Hannan's Flat Prospect</strong></td>
<td>236493 (Gunning)</td>
</tr>
<tr>
<td><strong>Hardwicke Prospect</strong></td>
<td>985107 (Canberra)</td>
</tr>
<tr>
<td><strong>Ingelara Prospect</strong></td>
<td>956386 (Michelago)</td>
</tr>
<tr>
<td><strong>Kingfisher Prospect</strong></td>
<td>986149 to 989185 (Canberra)</td>
</tr>
<tr>
<td><strong>Michelago Adit Prospect</strong></td>
<td>997513 (Michelago)</td>
</tr>
<tr>
<td><strong>Mount Allen Prospect</strong></td>
<td>002520 (Michelago)</td>
</tr>
<tr>
<td><strong>Mount Black Fault Deposits</strong></td>
<td>549536 to 558508 (Tantangara)</td>
</tr>
<tr>
<td><strong>Murrumbateman Creek Prospect</strong></td>
<td>952130 (Canberra)</td>
</tr>
<tr>
<td><strong>Oak Hill Prospect</strong></td>
<td>952088 to 958098 (Canberra)</td>
</tr>
<tr>
<td><strong>Olley's Chert</strong></td>
<td>127650 (Michelago) around &quot;Silverton&quot; homestead.</td>
</tr>
<tr>
<td><strong>Peak View Prospect</strong></td>
<td>134070 (Cooma)</td>
</tr>
<tr>
<td><strong>Picasso Prospect</strong></td>
<td>930015 (Cooma)</td>
</tr>
<tr>
<td><strong>Ponderose Prospect</strong></td>
<td>956414 to 958421 (Michelago)</td>
</tr>
<tr>
<td><strong>Riversdale Prospect</strong></td>
<td>918103 (Cooma)</td>
</tr>
<tr>
<td><strong>Rock Flat Prospect</strong></td>
<td>992801 (Cooma)</td>
</tr>
<tr>
<td><strong>Skidmore North Prospect</strong></td>
<td>004901 (Cooma)</td>
</tr>
<tr>
<td><strong>Skidmore (ESSO) Prospect</strong></td>
<td>002907 (Cooma)</td>
</tr>
<tr>
<td><strong>Square Range Prospect</strong></td>
<td>035800 (Cooma)</td>
</tr>
<tr>
<td><strong>Stonehenge Prospect</strong></td>
<td>954980 (Cooma)</td>
</tr>
<tr>
<td><strong>Sweetwood Lea Prospect</strong></td>
<td>&quot;4km to the north of the Hume Highway in a similar geological environment to that of the Breadalbane Prospects&quot; (Felton, 1977)</td>
</tr>
<tr>
<td><strong>The Glen Prospect</strong></td>
<td>330323 (Goulburn)</td>
</tr>
<tr>
<td><strong>Two Eagles Prospect</strong></td>
<td>128790 (Cooma)</td>
</tr>
<tr>
<td><strong>Westmead Park Prospect</strong></td>
<td>999122 (Canberra)</td>
</tr>
<tr>
<td><strong>Westmead Park Grid</strong></td>
<td>965115 to 985148 (Canberra)</td>
</tr>
</tbody>
</table>
Appendix 3  

