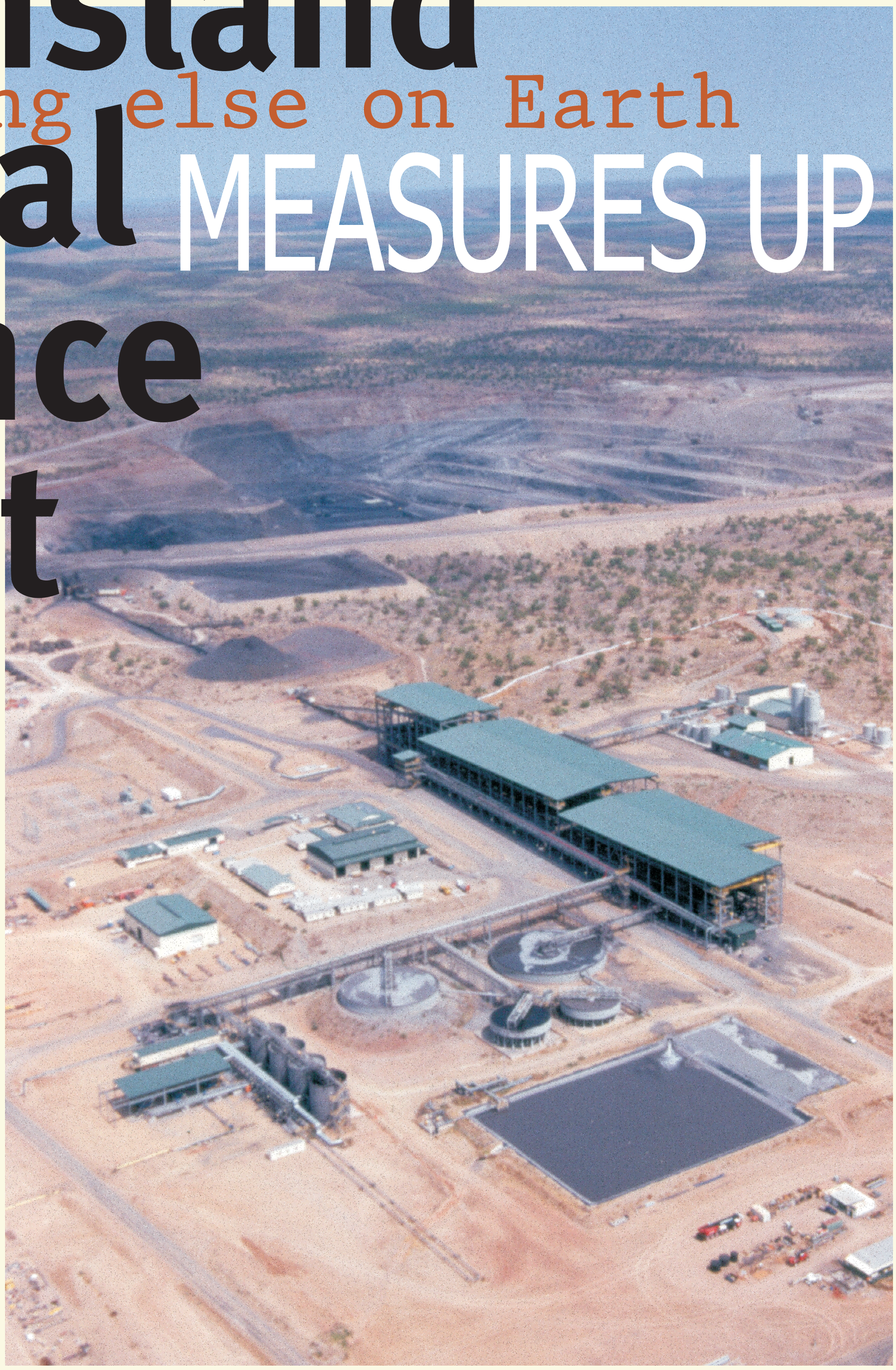
North-West Queensland Mineral Province Report

Nothing else on Earth

MEASURES UP



Queensland Government
Department of Mines and Energy

SRK Consulting

TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS

ESRI AU

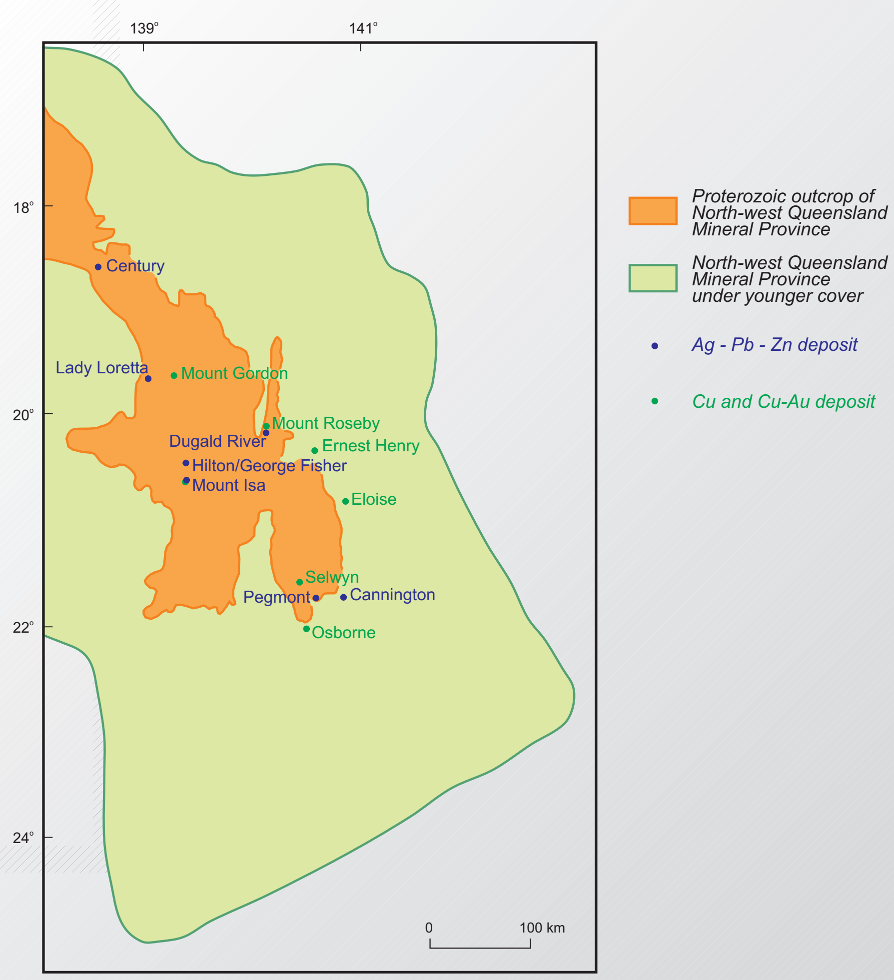
The North-west Queensland Mineral Province, encompassing the Proterozoic Mount Isa Inlier and its extensions under cover, is one of the most richly endowed mineralised regions of the globe. It contains world class zinc, lead, silver and copper deposits (Table 1), is a major source of the world's zinc, lead and silver, and is a significant producer of copper.

Although it has a long and distinguished exploration history dating back to 1868 and is regarded as mature exploration ground by the industry, no fewer than nine base and previous metal discoveries were made in the 1988 to 1994 period. Of these, six have since been brought into production, namely, Eloise, Osborne, Tick Hill, Century, Cannington and Ernest Henry. Century is now the world's second largest zinc mine, while Cannington is the foremost global producer of lead and silver.

Many of the recent spate of discoveries were made under relatively shallow cover (<80m) around the fringes of the exposed ground, using geological concepts and geophysical techniques.

The bulk of the unexposed Proterozoic elsewhere in the region, comprising an area three times the size of the exposed ground, is virtually unexplored.

Overall, the region is regarded as one of the most prospective tracts of the globe for zinc, lead, silver and copper, in the form of giant sediment-hosted stratiform Zn-Pb-Ag deposits, Broken Hill-style Pb-Zn-Ag, Mount Isa-style Cu, iron oxide Cu-Au systems, and other styles.



Major base metal deposits, North-west Queensland Mineral Province.