Locations of the samples used for whole-rock geochemistry

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Field No.</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>WDP 1</td>
<td>R105</td>
<td>Near Riversdale Road G.R. 93081098</td>
</tr>
<tr>
<td>WDP 2</td>
<td>R233</td>
<td>Southeast of Cosgrove Hill G.R. 94141446</td>
</tr>
<tr>
<td>WDP 3</td>
<td>R295</td>
<td>On Bradley’s access road G.R. 94990554</td>
</tr>
<tr>
<td>WDP 4</td>
<td>R358</td>
<td>East of Gamma–Delta Prospect G.R. 94839766</td>
</tr>
<tr>
<td>WDP 5</td>
<td>R610</td>
<td>Gamma–Delta Prospect G.R. 93989773</td>
</tr>
<tr>
<td>WDP 6</td>
<td>R675</td>
<td>Gamma–Delta Prospect G.R. 93909755</td>
</tr>
<tr>
<td>WDP 7</td>
<td>R676</td>
<td>Gamma–Delta Prospect G.R. 94059737</td>
</tr>
<tr>
<td>WDP 8</td>
<td>R 677</td>
<td>Near Harnett Prospect G.R. 95600080</td>
</tr>
<tr>
<td>WDP 9</td>
<td>G1–4</td>
<td>Gillans Prospect drill–hole BRYG 001 48.6m</td>
</tr>
<tr>
<td>WDP 10</td>
<td>G2–7</td>
<td>Gillans Prospect drill–hole BRYG 002 74.5m</td>
</tr>
<tr>
<td>WDP 11</td>
<td>G2–12</td>
<td>Gillans Prospect drill–hole BRYG 002 121.6m</td>
</tr>
<tr>
<td>WDP 12</td>
<td>Z1–35</td>
<td>Stonehenge prospect drill–hole BRYZ 001 246.2m</td>
</tr>
<tr>
<td>WDP 13</td>
<td>Z2–1</td>
<td>Stonehenge prospect drill–hole BRYZ 002 44.1m</td>
</tr>
<tr>
<td>WDP 14</td>
<td>Z2–21</td>
<td>Stonehenge prospect drill–hole BRYZ 002 159.4m</td>
</tr>
<tr>
<td>WDP 15</td>
<td>BL1–12</td>
<td>Billilingra Prospect drill–hole DDH–BL1 93.1m</td>
</tr>
<tr>
<td>WDP 16</td>
<td>BL1–28</td>
<td>Billilingra Prospect drill–hole DDH–BL1 150.0m</td>
</tr>
<tr>
<td>WDP 17</td>
<td>BL1–44</td>
<td>Billilingra Prospect drill–hole DDH–BL1 228.7m</td>
</tr>
<tr>
<td>WDP 18</td>
<td>BL1–54</td>
<td>Billilingra Prospect drill–hole DDH–BL1 262.1m</td>
</tr>
<tr>
<td>WDP 19</td>
<td>H3–4</td>
<td>Harnett Prospect drill–hole DDH–H3 36.3m</td>
</tr>
<tr>
<td>WDP 20</td>
<td>H3–15</td>
<td>Harnett Prospect drill–hole DDH–H3 93.2m</td>
</tr>
<tr>
<td>WDP 21</td>
<td>H3–19</td>
<td>Harnett Prospect drill–hole DDH–H3 132.4m</td>
</tr>
<tr>
<td>WDP 22</td>
<td>H3–32</td>
<td>Harnett Prospect drill–hole DDH–H3 200.7m</td>
</tr>
<tr>
<td>WDP 23</td>
<td>H3–09</td>
<td>Harnett Prospect drill–hole DDH–H3 62.9m</td>
</tr>
<tr>
<td>WDP 24</td>
<td>H3–40</td>
<td>Harnett Prospect drill–hole DDH–H3 233.0</td>
</tr>
<tr>
<td>WDP 25</td>
<td>H3–52</td>
<td>Harnett Prospect drill–hole DDH–H3 269.3m</td>
</tr>
<tr>
<td>WDP 26</td>
<td>H3–67</td>
<td>Harnett Prospect drill–hole DDH–H3 328.9m</td>
</tr>
<tr>
<td>WDP 27</td>
<td>H3–78</td>
<td>Harnett Prospect drill–hole DDH–H3 367.3m</td>
</tr>
<tr>
<td>WDP 28</td>
<td>H3–85</td>
<td>Harnett Prospect drill–hole DDH–H3 392.7m</td>
</tr>
<tr>
<td>WDP 29</td>
<td>DA156628</td>
<td>Peak View Prospect drill–hole PVD 14 256.45–256.55</td>
</tr>
<tr>
<td>WDP 30</td>
<td>DA156638</td>
<td>Peak View Prospect drill–hole PVD 6 54.1–54.2</td>
</tr>
<tr>
<td>WDP 31</td>
<td>DA156657</td>
<td>Peak View Prospect drill–hole PVD 3 43.6–43.7</td>
</tr>
<tr>
<td>WDP 32</td>
<td>DA156660</td>
<td>Peak View Prospect drill–hole PVD 3 84.6–84.9</td>
</tr>
<tr>
<td>WDP 33</td>
<td>DA156664</td>
<td>Peak View Prospect drill–hole PVD 3 14.2–14.35</td>
</tr>
<tr>
<td>WDP 34</td>
<td>DA156667</td>
<td>Peak View Prospect drill–hole PVD 7 39.8–40.1</td>
</tr>
<tr>
<td>WDP 35</td>
<td>DA156671</td>
<td>Peak View Prospect drill–hole PVD 7 64.75–64.9</td>
</tr>
<tr>
<td>WDP 36</td>
<td>DA156673</td>
<td>Peak View Prospect drill–hole PVD 7 70.4–70.65</td>
</tr>
<tr>
<td>WDP 37</td>
<td>DA156692</td>
<td>Peak View Prospect drill–hole PVD 7 104.8–104.95</td>
</tr>
<tr>
<td>WDP 38</td>
<td>DA236024</td>
<td>Peak View Prospect drill–hole PVD 2 44.2–44.35m</td>
</tr>
<tr>
<td>WDP 39</td>
<td>DA236026</td>
<td>Peak View Prospect drill–hole PVD 2 56.7–56.8</td>
</tr>
<tr>
<td>WDP 40</td>
<td>DA236034</td>
<td>Peak View Prospect drill–hole PVD 2 104.0–104.1m</td>
</tr>
</tbody>
</table>
Appendix 4  Geochemistry of the metavolcanic rocks.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>WDP 5</th>
<th>WDP 6</th>
<th>WDP 7</th>
<th>WDP 9</th>
<th>WDP 10</th>
<th>WDP 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field No.</td>
<td>R610</td>
<td>R675</td>
<td>R676</td>
<td>G1-4</td>
<td>G2-7</td>
<td>G2-12</td>
</tr>
<tr>
<td>Facies</td>
<td>Bv</td>
<td>Bv</td>
<td>Bv</td>
<td>Bv</td>
<td>Bv</td>
<td>Bv</td>
</tr>
<tr>
<td>Notes</td>
<td>foliated</td>
<td>foliated</td>
<td>plag. xls</td>
<td>plag. xls</td>
<td>plag. xls</td>
<td>siliceous</td>
</tr>
</tbody>
</table>

**Major elements (wt %)**

<table>
<thead>
<tr>
<th>Element</th>
<th>WDP 5</th>
<th>WDP 6</th>
<th>WDP 7</th>
<th>WDP 9</th>
<th>WDP 10</th>
<th>WDP 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>68.85</td>
<td>67.24</td>
<td>68.19</td>
<td>65.67</td>
<td>65.19</td>
<td>76.25</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.69</td>
<td>0.62</td>
<td>0.50</td>
<td>0.51</td>
<td>0.53</td>
<td>0.13</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>15.44</td>
<td>14.32</td>
<td>14.41</td>
<td>14.59</td>
<td>14.40</td>
<td>13.41</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>2.99</td>
<td>5.68</td>
<td>4.45</td>
<td>5.15</td>
<td>5.49</td>
<td>0.42</td>
</tr>
<tr>
<td>MnO</td>
<td>0.09</td>
<td>0.06</td>
<td>0.09</td>
<td>0.05</td>
<td>0.04</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>MgO</td>
<td>1.28</td>
<td>2.69</td>
<td>2.04</td>
<td>2.85</td>
<td>3.41</td>
<td>0.60</td>
</tr>
<tr>
<td>CaO</td>
<td>4.36</td>
<td>2.45</td>
<td>4.51</td>
<td>4.70</td>
<td>4.54</td>
<td>2.18</td>
</tr>
<tr>
<td>Na₂O</td>
<td>1.85</td>
<td>2.58</td>
<td>2.73</td>
<td>2.37</td>
<td>2.11</td>
<td>5.46</td>
</tr>
<tr>
<td>K₂O</td>
<td>3.09</td>
<td>3.17</td>
<td>2.40</td>
<td>1.85</td>
<td>2.11</td>
<td>0.28</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.15</td>
<td>0.14</td>
<td>0.12</td>
<td>0.10</td>
<td>0.11</td>
<td>0.04</td>
</tr>
<tr>
<td>S</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>H₂O⁺</td>
<td>1.18</td>
<td>1.40</td>
<td>1.12</td>
<td>2.02</td>
<td>2.06</td>
<td>0.45</td>
</tr>
<tr>
<td>H₂O⁻</td>
<td>0.13</td>
<td>0.14</td>
<td>0.08</td>
<td>0.43</td>
<td>0.28</td>
<td>0.17</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.11</td>
<td>0.16</td>
<td>0.15</td>
<td>0.06</td>
<td>0.00</td>
<td>0.02</td>
</tr>
<tr>
<td>rest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>100.11</td>
<td>100.50</td>
<td>100.65</td>
<td>100.32</td>
<td>100.29</td>
<td>99.41</td>
</tr>
</tbody>
</table>

**Trace Elements (ppm)**

<table>
<thead>
<tr>
<th>Element</th>
<th>WDP 5</th>
<th>WDP 6</th>
<th>WDP 7</th>
<th>WDP 9</th>
<th>WDP 10</th>
<th>WDP 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ba</td>
<td>280</td>
<td>430</td>
<td>965</td>
<td>330</td>
<td>400</td>
<td>66</td>
</tr>
<tr>
<td>Rb</td>
<td>109</td>
<td>135</td>
<td>97</td>
<td>98</td>
<td>112</td>
<td>12</td>
</tr>
<tr>
<td>Sr</td>
<td>65</td>
<td>61</td>
<td>273</td>
<td>185</td>
<td>225</td>
<td>273</td>
</tr>
<tr>
<td>Yb</td>
<td>8</td>
<td>5</td>
<td>15</td>
<td>9</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>Th</td>
<td>19.5(21)</td>
<td>18(18.5)</td>
<td>19(18.5)</td>
<td>17</td>
<td>16.5</td>
<td>28</td>
</tr>
<tr>
<td>U</td>
<td>3.5(3.5)</td>
<td>3(3.0)</td>
<td>3.5(3.0)</td>
<td>3</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>Zr</td>
<td>206</td>
<td>179</td>
<td>144</td>
<td>141</td>
<td>135</td>
<td>96</td>
</tr>
<tr>
<td>Hf</td>
<td>5.9</td>
<td>4.8</td>
<td>4.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>32</td>
<td>28</td>
<td>24</td>
<td>25</td>
<td>28</td>
<td>34</td>
</tr>
<tr>
<td>La</td>
<td>40</td>
<td>32</td>
<td>37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ce</td>
<td>67(81)</td>
<td>54(67)</td>
<td>57(69)</td>
<td>62</td>
<td>57</td>
<td>70</td>
</tr>
<tr>
<td>Nd</td>
<td>82</td>
<td>30</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sm</td>
<td>7.1</td>
<td>5.8</td>
<td>5.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eu</td>
<td>1.09</td>
<td>1.06</td>
<td>1.11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gd</td>
<td>6.6</td>
<td>5.4</td>
<td>4.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tb</td>
<td>1.0</td>
<td>0.8</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ho</td>
<td>1.0</td>
<td>0.9</td>
<td>0.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yb</td>
<td>3.2</td>
<td>2.9</td>
<td>2.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lu</td>
<td>0.48</td>
<td>0.45</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cs</td>
<td>2.3</td>
<td>3.2</td>
<td>2.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sc</td>
<td>18</td>
<td>18</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>98</td>
<td>100</td>
<td>89</td>
<td>107</td>
<td>110</td>
<td>16</td>
</tr>
<tr>
<td>Cr</td>
<td>65(69)</td>
<td>56(56)</td>
<td>39(39)</td>
<td>34(9)</td>
<td>39</td>
<td>115</td>
</tr>
<tr>
<td>Cu</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>26</td>
<td>2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Zn</td>
<td>25</td>
<td>39</td>
<td>38</td>
<td>27</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Ga</td>
<td>18.5</td>
<td>17</td>
<td>15.5</td>
<td>17</td>
<td>17</td>
<td>13.5</td>
</tr>
</tbody>
</table>

Note that numbers in brackets are by INAA.
Appendix 4  Geochemistry of the metavolcanic rocks.  Continued

UNIT C AND FACIES Dkb

<table>
<thead>
<tr>
<th>Sample</th>
<th>WDP 1</th>
<th>ER 72</th>
<th>WDP 4</th>
<th>WDP 15</th>
<th>WDP 16</th>
<th>WDP 17</th>
<th>WDP 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field No.</td>
<td>R105</td>
<td>R358</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Facies</td>
<td>Cp</td>
<td>Cp</td>
<td>Cp</td>
<td>Dkb</td>
<td>Dkb</td>
<td>Dkb</td>
<td>Dkb</td>
</tr>
<tr>
<td>Notes</td>
<td>foliated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Major elements (wt %)

<table>
<thead>
<tr>
<th></th>
<th>SiO2</th>
<th>TiO2</th>
<th>Al2O3</th>
<th>Fe2O3</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na2O</th>
<th>P2O5</th>
<th>H2O+</th>
<th>H2O-</th>
<th>CO2</th>
<th>rest</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field No.</td>
<td>R105</td>
<td>R358</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Facies</td>
<td>Cp</td>
<td>Cp</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Notes</td>
<td>foliated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Trace elements (ppm)

<table>
<thead>
<tr>
<th></th>
<th>Ba</th>
<th>Sr</th>
<th>Yb</th>
<th>Tb</th>
<th>Ho</th>
<th>Yb</th>
<th>La</th>
<th>Ce</th>
<th>Ce</th>
<th>Sm</th>
<th>Eu</th>
<th>Gd</th>
<th>Tb</th>
<th>Ho</th>
<th>Yb</th>
<th>Ln</th>
<th>Sm</th>
<th>Sc</th>
<th>V</th>
<th>Cr</th>
<th>Cu</th>
<th>Zn</th>
<th>Ga</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field No.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Facies</td>
<td>Cp</td>
<td>Cp</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note that numbers in brackets are by INAA.
## Appendix 4  Geochemistry of the metavolcanic rocks.  Continued

### FACIES Dv

<table>
<thead>
<tr>
<th>Sample Field No.</th>
<th>WDP 19 H3-4</th>
<th>WDP 20 H3-15</th>
<th>WDP 21 H3-49</th>
<th>WDP 22 H3-32</th>
<th>WDP 23 H3-9</th>
<th>WDP 24 H3-40</th>
<th>WDP 25 H3-52</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facies Dv</td>
<td>Dv</td>
<td>Dv</td>
<td>Dv</td>
<td>Dv</td>
<td>Dv</td>
<td>Dgv</td>
<td>Dv</td>
</tr>
<tr>
<td>Notes sericitic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Major elements (wt %)