TABLE 1: MAJOR DEPOSITS, NORTH-WEST QUEENSLAND MINERAL PROVINCE

	Resource Data						
Deposit	**Mt**	**% Pb**	**% Zn**	**% Cu**	**g/t Au**	**g/t Ag**	**References**
Zn-Pb							
CANNINGTON	43.8	11.6	4.4			538	Walters & Bailey (1998)
CENTURY	98.5	1.7	11.6			43	Broadbent & Waltho (1998); Pasminco Ltd 1999 Annual Report
DUGALD RIVER	49.9	1.9	11.5			37	Newbery & others (1993); Pasminco Ltd 2000 Annual Report
HILTON/GEORGE FISHER	146.2	5.6	10.5			110	Forrestal (1990); MIM Holdings Ltd 1999 Annual Report
LADY LORETTA	13.6	5.9	17.1			97	Hancock & Purvis (1990); Buka Minerals Ltd announcement June 6 2000
MOUNT ISA	125	6	7			160	Forrestal (1990)
PEGMONT	8.6	7.6	3.5			150	Locsei (1977); Register of Australian Mining 1999/2000
Cu and Cu-Au							
ELOISE	3.1			5.5	1.4		Baker (1998)
ERNEST HENRY	127			1.1	0.55		Ryan (1998)
MOUNT ISA	255			3.3			Perkins (1990)
MOUNT GORDON	21			4.6			Richardson & Moy (1998)
MOUNT ROSEBY	62.3			0.75			Universal Resources Ltd, based on CRA Exploration Pty Ltd reports
OSBORNE	11.3			2.9	1.18		Adshead & others (1998)
SELWYN	7.4			1.9	3.8		Rotherham & others (1998)

North-West Queensland Mineral Province

Nothing else on earth measures up

compiled by

Queensland Department of Mines and Energy

Taylor Wall and Associates

SRK Consulting Pty Ltd

ESRI Australia

The North-west Queensland Mineral Province Study was conceived by the Queensland Department of Mines and Energy as part of the Prospectivity Plus initiative, which aims to:

- provide industry with new geoscientific data in areas of high mineral potential,
- increase the accessibility of information by developing modern digital systems, and
- promote Queensland's mineral prospectivity to both domestic and international markets.

The Study was implemented with a view to enhancing the impetus, effectiveness and success rate of exploration activities in the North-west Queensland region by:

- providing fresh insights into the geology and mineralisation,
- developing new exploration concepts and specific base and precious metal targets, and
- making the new data available to industry in a readily accessible digital form.

The Study was undertaken over the period March to October 2000 by a team comprising industry consultants, Taylor Wall and Associates, SRK Consulting Pty Ltd and ESRI Australia and personnel from the Department of Mines and Energy. Worldwide, it is thought to represent the first ever collaborative venture between consultants and a State Mining Department with the specific intention of identifying exploration targets for industry.

Using the wealth of public domain geological, geophysical, and research data available for the region, together with geophysical data provided by MIM Holdings Ltd, the Study team has produced the following new data:

- a state-of-the-art, 4D tectonostratigraphic and structural synthesis,
- new digital geological maps, with geology interpreted under post-mineralisation cover,
- a time-space framework digitally linked with maps, stratigraphic, lithological and geochronological information, and
- a summary of the key characteristics and targeting criteria for the various deposit styles of the region, with ranked targets for each of the main deposit styles.

The Study is of particular interest to mineral explorers as it:

- provides in digital GIS format the first fully integrated geological interpretation of the outcropping and covered areas of this world-class mineral province,
- identifies and ranks priority target zones for base metal and gold deposits, based on practical deposit models, explicit exploration criteria and the new stratigraphic, structural and igneous framework, and
- demonstrates the global standing of the North-west Queensland Mineral Province in terms of mineral endowment, regulatory framework and untested opportunities.

MAIN CONTRIBUTORS

Queensland Department of Mines and Energy:

Mr TJ Denaro, Mr LJ Hutton, Mr PJT Donchack

Taylor Wall & Associates

Mr S Taylor, Dr VJ Wall, Dr MC Hinman

SRK Consulting Pty Ltd

Dr MA Etheridge, Mr R Bartsch

ESRI Australia

Mr A Hender, Mr D Gooding

ADDRESS FOR CORRESPONDENCE:
Department of Mines and Energy, Queensland
QMEC Building, 61 Mary Street, Brisbane 4000
(GPO Box 194, Brisbane 4001)
Telephone: (07) 3237 1411; International +61 7 3237 1411
Facsimile: (07) 3235 4074: International +61 7 3235 4074
Email: www.dme.qld.gov.au

Graphics : L Blight, T Moore, N Gatehouse, C Roberts, B Rapkins, R Blight
Image Processing: R Huber
Desktop Publishing: JW Beeston, SA Beeston
CD-ROM preparation: A Philp

Printed by: GOPRINT, 371 Vulture Street, Woolloongabba 4102
Issued: November, 2000

Published by the Queensland Department of Mines and Energy
Issued under the Authority of the Minister for Mines and Energy

National Library of Australia card number and ISBN 0 7242 7250 X

REFERENCE: QUEENSLAND DEPARTMENT OF MINES AND ENERGY, TAYLOR WALL & ASSOCIATES, SRK CONSULTING PTY LTD & ESRI AUSTRALIA, 2000: *North-West Queensland Mineral Province Report. Queensland Department of Mines and Energy, Brisbane.*

Projection: The plates in this report and the data sets on the CD-ROM are in Universal Transverse Mercator Projection, using Australian Geodetic Datum 1966 (AGD66).

CONTENTS

1. INTRODUCTION . . . 1
    1.1 PHILOSOPHY AND APPROACH . . . 1
    1.2 KEY OUTCOMES . . . 1
    1.3 PROJECT PARTICIPANTS . . . 2
2. USER GUIDE . . . 3
    2.1 PROJECTION . . . 3
    2.2 REPORT . . . 3
        Hard Copy Report . . . 3
        CD-ROM . . . 3
    2.3 DIGITAL GIS (CD-ROM) . . . 3
3. NORTH-WEST QUEENSLAND MINERAL PROVINCE . . . 4
    3.1 LOCATION . . . 4
    3.2 TOPOGRAPHY . . . 4
    3.3 CLIMATE . . . 4
    3.4 VEGETATION . . . 4
    3.5 LAND USE . . . 5
    3.6 ADMINISTRATION . . . 5
    3.7 INFRASTRUCTURE . . . 5
4. DATA COVERAGE AND SOURCES . . . 9
    4.1 OVERVIEW . . . 9
    4.2 GEOLOGY . . . 9
    4.3 GEOCHEMISTRY . . . 9
    4.4 GEOPHYSICS . . . 9
    4.5 DRILLING . . . 9
    4.6 OPEN FILE REPORTS . . . 9
5. GEOLOGY . . . 15
    5.1 INTRODUCTION . . . 15
    5.2 TIME-SPACE FRAMEWORK . . . 15
        Methodology and Approach . . . 15
        Event Stratigraphy - Key Outcomes . . . 16
    5.3 PROTEROZOIC GEOLOGY . . . 17
        Methodology and Approach . . . 17
        Key Bibliographic References . . . 18
        Proterozoic Geology - Key Outcomes . . . 18
    5.4 PHANEROZOIC GEOLOGY . . . 22
        Neoproterozoic to Palaeozoic Events and Sequences . . . 22
        Neoproterozoic to Palaeozoic Depositional Episodes . . . 22
        Palaeozoic Tectonics . . . 22
        Mesozoic Events and Sequences . . . 22
        Mesozoic Depositional Episodes . . . 23
        Mesozoic Tectonics . . . 23
        Cenozoic Events and Sequences . . . 23
        Cenozoic Depositional Episodes . . . 23
        Cenozoic Deep Weathering Profiles . . . 23
        Cenozoic Tectonics . . . 23
        Cenozoic Regolith . . . 23
    5.5 SYNTHESIS OF TECTONOSTRATIGRAPHIC ELEMENTS AND MINERALISATION . . . 28
6. MINERALISATION . . . 32
    6.1 OVERVIEW . . . 32
    6.2 TARGET STYLES . . . 35
        Introduction . . . 35
        Sediment-Hosted Zn, Pb, Ag Systems . . . 35
        Metasediment-Hosted Copper: Isa-Style . . . 42
        Other Copper System Styles . . . 44
        Copper-Gold ± Iron Oxide Systems . . . 48
        Pluton-Related Gold Systems . . . 52
        Other Commodities and styles of Mineralisation 55
7. EXPLORATION . . . 60
    7.1 EXPLORATION HISTORY . . . 60
    7.2 CURRENT EXPLORATION TENURE . . . 61
    7.3 LAND ACCESS . . . 61
    7.4 NATIVE TITLE . . . 61
8. GLOBAL SIGNIFICANCE OF THE NORTH-WEST QUEENSLAND MINERAL PROVINCE . . . 65
    8.1 MINERAL ENDOWMENT . . . 65
        Zinc . . . 65
        Lead . . . 65
        Silver . . . 65
        Copper . . . 65
    8.2 MINERAL PRODUCTION . . . 66
        Zinc . . . 66
        Lead . . . 66
        Silver . . . 66
        Copper . . . 66
    8.3 DISCOVERY RECORD . . . 66
9. REGULATIONS GOVERNING EXPLORATION AND MINING IN QUEENSLAND . . . 72