<table>
<thead>
<tr>
<th></th>
<th>WDP 19</th>
<th>WDP 20</th>
<th>WDP 21</th>
<th>WDP 22</th>
<th>WDP 23</th>
<th>WDP 24</th>
<th>WDP 25</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>58.29</td>
<td>63.60</td>
<td>63.57</td>
<td>64.76</td>
<td>59.26</td>
<td>72.56</td>
<td>67.34</td>
</tr>
<tr>
<td>TiO2</td>
<td>0.57</td>
<td>0.63</td>
<td>0.62</td>
<td>0.64</td>
<td>0.54</td>
<td>0.60</td>
<td>0.57</td>
</tr>
<tr>
<td>Fe2O3</td>
<td>7.04</td>
<td>5.65</td>
<td>5.87</td>
<td>6.15</td>
<td>6.22</td>
<td>3.76</td>
<td>4.28</td>
</tr>
<tr>
<td>MnO</td>
<td>0.12</td>
<td>0.09</td>
<td>0.09</td>
<td>0.07</td>
<td>0.11</td>
<td>&lt;0.01</td>
<td>0.06</td>
</tr>
<tr>
<td>MgO</td>
<td>8.08</td>
<td>3.41</td>
<td>2.56</td>
<td>3.39</td>
<td>6.76</td>
<td>0.47</td>
<td>1.85</td>
</tr>
<tr>
<td>CaO</td>
<td>2.06</td>
<td>2.36</td>
<td>3.22</td>
<td>1.28</td>
<td>5.94</td>
<td>0.25</td>
<td>1.91</td>
</tr>
<tr>
<td>Na2O</td>
<td>4.32</td>
<td>0.89</td>
<td>2.39</td>
<td>0.90</td>
<td>1.84</td>
<td>0.06</td>
<td>1.22</td>
</tr>
<tr>
<td>K2O</td>
<td>1.12</td>
<td>4.90</td>
<td>4.37</td>
<td>5.17</td>
<td>2.65</td>
<td>4.68</td>
<td>5.46</td>
</tr>
<tr>
<td>P2O5</td>
<td>0.14</td>
<td>0.15</td>
<td>0.14</td>
<td>0.15</td>
<td>0.14</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>S</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>2.29</td>
<td>0.46</td>
</tr>
<tr>
<td>H2O+</td>
<td>3.74</td>
<td>3.04</td>
<td>2.10</td>
<td>2.89</td>
<td>3.06</td>
<td>1.84</td>
<td>2.21</td>
</tr>
<tr>
<td>H2O-</td>
<td>0.24</td>
<td>0.28</td>
<td>0.24</td>
<td>0.24</td>
<td>0.37</td>
<td>0.16</td>
<td>0.20</td>
</tr>
<tr>
<td>CO2</td>
<td>1.04</td>
<td>1.42</td>
<td>2.08</td>
<td>0.65</td>
<td>0.79</td>
<td>3.65</td>
<td>2.14</td>
</tr>
<tr>
<td>rest</td>
<td>100.22</td>
<td>99.80</td>
<td>99.14</td>
<td>100.00</td>
<td>100.37</td>
<td>99.35</td>
<td>99.76</td>
</tr>
</tbody>
</table>

### Trace elements (ppm)

<table>
<thead>
<tr>
<th>Ba</th>
<th>140</th>
<th>610</th>
<th>540</th>
<th>630</th>
<th>720</th>
<th>420</th>
<th>1030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rb</td>
<td>45</td>
<td>220</td>
<td>188</td>
<td>231</td>
<td>73</td>
<td>169</td>
<td>247</td>
</tr>
<tr>
<td>Sr</td>
<td>153</td>
<td>49</td>
<td>119</td>
<td>43</td>
<td>449</td>
<td>10</td>
<td>51</td>
</tr>
<tr>
<td>Pb</td>
<td>10</td>
<td>23</td>
<td>7</td>
<td>5</td>
<td>18</td>
<td>46</td>
<td>24</td>
</tr>
<tr>
<td>Th</td>
<td>17(17.0)</td>
<td>15</td>
<td>14</td>
<td>14.5(13.0)</td>
<td>16</td>
<td>16</td>
<td>15.5(15.0)</td>
</tr>
<tr>
<td>U</td>
<td>3(3.5)</td>
<td>2.5</td>
<td>2.5</td>
<td>3(2.5)</td>
<td>3</td>
<td>5.5</td>
<td>5.5(4.5)</td>
</tr>
<tr>
<td>Zr</td>
<td>173</td>
<td>186</td>
<td>164</td>
<td>170</td>
<td>160</td>
<td>150</td>
<td>147</td>
</tr>
<tr>
<td>Hf</td>
<td>4.5</td>
<td></td>
<td></td>
<td>4.1</td>
<td></td>
<td></td>
<td>4.0</td>
</tr>
<tr>
<td>Y</td>
<td>25</td>
<td>27</td>
<td>32</td>
<td>34</td>
<td>23</td>
<td>21</td>
<td>29</td>
</tr>
<tr>
<td>La</td>
<td>37</td>
<td></td>
<td></td>
<td>33</td>
<td></td>
<td></td>
<td>35</td>
</tr>
<tr>
<td>Ce</td>
<td>66(73)</td>
<td>62</td>
<td>66</td>
<td>65(70)</td>
<td>66</td>
<td>56</td>
<td>64(67)</td>
</tr>
<tr>
<td>Nd</td>
<td>32</td>
<td></td>
<td></td>
<td>34</td>
<td></td>
<td></td>
<td>31</td>
</tr>
<tr>
<td>Sm</td>
<td>6.1</td>
<td></td>
<td></td>
<td>7.2</td>
<td></td>
<td></td>
<td>6.2</td>
</tr>
<tr>
<td>Eu</td>
<td>1.25</td>
<td></td>
<td></td>
<td>1.29</td>
<td></td>
<td></td>
<td>1.19</td>
</tr>
<tr>
<td>Gd</td>
<td>5.2</td>
<td></td>
<td></td>
<td>6.3</td>
<td></td>
<td></td>
<td>5.5</td>
</tr>
<tr>
<td>Tb</td>
<td>0.8</td>
<td></td>
<td></td>
<td>1.0</td>
<td></td>
<td></td>
<td>0.8</td>
</tr>
<tr>
<td>Ho</td>
<td>0.9</td>
<td></td>
<td></td>
<td>1.3</td>
<td></td>
<td></td>
<td>0.9</td>
</tr>
<tr>
<td>Yb</td>
<td>2.5</td>
<td></td>
<td></td>
<td>3.3</td>
<td></td>
<td></td>
<td>2.8</td>
</tr>
<tr>
<td>Lu</td>
<td>0.38</td>
<td></td>
<td></td>
<td>0.49</td>
<td></td>
<td></td>
<td>0.43</td>
</tr>
<tr>
<td>Cs</td>
<td>4.2</td>
<td></td>
<td></td>
<td>10.0</td>
<td></td>
<td></td>
<td>6.8</td>
</tr>
<tr>
<td>Sc</td>
<td>25</td>
<td></td>
<td></td>
<td>23</td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>V</td>
<td>121</td>
<td>132</td>
<td>135</td>
<td>140</td>
<td>131</td>
<td>163</td>
<td>142</td>
</tr>
<tr>
<td>Cr</td>
<td>515(560)</td>
<td>50</td>
<td>46</td>
<td>53(52)</td>
<td>487</td>
<td>43</td>
<td>51(51)</td>
</tr>
<tr>
<td>Cu</td>
<td>&lt;1</td>
<td>21</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>39</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>Zn</td>
<td>165</td>
<td>108</td>
<td>96</td>
<td>99</td>
<td>65</td>
<td>22</td>
<td>94</td>
</tr>
<tr>
<td>Ga</td>
<td>17</td>
<td>17</td>
<td>16.5</td>
<td>17</td>
<td>16</td>
<td>32.5</td>
<td>15.5</td>
</tr>
</tbody>
</table>

Note that numbers in brackets are by INAA.
## Appendix 4  Geochemistry of the metavolcanic rocks. Continued

### UNITS E and F

<table>
<thead>
<tr>
<th>Sample</th>
<th>WDP 26</th>
<th>WDP 27</th>
<th>WDP 28</th>
<th>WDP 13</th>
<th>WDP 2</th>
<th>WDP 3</th>
<th>WDP 12</th>
<th>WDP 14</th>
<th>WDP 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field No.</td>
<td>H3-67</td>
<td>H3-78</td>
<td>H3-85</td>
<td>Z2-1</td>
<td>R233</td>
<td>R295</td>
<td>Z1-35</td>
<td>Z2-21</td>
<td>R677</td>
</tr>
<tr>
<td>Notes</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Facies</td>
<td>Es</td>
<td>Es</td>
<td>Ehv</td>
<td>Evs</td>
<td>Ehv</td>
<td>Ehv</td>
<td>Evs</td>
<td>Evs</td>
<td>Fhv</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>sericitic</td>
<td>sericitic</td>
<td>fresh</td>
<td></td>
<td>fresh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major elements (wt %)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
<td>70.12</td>
<td>67.31</td>
<td>66.98</td>
<td>65.16</td>
<td>65.18</td>
<td>64.42</td>
<td>61.08</td>
<td>62.53</td>
<td>67.74</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.79</td>
<td>0.52</td>
<td>0.55</td>
<td>0.58</td>
<td>0.62</td>
<td>0.61</td>
<td>0.51</td>
<td>0.46</td>
<td>0.47</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.14</td>
<td>3.96</td>
<td>4.60</td>
<td>5.23</td>
<td>5.54</td>
<td>5.49</td>
<td>5.25</td>
<td>5.49</td>
<td>4.59</td>
</tr>
<tr>
<td>MnO</td>
<td>&lt;0.01</td>
<td>0.01</td>
<td>0.07</td>
<td>0.14</td>
<td>0.05</td>
<td>0.05</td>
<td>0.11</td>
<td>0.08</td>
<td>0.07</td>
</tr>
<tr>
<td>MgO</td>
<td>0.26</td>
<td>0.85</td>
<td>1.08</td>
<td>3.96</td>
<td>4.60</td>
<td>5.23</td>
<td>5.54</td>
<td>5.49</td>
<td>4.59</td>
</tr>
<tr>
<td>CaO</td>
<td>0.07</td>
<td>0.41</td>
<td>0.33</td>
<td>0.32</td>
<td>0.31</td>
<td>0.30</td>
<td>0.29</td>
<td>0.28</td>
<td>0.27</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.06</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>K₂O</td>
<td>3.90</td>
<td>8.46</td>
<td>6.67</td>
<td>5.16</td>
<td>2.91</td>
<td>2.95</td>
<td>1.44</td>
<td>2.08</td>
<td>2.92</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.02</td>
<td>2.80</td>
<td>0.28</td>
<td>0.04</td>
<td>0.05</td>
<td>0.02</td>
<td>0.18</td>
<td>0.19</td>
<td>0.03</td>
</tr>
<tr>
<td>H₂O+</td>
<td>2.86</td>
<td>1.19</td>
<td>1.93</td>
<td>2.38</td>
<td>2.20</td>
<td>2.32</td>
<td>2.45</td>
<td>2.57</td>
<td>2.21</td>
</tr>
<tr>
<td>H₂O-</td>
<td>0.38</td>
<td>0.16</td>
<td>0.14</td>
<td>0.29</td>
<td>0.17</td>
<td>0.18</td>
<td>0.33</td>
<td>0.30</td>
<td>0.10</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.18</td>
<td>3.72</td>
<td>2.60</td>
<td>1.46</td>
<td>0.20</td>
<td>0.28</td>
<td>0.64</td>
<td>2.47</td>
<td>0.23</td>
</tr>
<tr>
<td>rest</td>
<td>Total</td>
<td>100.45</td>
<td>98.74</td>
<td>98.70</td>
<td>99.58</td>
<td>101.13</td>
<td>98.98</td>
<td>98.86</td>
<td>100.71</td>
</tr>
</tbody>
</table>

### Trace elements (ppm)

| | Ba | Rb | Sr | Nb | Cs | La | Ce | Nd | Sm | Eu | Gd | Tb | Ho | Er | Tm | Yb | Lu | Gd | Sc | V | Cr | Cu | Zn | Ga |
| | 1150 | 161 | 14 | 84(85) | 39 | 5.8 | 144 | 84(85) | 39 | 5.8 | 144 | 34 | 13 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| | 2100 | 310 | 46.5 | 64(61) | 27 | 5.8 | 144 | 42 | 144 | 5.8 | 144 | 34 | 13 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| | 500 | 319 | 46.5 | 64(61) | 27 | 5.8 | 144 | 50 | 64(61) | 50 | 64(61) | 30 | 20 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| | 615 | 255 | 122 | 55 | 50 | 6.5 | 60 | 67(72) | 67 | 58 | 62 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| | 615 | 255 | 122 | 55 | 50 | 6.5 | 60 | 67(72) | 67 | 58 | 62 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| | 615 | 255 | 122 | 55 | 50 | 6.5 | 60 | 67(72) | 67 | 58 | 62 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| | 615 | 255 | 122 | 55 | 50 | 6.5 | 60 | 67(72) | 67 | 58 | 62 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| | 615 | 255 | 122 | 55 | 50 | 6.5 | 60 | 67(72) | 67 | 58 | 62 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| | 615 | 255 | 122 | 55 | 50 | 6.5 | 60 | 67(72) | 67 | 58 | 62 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| | 615 | 255 | 122 | 55 | 50 | 6.5 | 60 | 67(72) | 67 | 58 | 62 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| | 615 | 255 | 122 | 55 | 50 | 6.5 | 60 | 67(72) | 67 | 58 | 62 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| | 615 | 255 | 122 | 55 | 50 | 6.5 | 60 | 67(72) | 67 | 58 | 62 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| | 615 | 255 | 122 | 55 | 50 | 6.5 | 60 | 67(72) | 67 | 58 | 62 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| | 615 | 255 | 122 | 55 | 50 | 6.5 | 60 | 67(72) | 67 | 58 | 62 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |

Note that numbers in brackets are by INAA.
Appendix 4  Geochemistry of the metavolcanic rocks.  Continued

PEAK VIEW PROSPECT Footwall rocks

<table>
<thead>
<tr>
<th>Sample Field No.</th>
<th>WDP 29 P 628</th>
<th>WDP 30 P 638</th>
<th>WDP 31 P 657</th>
<th>WDP 32 P 660</th>
<th>WDP 37 P 692</th>
<th>WDP 40 P 034</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facies Notes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major elements (wt %)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SiO2</td>
<td>60.87</td>
<td>54.57</td>
<td>62.35</td>
<td>65.84</td>
<td>65.03</td>
<td>60.80</td>
</tr>
<tr>
<td>TiO2</td>
<td>0.51</td>
<td>0.46</td>
<td>0.53</td>
<td>0.53</td>
<td>0.46</td>
<td>0.56</td>
</tr>
<tr>
<td>Al2O3</td>
<td>14.28</td>
<td>15.24</td>
<td>15.76</td>
<td>15.39</td>
<td>13.82</td>
<td>14.74</td>
</tr>
<tr>
<td>Fe2O3</td>
<td>6.20</td>
<td>7.69</td>
<td>5.99</td>
<td>5.34</td>
<td>5.90</td>
<td>6.15</td>
</tr>
<tr>
<td>MnO</td>
<td>0.10</td>
<td>0.13</td>
<td>0.07</td>
<td>0.07</td>
<td>0.12</td>
<td>0.07</td>
</tr>
<tr>
<td>MgO</td>
<td>4.94</td>
<td>6.14</td>
<td>4.29</td>
<td>3.61</td>
<td>4.87</td>
<td>4.12</td>
</tr>
<tr>
<td>CaO</td>
<td>2.78</td>
<td>4.72</td>
<td>0.90</td>
<td>0.71</td>
<td>0.60</td>
<td>3.73</td>
</tr>
<tr>
<td>Na2O</td>
<td>3.77</td>
<td>3.47</td>
<td>4.56</td>
<td>6.07</td>
<td>1.87</td>
<td>1.02</td>
</tr>
<tr>
<td>K2O</td>
<td>2.92</td>
<td>1.95</td>
<td>2.29</td>
<td>0.89</td>
<td>4.52</td>
<td>2.84</td>
</tr>
<tr>
<td>P2O5</td>
<td>0.15</td>
<td>0.09</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
<td>0.11</td>
</tr>
<tr>
<td>S</td>
<td>0.08</td>
<td>0.29</td>
<td>0.09</td>
<td>0.09</td>
<td>0.29</td>
<td>1.09</td>
</tr>
<tr>
<td>H2O+</td>
<td>2.77</td>
<td>3.97</td>
<td>3.91</td>
<td>2.46</td>
<td>2.92</td>
<td>3.60</td>
</tr>
<tr>
<td>H2O-</td>
<td>0.14</td>
<td>0.21</td>
<td>0.16</td>
<td>0.23</td>
<td>0.18</td>
<td>0.29</td>
</tr>
<tr>
<td>CO2</td>
<td>1.89</td>
<td>3.83</td>
<td>0.78</td>
<td>0.26</td>
<td>0.89</td>
<td>4.57</td>
</tr>
<tr>
<td>rest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>99.51</td>
<td>98.93</td>
<td>101.00</td>
<td>101.33</td>
<td>100.68</td>
<td>99.12</td>
</tr>
</tbody>
</table>

Trace elements (ppm)

|            |            |            |            |            |            |            |
| Ba         | 550        | 470        | 1250       | 175        | 2070       | 315        |
| Rb         | 39          | 37         | 75         | 24         | 109        | 106        |
| Sr         | 130         | 143        | 94         | 120        | 55         | 52         |
| Yb         | 3           | 3          | <1         | 2          | 3          | 6          |
| Th         | 13.5        | 7          | 14.5       | 13.5       | 13         | 13         |
| U          | 3.5         | 3.5        | 3          | 3          | 2.5        | 3          |
| Zr         | 142         | 98         | 158        | 160        | 130        | 154        |
| Hf         | 18          | 22         | 22         | 23         | 19         | 20         |
| Y          | 74          | 34         | 57         | 51         | 44         | 50         |
| La         | 154         | 187        | 153        | 150        | 132        | 151        |
| Ce         | 131         | 46         | 152        | 36         | 134        | 132        |
| Nd         | <1          | 118        | 13        | <1         | 12         | 1          |
| Sm         | 56          | 97         | 106        | 47         | 167        | 49         |
| Eu         | 16          | 17         | 17         | 17.5       | 15         | 17         |

Note that numbers in brackets are by INAA.
Appendix 4. Geochemistry of the metavolcanic rocks.  

### PEAK VIEW PROSPECT Hangingwall rocks

<table>
<thead>
<tr>
<th>Sample</th>
<th>WDP 33</th>
<th>WDP 34</th>
<th>WDP 35</th>
<th>WDP 36</th>
<th>WDP 38</th>
<th>WDP 39</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field No.</td>
<td>P664</td>
<td>P667</td>
<td>P671</td>
<td>P673</td>
<td>P024</td>
<td>P026</td>
</tr>
<tr>
<td>Facies</td>
<td>Notes</td>
<td>Notes</td>
<td>Notes</td>
<td>Notes</td>
<td>Notes</td>
<td>Notes</td>
</tr>
<tr>
<td>Major elements (wt %)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
<td>74.41</td>
<td>80.48</td>
<td>71.73</td>
<td>74.55</td>
<td>73.01</td>
<td>75.59</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.11</td>
<td>0.08</td>
<td>0.12</td>
<td>0.12</td>
<td>0.23</td>
<td>0.20</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>13.98</td>
<td>10.91</td>
<td>14.58</td>
<td>13.35</td>
<td>14.43</td>
<td>12.80</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>1.69</td>
<td>0.40</td>
<td>1.49</td>
<td>1.46</td>
<td>2.43</td>
<td>1.92</td>
</tr>
<tr>
<td>MnO</td>
<td>0.01</td>
<td>&lt;0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>MgO</td>
<td>1.60</td>
<td>0.20</td>
<td>4.06</td>
<td>1.66</td>
<td>1.01</td>
<td>0.83</td>
</tr>
<tr>
<td>CaO</td>
<td>0.43</td>
<td>0.53</td>
<td>0.08</td>
<td>0.21</td>
<td>0.18</td>
<td>1.06</td>
</tr>
<tr>
<td>Na₂O</td>
<td>1.06</td>
<td>5.93</td>
<td>0.57</td>
<td>3.49</td>
<td>5.55</td>
<td>1.90</td>
</tr>
<tr>
<td>K₂O</td>
<td>4.68</td>
<td>0.08</td>
<td>4.92</td>
<td>2.55</td>
<td>1.80</td>
<td>3.27</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.01</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>S</td>
<td>0.01</td>
<td>0.11</td>
<td>0.01</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>H₂O⁺</td>
<td>2.05</td>
<td>0.40</td>
<td>2.76</td>
<td>1.65</td>
<td>1.25</td>
<td>1.82</td>
</tr>
<tr>
<td>H₂O⁻</td>
<td>0.20</td>
<td>0.07</td>
<td>0.18</td>
<td>0.19</td>
<td>0.14</td>
<td>0.26</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.37</td>
<td>0.36</td>
<td>0.05</td>
<td>0.17</td>
<td>0.10</td>
<td>0.79</td>
</tr>
<tr>
<td>rest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>100.24</td>
<td>99.21</td>
<td>100.53</td>
<td>99.28</td>
<td>100.11</td>
<td>99.72</td>
</tr>
</tbody>
</table>