9.1 GENERAL ASPECTS 72
9.2 FOREIGN INVESTMENT 72
9.3 MINERAL REGULATIONS IN QUEENSLAND . . 72
9.4 FORMS OF MINERAL TITLE IN QUEENSLAND . 72
Exploration Permit 72
Mineral Development Licence 72
Mining Lease 73
9.5 THE EXPLORATION PERMIT APPLICATION PROCEDURE IN QUEENSLAND. 73
9.6 ENVIRONMENTAL REGULATIONS 73
9.7 COMPARISON OF MINING/EXPLORATION REGULATIONS IN QUEENSLAND WITH OTHER JURISDICTIONS WORLDWIDE 73
10. MINERAL INDUSTRY TAXATION 75
10.1 SUMMARY OF TAXATION IN QUEENSLAND . . 75
Commonwealth Taxes 75
Queensland Government Taxes 75
10.2 COMPARISON ON THE TAXATION REGIME IN QUEENSLAND WITH OTHER JURISDICTIONS WORLDWIDE 75
11. DISCOVERY POTENTIAL 77
11.1 GENERAL COMMENTS 77
11.2 POST-MINERALISATION COVER 77
Cover Depths 77
Regolith 77
11.3 PRIORITY TARGET AREAS 81
ACKNOWLEDGEMENTS 82
REFERENCES 82

TABLES

5.1: Tectonic events, North-west Queensland Mineral Province 29
6.1: Mineral deposit styles, North-west Queensland Mineral Province 33
6.2: Key target styles in the North-west Queensland Mineral Province 33
7.1: North-west Queensland Mineral Province - History of major discoveries 63
8.1: Ranking of world-class zinc deposits by zinc content 67
8.2: Comparison of overall lead and zinc contents in major mineralised provinces world wide 67
8.3: Ranking of world-class lead deposits by lead content 68
8.4: The world's largest silver districts/deposits 68
8.5: North-west Queensland Mineral Province, Year 1999/2000 production 69
8.6: Base metal discoveries 1980-2000 70
8.7: The largest zinc discoveries since 1980 71
11.1: Isa-Century Style Zn-Pb-Ag targets 90
11.2: Broken Hill-Cannington Style Ag-Pb-Zn targets 94
11.3: Isa Style copper targets 95
11.4: Cu-Au targets 98
11.5: Tick Hill style Au targets 111
11.6: Other pluton-related gold targets 113
11.7: Diamond targets 113

FIGURES

1.1: Location of North-west Queensland Mineral Province Study 1
5.1: Australian Proterozoic Apparent Polar Wander Path 15
6.1: Cross section, Mount Isa copper orebody 45
8.1: Comparison of size and Zn-Pb content of the world's major zinc-lead provinces 65
9.1: Department of Mines and Energy administrative regions 74
10.1: Model copper mine after tax rates of return 76
10.2: Model gold mine after tax rates of return 76

PLATES

1: Geography - Physical/Cultural 6
2: Major Queensland Infrastructure 7
3: Geography - Infrastructure 8
4: Data coverage and Sources - Geology 10
5: Data coverage and Sources - Geochemistry 11
6: Data coverage and Sources - Geophysics 12
7: Data coverage and Sources - Drillholes 13
8: Data coverage and Sources - Open File Exploration 14
9: Proterozoic Geology by Event 20
10: Proterozoic Geology by Dominant Rock Type 21
11: Event Stratigraphy - Palaeozoic 24
12: Event Stratigraphy - Mesozoic 25
13: Event Stratigraphy - Cenozoic 26
14: Geology - Phanerozoic 27
15: Mineralisation - Overview 34
16: Target Model: Stratabound Zn-Pb-Ag, Isa-Century Style 39
17: Target Model: Stratabound Ag-Pb-Zn, Broken Hill-Cannington Style 40
18: Mineralisation - Zn-Pb-Ag 41
19: Target Model: Metasediment-Hosted Cu, Isa Style 46
20: Mineralisation - Cu 47
21: Target Model: Iron oxide Cu-Au Systems 50
22: Mineralisation - Cu-Au 51
23: Target Model: Tick Hill Style Au 53
24: Mineralisation - Au 54
25: Mineralisation - Other 59
26: Exploration - Current 64
27: Cover Depth - Toolebuc Formation 78
28: Cover Depth - Georgina Basin 79
29: Cover Depth - Proterozoic 80
30: Geological Legend 88
31: Lithological Key 89

MAPS

1: Proterozoic Event Stratigraphy
2: Geological Synthesis
3: Mineralisation
4: Tectonic Framework
5: Discovery Potential - Zinc-Lead-Silver
6: Discovery Potential - Copper
7: Discovery Potential - Copper-Gold and Gold

1. INTRODUCTION

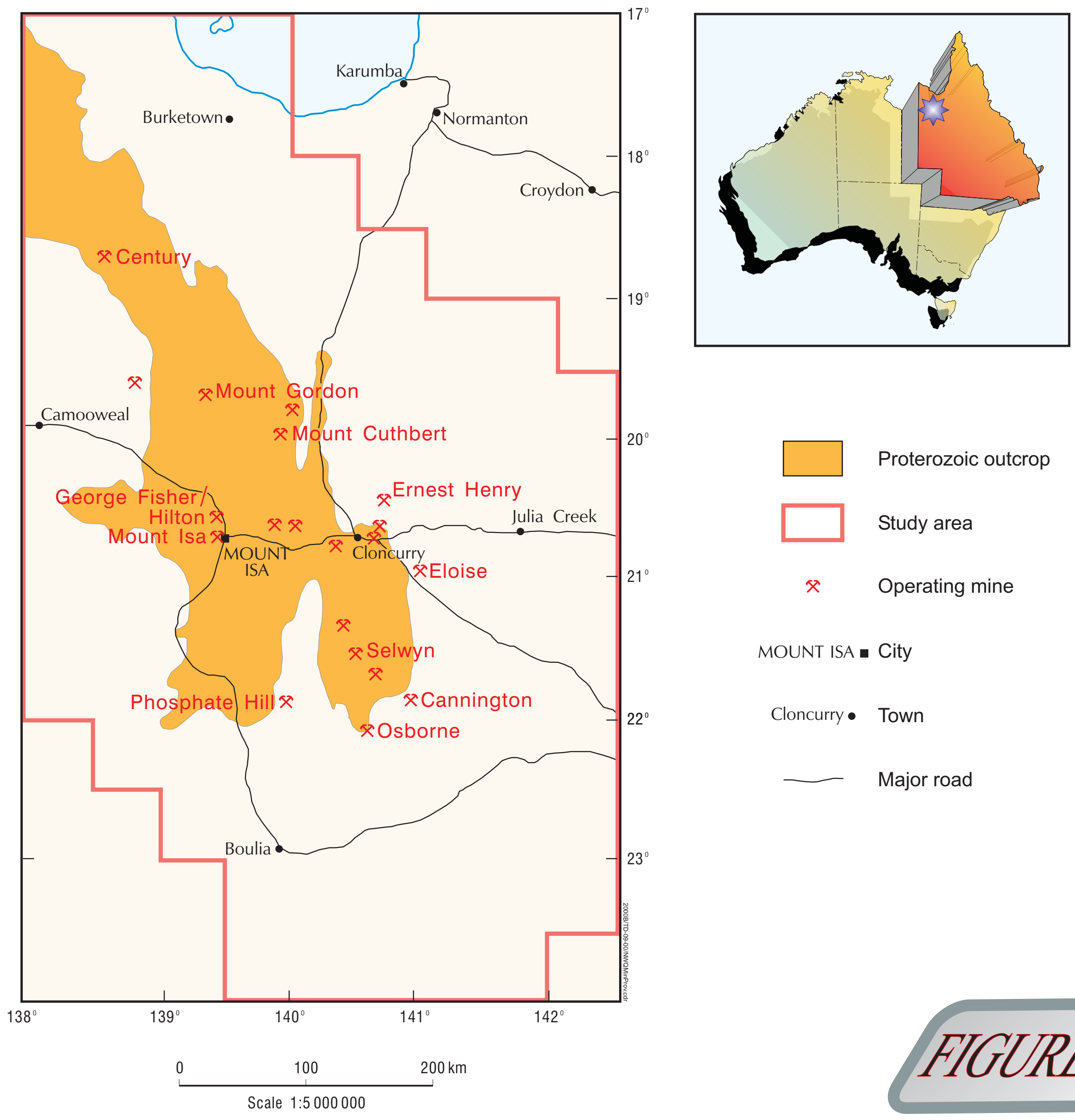


FIGURE 1.1

Location of North-west Queensland Mineral Province Study

The North-west Queensland Mineral Province Study was initiated by the Queensland Department of Mines and Energy (DME) with a view to enhancing the level and effectiveness of exploration activity in the region, through providing fresh insights into its geology, tectonostratigraphic evolution and mineralisation. The primary goal of the project has been to demonstrate that quality, untested targets exist, and therefore that this world-class mineral province should be in the portfolio of all serious mineral explorers.

The Study involved a comprehensive analysis of the area shown in Figure 1.1, by industry consultants Taylor Wall and Associates ('TWA') and SRK Consulting ('SRK'), in collaboration with senior geological staff from the Department of Mines and Energy. All personnel involved in the Study have previous experience and expertise in the region in company exploration, research work, consulting assignments or Government mapping programmes. Digital data capture, design and production were undertaken by ESRI Australia.

The Study was conducted over the period March to October 2000, using public domain geological, geophysical and geochemical data, the latest research results, proprietary geophysical data made available by MIM Holdings Ltd, and geochemical data provided by Terra Search Pty Ltd.

1.1 PHILOSOPHY AND APPROACH

The underlying philosophy of the project has been to deliver a knowledge product rather than simply a data package. The emphasis has been on an innovative and accessible interpretation of the geology, the tectonostratigraphic and structural framework, and practical mineral deposit models, leading to robust targeting criteria and target zones. This approach recognises that the key decision points and value-drivers in exploration relate to efficiently identifying and drill-testing the lowest risk targets. It is therefore designed to add real value to the industry by reducing the time and cost to define such targets.

It should be emphasized at the outset that the scale of geological interpretation was 1:250 000, with 1:100 000 in some areas. At this scale, it is generally not possible to define deposit-scale drill targets, so most of the targets are tenement-scale areas and targeting criteria are designed for that scale. However, the mineral deposit models and aspects of the exploration and targeting criteria are applicable at deposit scale, and can be used to design follow-up programs to define and assess drill targets.

Despite the emphasis on interpretation and knowledge delivery, the digital product contains a substantial data/information package, some of which has not previously been in the public domain. In addition there is a particularly comprehensive set of metadata, including links to privately held data that are commercially available from third parties.

The digital product in particular is structured so that all of the information is available to enable the user to independently assess the identified targets, and indeed to generate additional targets. The GIS provides the capability to select, separate and then overlay numerous subsets of the data/interpretation products, and thereby to enable the user to interact with the product in depth.

1.2 KEY OUTCOMES

The key outcomes of each component of the study are listed in each of the following chapters. The points summarised below are the major overall highlights for intending mineral explorers in the North-west Queensland Mineral Province.

- The North-west Queensland Mineral Province is a world-class mineral province, with a very attractive spread of commodities and deposit types. It is a major source of the world's zinc, lead and silver output and a significant producer of copper. Most importantly, despite its long history of production and exploration, it hosts a significant proportion of the world's newly discovered (that is, since 1980) zinc, lead, silver and copper resources. The North-west Queensland Mineral Province has continued to produce new world-class base metal deposits at a time of historically low global discovery rates. Most of these resources were under post-mineralisation cover or geologically blind, and were discovered with a combination of sophisticated geological, geophysical and geochemical techniques. This study provides a further advance of information and knowledge, particularly in the covered areas, to assist in the discovery of the next generation of world-class mines in the region.

- The rich mineral endowment of the North-west Queensland Mineral Province is largely a function of its long and episodic history of basin formation, its structural complexity, and the repeated crust-mantle interaction that produced metal-rich magmas susceptible to fractionation. The key outcome of this study, and the underpinning of the targeting, is the production of an internally consistent four-dimensional geological framework that integrates all of these influences on deposit formation and localisation. Presentation in an accessible, updateable and interactive digital GIS is then fundamental to the accessibility and utility of the study results.

- Silver-lead-zinc potential and targets. A comprehensive new structural and tectonostratigraphic framework has been produced for the ~1700–1600Ma basin system that contains the world-class silver-lead-zinc deposits (for example, Mount Isa-Hilton-George Fisher, Century, Lady Loretta, Cannington) of the region. The sequence stratigraphic approach recently applied to the western part of the region by AGSO's NABRE project has been extended to the whole region and used, in combination with a dynamic structural framework and distinctive geophysical signatures, to define new target zones for these deposits.

- Mount Isa-style copper potential and targets. The Mount Isa copper deposit is an enigmatic, but particularly attractive target (255Mt at 3.3%Cu). Smaller examples (for example, Mount Gordon, Mount Cuthbert) are also of interest to small to medium companies, especially as solvent extraction/ electrowinning (SX-EW) propositions. The structural, stratigraphic and lithological framework in this product provides new targeting criteria and targets for this deposit type.

- Iron-oxide copper-gold potential and targets. Despite the long history of copper mining in the eastern part of the North-west Queensland Mineral Province, the discovery of the Osborne, Selwyn and Ernest Henry mines over the last 20 years has only recently highlighted the province's capacity to deliver world-class deposits of this very attractive style. The common association of magnetite with these deposits led to an initial rush to drill high intensity magnetic anomalies. However, as detailed in this study, it has proved necessary to take a more comprehensive approach to targeting based on multiple geological, geophysical and geochemical/alteration criteria. This study has focused on the recognition of complexly structured and altered roof zones of the ~1500Ma Williams granitoids suite from multiple geophysical and geological criteria to generate numerous target zones for this deposit type.

- Potential for other deposit types. Numerous other deposit styles are present in the North-west Queensland Mineral Province, some of which provide attractive targets for both small and large mining companies (for example, Tick Hill high-grade gold, Cambrian phosphate, potentially diamond-bearing kimberlitic intrusions).

1.3 PROJECT PARTICIPANTS

The main participants and their major contributions were as follows:

Taylor Wall and Associates

Stewart Taylor — Global significance of the region; Regulatory framework

Vic Wall — Target models; Western Succession targeting

Mark Hinman — Western Succession interpretation and targeting; Proterozoic time-space framework; Tectonic and structural framework

SRK Consulting

Mike Etheridge — Tectonic and structural framework; Eastern Succession targeting

Roland Bartsch — Eastern Succession interpretation and targeting

Queensland Department of Mines and Energy

Terry Denaro — Background data sets; Mineral occurrence data; depth of cover contouring

Laurie Hutton — Western Succession interpretation; Palaeozoic time-space

Paul Donchak — Eastern Succession interpretation

ESRI Australia

Adam Hender — GIS design and production

Dave Gooding — Data capture

2. USER GUIDE

2.1 PROJECTION

The plates in this report and the data sets on the CD-ROM are in Universal Transverse Mercator Projection, using Australian Geodetic Datum 1966 (AGD66). AGD66 has been chosen, rather than Geodetic Datum of Australia 1994 (GDA94), because:

- it is common to the majority of the data sets used, and
- data from the Department of Mines and Energy's Mineral and Energy Resource Location and Information Network (MERLIN) corporate database are currently in AGD66.

The Department is currently in the process of upgrading its systems to GDA94.

2.2 REPORT

Hard copy report

The report begins with a brief users guide to both digital and hard copy products (Chapter 2). The latter is straightforward, but the digital product requires some time investment to extract maximum value. Within the digital product itself are specific instructions for its use.

The users guide is followed by an outline of the geography and infrastructure of the North-west Queensland Mineral Province (Chapter 3), and a description of the geoscientific and exploration data coverage and sources (Chapter 4). Chapter 4 covers the data included in this product; an extensive metadata coverage is included as Appendix 1 on the CD-ROM.

Chapter 5 covers the principal geological products and outcomes. It does not include a systematic text description of the geology, both because the products (solid geology map, time-space chart and structural-tectonic framework) are comprehensive and largely self-explanatory, and because there is an extensive array of modern, comprehensive, published geological summary material. However, it does describe the key outcomes derived from the various products/components of the study.

The second half of the report is devoted to aspects specifically related to mineralisation and exploration. It begins with a summary of the principal deposit styles and occurrences, including key exploration and target ranking criteria (Chapter 6), followed by an outline of the history and current status of exploration activity in the province, with information on land access (Chapter 7).

The report then places the mineral endowment and discovery record (Chapter 8), the regulatory environment (Chapter 9) and the taxation regime (Chapter 10) of the North-west Queensland Mineral Province into a global context, to demonstrate that this indeed is one of the world's premier places for mining companies to do business.

Finally, the discovery potential of the North-west Queensland Mineral Province is highlighted via the description and ranking of priority target areas for the principal deposit styles (Chapter 11). Summary maps at 1:1 000 000 show the locations of the targets against a backdrop of the key geological features that controlled their localisation.

CD-ROM

The CD-ROM contains all of the above information, detailed tables and appendices that are not included in the hard copy report, and the digital GIS, as outlined in section 2.3.

2.3 DIGITAL GIS (CD-ROM)

A comprehensive digital Geographic Information System (GIS), that incorporates all of the interpretive products, substantial primary data/information and metadata, is available on the CD-ROM. The main components of the GIS are as follows:

- The core of the GIS is a new solid geology map of the Proterozoic basement. The map was compiled at 1:250 000 scale, and was based on an integrated interpretation of the outcropping geology, a new stitch of the open-file magnetic data, DME's gravity database, and, for the first time in a product in the public domain, Mount Isa Mines Ltd's spectacular high resolution airborne magnetic/radiometric open range survey. It also incorporates previously unpublished information and concepts accumulated by the interpretation team over 20 years of research, exploration and consulting in the region. The map in the digital product is a fully functional GIS with attribution of all polygons and structures.
- A comprehensive Time-Space (Event Stratigraphy) Chart that details, in each of the major geological domains of the North-west Queensland Mineral Province, the sequence stratigraphy, primary rock types, intrusive events, basin-forming events, deformational events and mineral deposits by either host rock age or deposition age. It also incorporates the key radiometric ages.
- A mineral deposits and occurrences database, with all occurrences attributed by location, commodity, size, deposit style and mineralising age/event.
- Mineral deposit models for all of the major styles, with essential geological elements and key targeting criteria.
- Depth of cover to Proterozoic basement.
- The tectonic and structural framework of the region, captured as major structures active during particular deformation events.
- Target areas for all of the major deposit styles. Each target area is attributed with the key targeting criteria for that style, cover depth (if applicable) and both an overall ranking and individual rankings for each attribute.
- The CD-ROM product is presented as HTML web pages and map views using ESRI Australia's "ReportExplorerAU" system. This system allows the integration of multiple spatial information views with report chapters.