Trace elements (ppm)

| Ba | 1210 | 38 | 450 | 300 | 420 | 475 |
| Rb | 204 | 3.5 | 209 | 117 | 34 | 164 |
| Sr | 79 | 136 | 26.5 | 116 | 153 | 139 |
| Pb | 10 | 5 | 10 | 6 | 4 | 5 |
| Th | 29 | 21 | 29.5 | 27.5 | 19 | 16 |
| U | 5 | 5.5 | 6 | 6 | 3 | 3.5 |
| Zr | 134 | 103 | 141 | 128 | 171 | 153 |
| Hf | | | | | | |
| Y | 41 | 29 | 31 | 46 | 20 | 23 |
| La | 79 | 62 | 77 | 87 | 69 | 55 |
| Ce | | | | | | |
| Nd | | | | | | |
| Sm | | | | | | |
| Eu | | | | | | |
| Gd | | | | | | |
| Tb | | | | | | |
| Ho | | | | | | |
| Er | | | | | | |
| Yb | | | | | | |
| Lu | | | | | | |
| Cs | | | | | | |
| Sc | | | | | | |
| V | <1 | <1 | <1 | 1 | 12 | 12 |
| Cr | <1 | <1 | <1 | <1 | <1 | 1 |
| Cu | <1 | 6 | <1 | <1 | <1 | <1 |
| Zn | 36 | 5 | 47 | 39 | 47 | 28 |
| Ga | 19 | 8 | 18 | 19.5 | 15 | 15.5 |

Note that numbers in brackets are by INAA.
Appendix 5  Analytical techniques

1 XRF and INAA analyses

Surface samples were collected with a sledge hammer and any possible source of contamination such as hammer marks and weathered material were removed. Samples from drillcore were ground on a diamond lap to remove all drilled and sawn surfaces and then washed in distilled water and dried. The samples were then crushed in a tungsten carbide splitter and crusher. This material was then reduced to sand size in a tungsten carbide swing mill and, after thoroughly homogenising the sand, a sample (=100g) was milled to a powder. The mill was thoroughly cleaned after each sample by milling with acid–washed sand and wiping it with alcohol. Other equipment was blown with compressed air and wiped with alcohol. Fragments of most samples were retained for W analysis in a separate plastic jar but these have not been crushed.

Samples (including duplicates) for major element analysis were fused in a lithium borate glass and the major elements were determined by X-ray fluorescence spectrometry with a Siemens SRS 300 spectrometer using a modified version of the technique of Norrish and Hutton (1969).

H$_2$O– was determined by measuring the weight lost after heating a =0.5gm sample in a platinum boat for over two hours at 110$^0$C. H$_2$O+ and CO$_2$ were determined by heating the same sample in a tube furnace for 30 minutes at 1100$^0$C in a stream of nitrogen gas. H$_2$O given off in the furnace was collected in a microabsorption tubes containing a mixture of P$_2$O$_5$ and pumice and CO$_2$ was collected in a microabsorption tube containing "carbosorb" soda asbestos with a small amount of P$_2$O$_5$.

Some of the trace elements (Ba, Rb, Sr, Pb, Th, U, Zr, Y, Ce, V, Cr, Cu, Zn and Ga) were measured by XRF with a Philips PW 1400 spectrometer using the techniques of Norrish and Chappell (1977). Duplicate pressed powder pellets composed of 2.5gm of sample with a few drops of PVA were enclosed in boric acid. Mass absorption coefficients were determined for Sr K$\alpha$ and Rb K$\alpha$ using =0.3gm of powder pressed into a hole in a perspex holder. Mass absorption coefficient determinations were repeated until the measurements differed by <1%.

The REE and a few trace elements (La, Ce, Nd, Sm, Eu, Gd, Tb, Ho, Yb, Lu, Sc, Cr, Cs, Hf, Th, U) were analysed by instrumental neutron activation analysis (INAA) using a modified version of the method of Jacobs et al. (1977). For each sample and a standard (Granite 2), about 0.3gm of powder was pressed into a polythene vial and irradiated in a neutron flux of 4x10$^{12}$ neutrons/cm$^2$/sec for 24 hours at the Australian Nuclear Science and Technology Organisation reactor at Lucas Heights in Sydney. The iron content of the sample was used as an internal flux monitor. Analysis was carried out using two spectrometers: a low energy Ge spectrometer (LEPS) and a high energy lithium–doped Ge crystal spectrometer. Analyses were corrected for time elapsed since irradiation, neutron flux gradient, dead time, background, half–life, height above detector, and interferences. Counting times were chosen to maximise the detection limit or minimise the error for each element. Four counts were mado over a period of seven weeks.
2 Sulphur isotope analyses

The samples were mostly taken from diamond-drillcore or percussion-drillchips by either gently crushing the rock or by drilling it with an engraver. The analyses were performed by Dr Shensu Sun at the Bureau of Mineral Resources in Canberra. SO$_2$ samples were prepared for mass spectrometry using the method of Robinson & Kusakabe (1975). The isotopic ratios were measured relative to secondary standards but are reported relative to Canon Diablo Troilite.
# Appendix 6  Details of the sulphur isotope samples