Minimum System Requirements:

CPU: *Pentium III 300 Mhz*
Monitor Resolution: *1024X768 pixels*
Memory*: 128 Mb*
CD-ROM*: 24 Speed*
Operating System*:*
Windows 98/NT4
Web Browser*: Internet Explorer 5.0 or higher*
Support Software Supplied*: Java 2 Runtime Environment and ESRI's ArcExplorer 3.0*

For software licensing agreements for ESRI Australia's ReportExplorerAU and Geoimage's MSS derived product, see this section on the CDRom.

3. NORTH-WEST QUEENSLAND MINERAL PROVINCE

3.1 LOCATION

The North-West Queensland Mineral Province is in the far north-west corner of the State of Queensland, Australia. The 291 030km^2 area covered in this study (Plate 1) extends between latitudes 17° and 24° south and longitudes 138° and 142°30' east, corresponding to an area from the Gulf of Carpentaria in the north to Springvale in the south and from the Queensland–Northern Territory border east to Julia Creek.

3.2 TOPOGRAPHY

Physiographically, the present land surface reflects the structure and geological history of the region, as well as local structures and rock types. Overall, the region can be described as a highly dissected peneplain with lesser relief and greater alluviation on the inland (southern and south-western) side of the divide than on the northern and eastern side. The average altitude of the Barkly Tableland along the south-western margin of the Proterozoic upland is 240–300m. The Gulf Country, to the north, has an average altitude of 60–120m at the foot of the upland. The western edge of the plains to the east has an average altitude of 105–210m (Carter & others, 1961).

The study area can be subdivided into the following general physiographic units (Stewart, 1954; Twidale, 1964) that broadly correspond to major geological subdivisions:

- Isa Highlands — this upland block projects in a north-north-westerly direction to within 50km of the Gulf of Carpentaria. It is a complex ridge that averages about 360m above sea level but locally exceeds 500m, and is coincident with the area of outcropping Proterozoic rocks, and associated Mesozoic and younger outliers. The complex geological structure is expressed in the topography and drainage patterns. The topography comprises homoclinal ridges and hogbacks, some with truncated crests, small plateaux, and alluvial deposits in the valleys. Present topographic levels indicate that the highlands have been truncated by a post-Mesozoic planation surface.

- Georgina Basin — the Georgina Basin is drained by the southward flowing Georgina River and its tributaries. In the north-west, it consists of black soil plains and a gently sloping topography, but becomes progressively more dissected near the Isa Highlands.

- Carpentaria Plain — this broad plain between the Isa Highlands and the Gulf of Carpentaria is essentially depositional, with an alluvial cover, braided stream channels and an uneven slope, and is drained by streams that flow into the Gulf of Carpentaria. It has a low gradient, with a rise of only 210m from the Gulf of Carpentaria to the divide between the Gulf and inland drainages. Several low lateritic plateaux occur within the plain. Broad expanses of bare mudflats, crossed by belts of sandy beach ridges, extend as coastal deposits around much of the Gulf.

- Inland Plain — this is the flat-lying plain of the Eromanga Basin. It is drained by the Diamantina River and its tributaries. Several low lateritic plateaux occur within the plain.

The outcropping Proterozoic rocks form a watershed or divide of continental importance. The only streams that cut across these rocks are the Gregory River, Lawn Hill Creek and Musselbrook Creek, which drain north to the Gulf of Carpentaria. South and west of the divide, streams drain inland as part of the Georgina-Diamantina system that terminates in Lake Eyre in South Australia. However, water only reaches Lake Eyre at intervals of several years. Even within the area of outcropping Proterozoic rocks, these streams are braided and heavily alluviated (Carter & others, 1961).

Streams north of the divide, such as the Leichhardt, Flinders, Cloncurry and Nicholson Rivers, drain into the Gulf of Carpentaria. These streams are more or less entrenched in the plains of the Gulf Country, but develop complex distributary systems in their lower courses (Carter & others, 1961).

Only four watercourses in the study area, the Gregory and O'Shannassy Rivers and Lawn Hill and Widdallion Creeks, are perennial. These are fed from springs tapping underground water in Palaeozoic limestones. Of the remainder, smaller watercourses only flow for a few days or weeks each year; larger ones may flow for several months. All of the larger watercourses and some of the smaller ones have a number of permanent waterholes. Surface water is fairly easy to find in most parts of the area for two to three months after the end of the 'wet season'. Large areas become essentially devoid of surface water later in the year (Carter & others, 1961). Much of the study area is reliant upon groundwater from the Great Artesian Basin and shallower sources for domestic and stock watering purposes.

3.3 CLIMATE

The study area is almost entirely within the tropics. The climate is semi-arid to sub-humid tropical, and ranges from a tropical, moderate rainfall, coastal climate in the north to a tropical, low rainfall, continental climate in the south. As the topographic range is less than 600m it does not significantly influence climate, except perhaps for a slightly increased rainfall in the higher country (Carter & others, 1961).

The climate comprises a warm dry season from April to September and a hot wet season from October to March. Average rainfall ranges from 260mm per annum in the south to 770mm per annum in the north. Peak rainfall is in the summer months, with the highest rainfall in January and February, although isolated storms can bring falls of up to 50mm at any time of the year. Mean daily temperature maxima range from 23°C in June and July to 38°C in November and December; daily maxima in excess of 40°C are common between October and February. Mean daily temperature minima range from less than 10°C in June, July and August, when there are occasional frosts, to about 25°C in December to February (Slatyer & Christian, 1954; Slatyer, 1964).

Due to access problems caused by heavy rainfall, field activities are not possible throughout most of the region in January and February. Occasionally, rain delays the resumption of field activities until early March.

3.4 VEGETATION

Because of the wide climatic range, there is a considerable diversity of vegetation throughout the study area, but in general the vegetation cover is sparse and does not cause any major access problems or impediments to exploration activities. The following description of vegetation types and distribution is based mainly on a report by Carter & others (1961).

The plains are generally sparsely timbered, except in the far north, where extensive tropical savannah with eucalyptus, scrub ti-tree and acacias provide moderate tree cover. Black soil plains support Mitchell grass and Flinders grass. In these areas, trees are confined to sandy rises and the margins of watercourses, where coolibah and similar mallee-type eucalypts grow to 3–10m in height.

Sandy soil in the south of the study area carries mulga, 'emu apple' and similar typical semi-arid zone trees. Gidyea and whitewood are also common. Bauhinia grows on the river flats north of Cloncurry, particularly where the soil is lime-rich. Silver-leaf box and similar eucalypts are abundant where soil is adequate and well-drained.

The stony hill country formed by outcropping Proterozoic rocks supports mainly eucalypts, including snappy gum, mountain gum and stunted boxes 3–7.5m high. There is commonly a moderate to heavy cover of scrub, consisting mainly of acacia (including 'turpentine bush') and ti-tree.

Varieties of the needle-sharp resinous grass spinifex thrive throughout the region, wherever the soil is poor or scanty and is well-drained. Spinifex forms as clumps that are generally 0.3–0.6m high but may grow to more than 1.5m high, presenting an obstacle to travel.

3.5 LAND USE

The North-west Queensland Mineral Province is a large and relatively remote part of Queensland. In terms of land area, grazing (particularly beef cattle) is by far the major land use. However, most of the Province's economic activity centres upon Mount Isa.

Apart from mining and associated down-stream processing and service industries, the major industries in the Province are:

- beef production,
- wool production,
- fishing and aquaculture,
- transport and freight services,
- engineering services, and
- tourism.

3.6 ADMINISTRATION

The North-West Queensland Mineral Province encompasses ten local governments (nine shires and one city council) and an independent Land Council (Mornington Island). Although most of the region's economic activity centres upon Mount Isa, there are strong links with Townsville, on the Queensland coast to the east, particularly for those shires in the corridor between these two centres. The Gulf communities, namely Burke, Carpentaria, Mornington and Doomadgee, also have links with Croydon and Etheridge shires (particularly through the Gulf Local Authority Development Association).

The region has a total population of approximately 35 000, of whom approximately 63% are based in Mount Isa. It has very high population mobility. Approximately 15% of the population in the region are temporary residents (Department of State Development, 2000).

3.7 INFRASTRUCTURE

Because it is a long-established mining district, the North-west Queensland Mineral Province is well served by a sound framework of local infrastructure, including good road, rail and air connections with the major population centres and ports in Queensland (Plates 2 and 3). Key aspects of the general infrastructure relevant to the mining industry are as follows:

- An established urban centre at Mount Isa (population 22,000) with a broad range of business and community facilities and services, including specific exploration/mining support groups.

- A major regional airport at Mount Isa with daily flights to and from Brisbane and Townsville and a weekly connection with Cairns. The airport at Cloncurry has recently been upgraded to handle the air traffic associated with the Ernest Henry and other mines in the local district.

- A good local network of sealed roads and unsealed tracks.

- Good road and rail access to the deep water port of Townsville, which has nine operational berths equipped with bulk handling facilities, five of which are currently being used to handle mineral and metal cargoes.

- Proximity to the general purpose port of Karumba, at the mouth of the Norman River, in the south-east corner of the Gulf of Carpentaria. The port has recently been upgraded to handle zinc concentrates that are transported via a 310km long slurry pipeline from the Century mine. The concentrates are taken through the shallow in-shore waters of the Gulf by 5000t barges to export vessels lying some 45km offshore.

- Reliable and economical energy sources, including the recently upgraded 325MW Mica Creek Power Station at Mount Isa, which generates electricity using gas piped 840km from Ballara in south-west Queensland.

- Secure and highly reliable telecommunications networks using the latest exchange and transmission technology.

Major mining industry facilities in the North-west Queensland Mineral Province and northern Queensland are as follows:

Mount Isa Copper and Lead Smelters

The MIM Holdings Ltd copper and lead smelters at Mount Isa smelt concentrates from the Mount Isa, Hilton, George Fisher and Ernest Henry mines to produce copper anode and crude lead containing silver. Recently, the production capacity of the copper smelter was upgraded from 180,000 to 250,000tpa copper. The lead smelter is currently being refurbished.

Phosphate Hill High Analysis Fertiliser Plant

WMC Fertilizer Ltd's ammonium phosphate fertiliser plant at Phosphate Hill comprises a phosphoric acid facility, ammonia plant and granulation plant, based on the extensive phosphorite resources on site. Natural gas from the Ballara-Mount Isa gas pipeline is used for ammonia production, process drying and power generation. A sulphuric acid plant has been constructed at Mount Isa, based on scrubbing of smelter gases from the Mount Isa copper smelter; additional sulphuric acid is sourced from the Sun Metals zinc refinery in Townsville. The Phosphate Hill operation produces diammonium phosphate and monoammonium phosphate.

Townsville Copper Refinery

The MIM Holdings Ltd copper refinery at Townsville is one of the world's leading electrolytic refineries, producing 99.9% pure LME Grade A copper. It treats anode copper produced at Mount Isa, by means of the MIM-developed ISA PROCESS, which uses permanent stainless steel cathode plates in association with copper cathode-stripping machinery. The production capacity has recently been upgraded from 210,000 to 270,000tpa Cu.

Sun Metals Zinc Smelter

The Sun Metals Corporation (a subsidiary of Korea Zinc Company Ltd) Zinc Smelter at Stuart, 11km south of Townsville, is the first new, large-scale greenfields zinc refinery to be built world-wide for over a decade. The operation produced its first metal in late November 1999, and is now operating at its Stage 1 capacity of 170,000tpa zinc metal production from ~400,000tpa of zinc concentrates sourced mainly from the north-west Queensland region. Some 325,000tpa of sulphuric acid by-product is transported mainly to the north-west Queensland region for use in fertiliser production and copper leaching plants.

Queensland Government
Department of Mines and Energy

GEOGRAPHY PHYSICAL-CULTURAL

Study area
Road, sealed
Railway

Image backdrop derived from the Geoimage Landsat MSS Mosaic
© Copyright Geoimage Pty Ltd ACN 010 840 294 / ABN 96 624 199 108 (1994)