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Mineral</th>
<th>Result $^{34}S%_\text{CDT}$</th>
<th>Facies</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>pyrrhotite</td>
<td>+5.4</td>
<td>Am</td>
<td>Gillans Prospect, BRYG 001, G1–19, 148.2m</td>
</tr>
<tr>
<td>B2</td>
<td>pyrrhotite</td>
<td>+4.8</td>
<td>Am</td>
<td>Gillans Prospect, BRYG 001, G1–25, 178.0m</td>
</tr>
<tr>
<td>B3</td>
<td>pyrite</td>
<td>+5.2</td>
<td>Am</td>
<td>Gillans Prospect, BRYG 001, G2–33, 195.5m</td>
</tr>
<tr>
<td>B4</td>
<td>pyrrhotite</td>
<td>+4.8</td>
<td>Am</td>
<td>Gillans prospect, BRYG 001, G2–41, 222.8m</td>
</tr>
<tr>
<td>B5</td>
<td>pyrite</td>
<td>+5.5</td>
<td>Bv</td>
<td>Picasso Prospect, BRYP 101, 43–44m</td>
</tr>
<tr>
<td>B6</td>
<td>pyrite</td>
<td>+5.8</td>
<td>Bv</td>
<td>Picasso Prospect, BRYP 101, 65–66m</td>
</tr>
<tr>
<td>B7</td>
<td>pyrite</td>
<td>+6.5</td>
<td>Bv</td>
<td>Picasso Prospect, BRYP 104, 74–78m</td>
</tr>
<tr>
<td>B8</td>
<td>pyrite</td>
<td>+4.5</td>
<td>Bv</td>
<td>Picasso Prospect, BRYP 104, 74–78m</td>
</tr>
<tr>
<td>B9</td>
<td>barite</td>
<td>+22.0</td>
<td>Es</td>
<td>Harnett Prospect, surface sample, R632</td>
</tr>
<tr>
<td>B10</td>
<td>barite</td>
<td>+20.5</td>
<td>Es</td>
<td>Harnett Prospect, surface sample, R632</td>
</tr>
<tr>
<td>B11</td>
<td>pyrite</td>
<td>−13.5</td>
<td>Dv</td>
<td>Harnett Prospect, DDH–H3, H3–35, 223.7m</td>
</tr>
<tr>
<td>B12</td>
<td>pyrite</td>
<td>−14.9</td>
<td>Dv†</td>
<td>Harnett Prospect, DDH–H3, H3–39, 232.6m</td>
</tr>
<tr>
<td>B13</td>
<td>pyrite</td>
<td>+0.4</td>
<td>Es</td>
<td>Harnett Prospect, DDH–H3, H3–61, 307.7m</td>
</tr>
<tr>
<td>B14</td>
<td>pyrite</td>
<td>−6.7</td>
<td>Es</td>
<td>Harnett Prospect, DDH–H3, H3–71, 339.3m</td>
</tr>
<tr>
<td>B15</td>
<td>pyrite</td>
<td>+3.5</td>
<td>Es</td>
<td>Harnett Prospect, DDH–H3, H3–79, 370.3m</td>
</tr>
<tr>
<td>B16</td>
<td>pyrite</td>
<td>+1.2</td>
<td>Dkb</td>
<td>Billilingra Prospect, DDH–BL1, BL1–3, 45.9m</td>
</tr>
<tr>
<td>B17</td>
<td>barite</td>
<td>+23.9</td>
<td>Dkb</td>
<td>Billilingra Prospect, DDH–BL1, BL1–3, 45.9m</td>
</tr>
<tr>
<td>B18</td>
<td>barite</td>
<td>+26.0</td>
<td>Dkb</td>
<td>Billilingra Prospect, DDH–BL1, BL1–22, 140.7m</td>
</tr>
<tr>
<td>B22</td>
<td>pyrite</td>
<td>−0.1</td>
<td>Es</td>
<td>Driscolls Hill Prospect, BRAD 101, 75–76m</td>
</tr>
<tr>
<td>B23</td>
<td>pyrite</td>
<td>+0.7</td>
<td>Es</td>
<td>Driscolls Hill Prospect, BRAD 101, 101–102m</td>
</tr>
<tr>
<td>B24</td>
<td>pyrite</td>
<td>−0.2</td>
<td>Es</td>
<td>Driscolls Hill Prospect, BRAD 101, 100–101m</td>
</tr>
<tr>
<td>B27</td>
<td>pyrite</td>
<td>+3.3</td>
<td>Dkb</td>
<td>Billilingra Prospect, DDH–BL1, BL1–5, 49.2m</td>
</tr>
<tr>
<td>B28</td>
<td>pyrite</td>
<td>−6.1*</td>
<td>Es</td>
<td>Driscolls Hill Prospect, BRAD 101, 33–34m</td>
</tr>
<tr>
<td>B29</td>
<td>pyrite</td>
<td>−3.1</td>
<td>Es</td>
<td>Driscolls Hill Prospect, BRAD 101, 33–34m</td>
</tr>
<tr>
<td>B30</td>
<td>barite</td>
<td></td>
<td>Ess</td>
<td>Barite Prospect, R554, Band G14</td>
</tr>
<tr>
<td>B31</td>
<td>barite</td>
<td></td>
<td>Ess</td>
<td>Barite Prospect, R555, Band G13</td>
</tr>
</tbody>
</table>

* Precision for analyses with an asterisk is ± 1–2‰, all other samples ±0.1‰.
† From the narrow sericitic, siliceous, pyritic interval from 223.8–237.0m.
Addendum 1. Page 37  The Mount Black deposit is the subject of a fluid inclusion and sulphur, carbon and oxygen isotope study by E. P. Ambler, P. M. Ashley, R.A. Both & T.H. Donnelly (Stable isotope and fluid inclusion study on the Mount Black lead-zinc deposit, southern New South Wales. *Geol. Soc. Aust. J.* 26, 399-409, 1979). The authors concluded that the deposit formed in a manner which was broadly analogous to that of Mississippi Valley-type deposits, but modified by and/or caused by an increased geothermal gradient due to the nearby granites.

Addendum 2. Page 37  In the northern end of the Tantangara Block there are a number of zones of sulphidic calc-silicate rocks which have been described by R.L. Stanton (Constitutional features, and some exploration implications, of three zinc-bearing stratiform skarns of eastern Australia, *Trans. Instn Min. Metall.* (Sect. B: earth sci.), 96, B37-57, 1987). Professor Stanton considers that the deposits did not form by metasomatic replacement of limestone, instead they formed as syngeneic, exhalative deposits which have subsequently undergone diagenetic/metamorphic recrystallization. Before the implications of this work for the Late Silurian regional metallogenesis can be evaluated fundamental problems concerning the age and structure of the host sequence and the genesis of the mineralization need to be considered. Professor Stanton describes the host sequence as apparently conformable and of Siluro-Devonian age. According to Owen and Wyborn (1979) the sulphidic calc-silicate bodies occur along the Koorabri Fault which separates the Late Silurian Cooleman Plains Group from the Early Devonian Mountain Creek Volcanics. Furthermore the exhalative origin for the mineralization is suggested as an alternative to the metasomatic replacement model for skarn-type deposits and there are no compelling arguments in favour of the model.