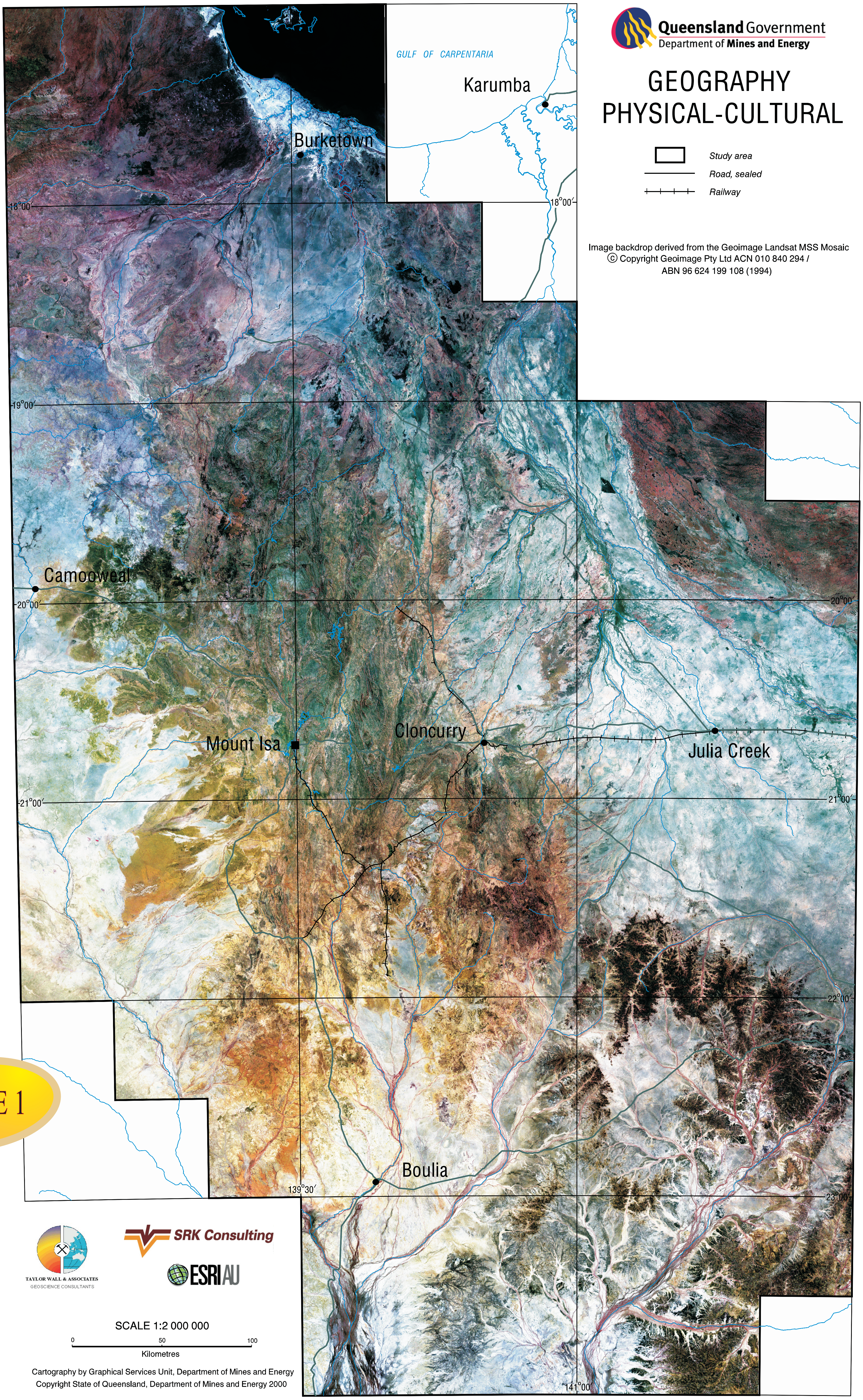


PLATE 1

TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS

SRK Consulting

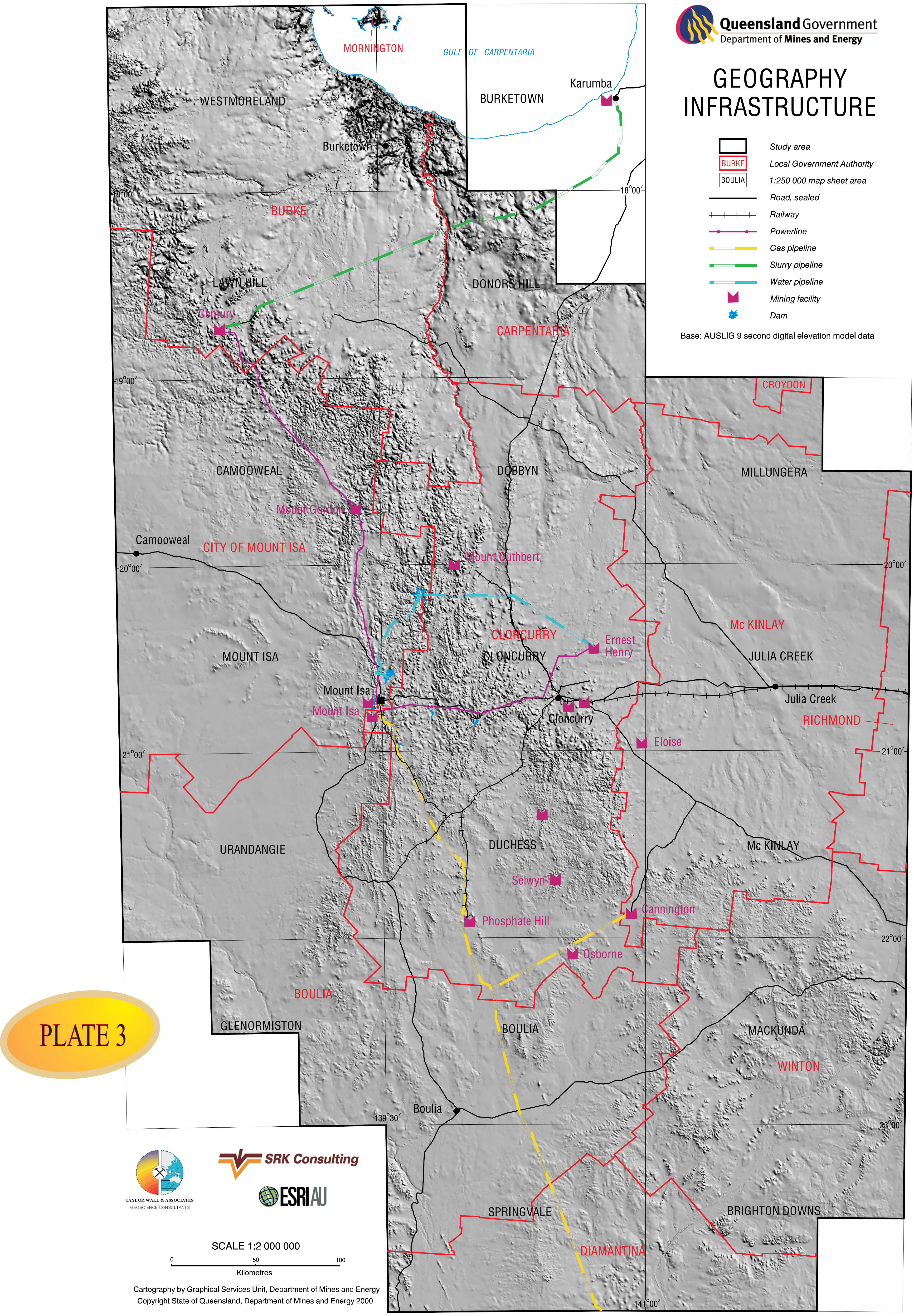
ESRI AU

SCALE 1:2 000 000

0 50 100
Kilometres

Cartography by Graphical Services Unit, Department of Mines and Energy

MAJOR INFRASTRUCTURE, QUEENSLAND


Queensland Government
Department of Mines and Energy
GEOGRAPHY
INFRASTRUCTURE
Study area
BURKE Local Government Authority
BOULIA 1:250 000 map sheet area
Road, sealed
Railway
Powerline
Gas pipeline
Slurry pipeline
Water pipeline
Mining facility
Dam
Base: AUSLIG 9 second digital elevation model data
MORNINGTON
GULF OF CARPENTARIA
WESTMORELAND
BURKETOWN
Karumba
Burketown
BURKE
LAWN HILL
DONORS HILL
Century
CARPENTARIA
CROYDON
CAMOOWEAL
DOBBYN
MILLUNGERA
Mount Gordon
Camooweal
CITY OF MOUNT ISA
Mount Cuthbert
Mc KINLAY
CLONCURRY
Ernest Henry
MOUNT ISA
JULIA CREEK
Mount Isa
Julia Creek
RICHMOND
Cloncurry
Eloise
URANDANGIE
DUCHESS
Mc KINLAY
Selwyn
Phosphate Hill
Cannington
Osborne
BOULIA
GLENORMISTON
BOULIA
MACKUNDA
WINTON
Boulia
SPRINGVALE
BRIGHTON DOWNS
DIAMANTINA
18°00′
19°00′
20°00′
21°00′
22°00′
23°00′
139°30′
141°00′
PLATE 3
TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS
SRK Consulting
ESRI AU
SCALE 1:2 000 000
0 50 100
Kilometres
Cartography by Graphical Services Unit, Department of Mines and Energy
Copyright State of Queensland, Department of Mines and Energy 2000

4. DATA COVERAGE AND SOURCES

4.1 OVERVIEW

Comprehensive, high quality data relevant to exploration in the region are available from various sources, in both hard copy and digital format, as detailed in Appendix 1 on the CD-ROM accompanying this report. Current prices for data products can be obtained from the listed data providers.

The data include topographic and geological maps, databases on mineral occurrences, geochronology and lithogeochemistry, summaries of geochemical and drillhole data, geophysical data from Government and company surveys, and maps showing the locations of historical exploration permits.

4.2 GEOLOGY

The North-west Queensland Mineral Province, because of its importance as a major base metals province, has long been the subject of regional and detailed geological studies by Government, universities and private industry. The wealth of geological data available includes:

- published and unpublished Government geological maps (and accompanying explanatory notes) at scales ranging from 1:2 500 000 to 1:100 000 (Plate 4),
- digital geological maps at scales ranging from 1:2 500 000 to 1:100 000,
- geochronological data,
- sequence stratigraphy mapping and fluid flow modelling,
- regolith studies, and
- mineral occurrence data bases.

4.3 GEOCHEMISTRY

Geochemical data available include whole rock, stream sediment, soil and rock chip geochemistry. Government data are available from the Australian Geological Survey Organisation. Company exploration data have been compiled by Terra Search Pty. Ltd. (Plate 5).

4.4 GEOPHYSICS

Geophysical data available (Plate 6) include:

- Government and company gravity surveys,
- Government and company aerial geophysical surveys (radiometrics, magnetics, electromagnetics),
- company ground geophysical surveys (magnetics, electromagnetics, electrical, radiometric), and
- Government and company seismic surveys.

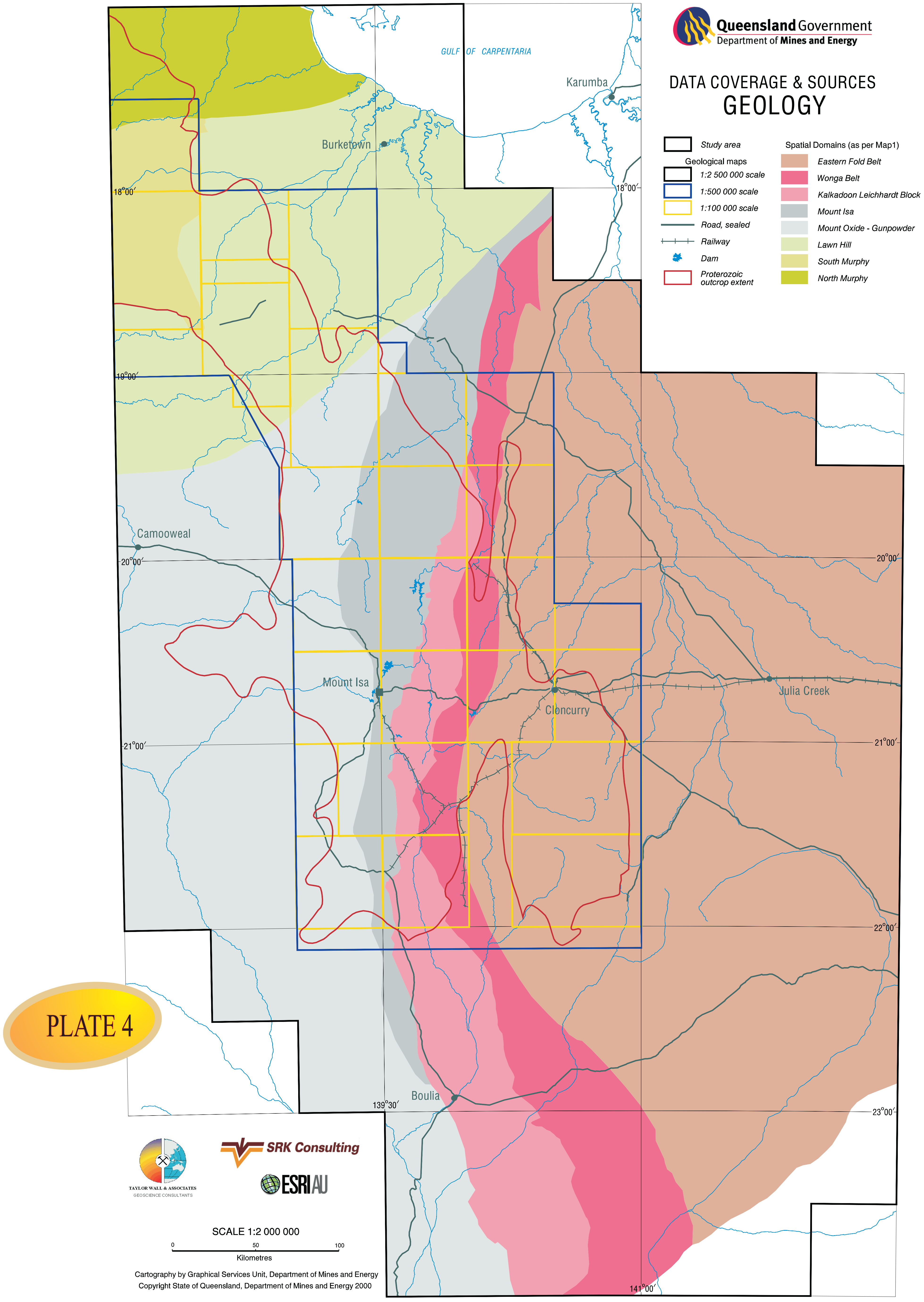
4.5 DRILLING

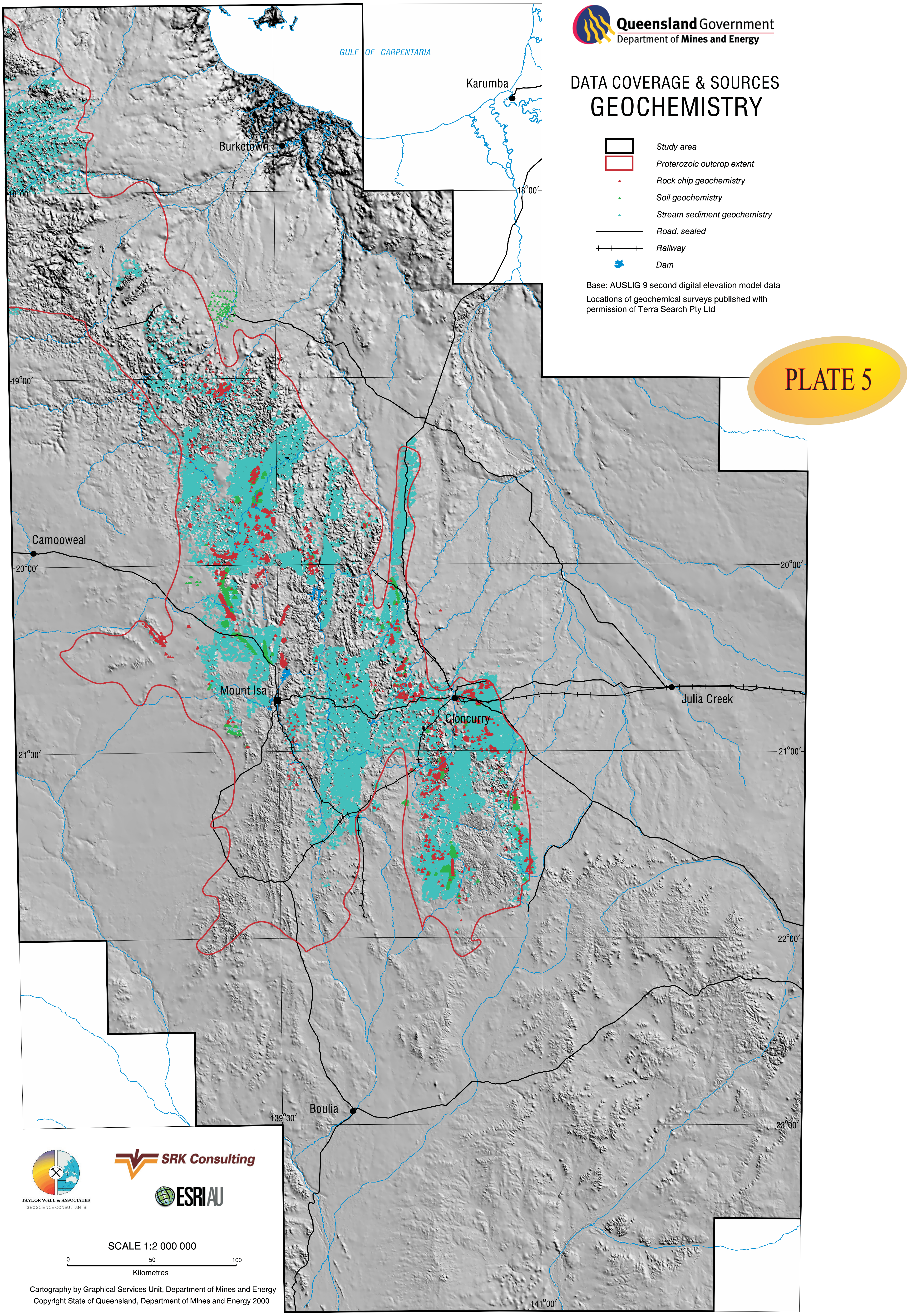
Numerous holes have been drilled in the study area for various purposes, including water bores, stratigraphic drillholes, petroleum exploration wells and mineral exploration drillholes (Plate 7). Digital data bases of these holes have been compiled by the Department of Mines and Energy, the Department of Natural Resources and Terra Search Pty. Ltd.

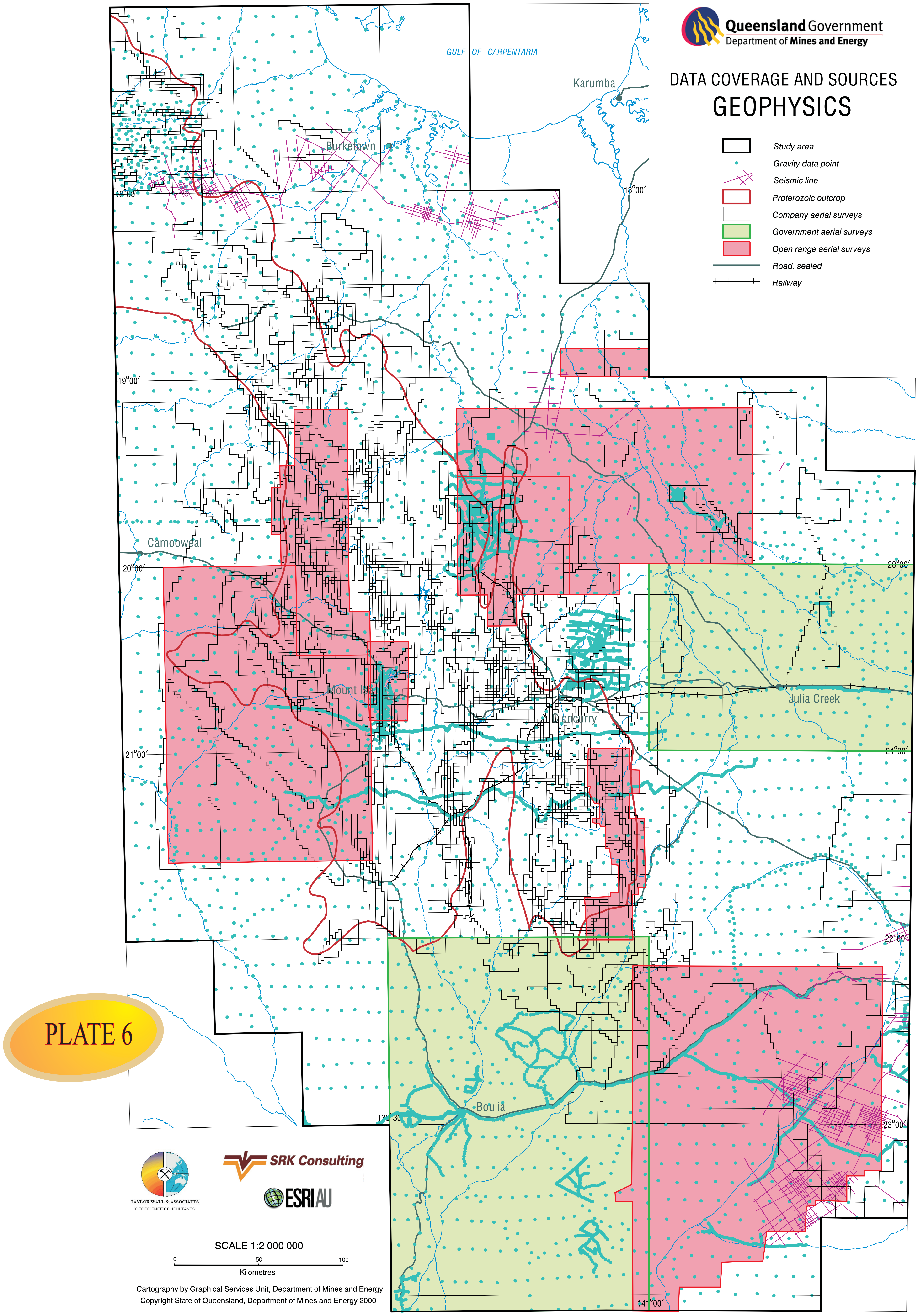
4.6 OPEN FILE REPORTS

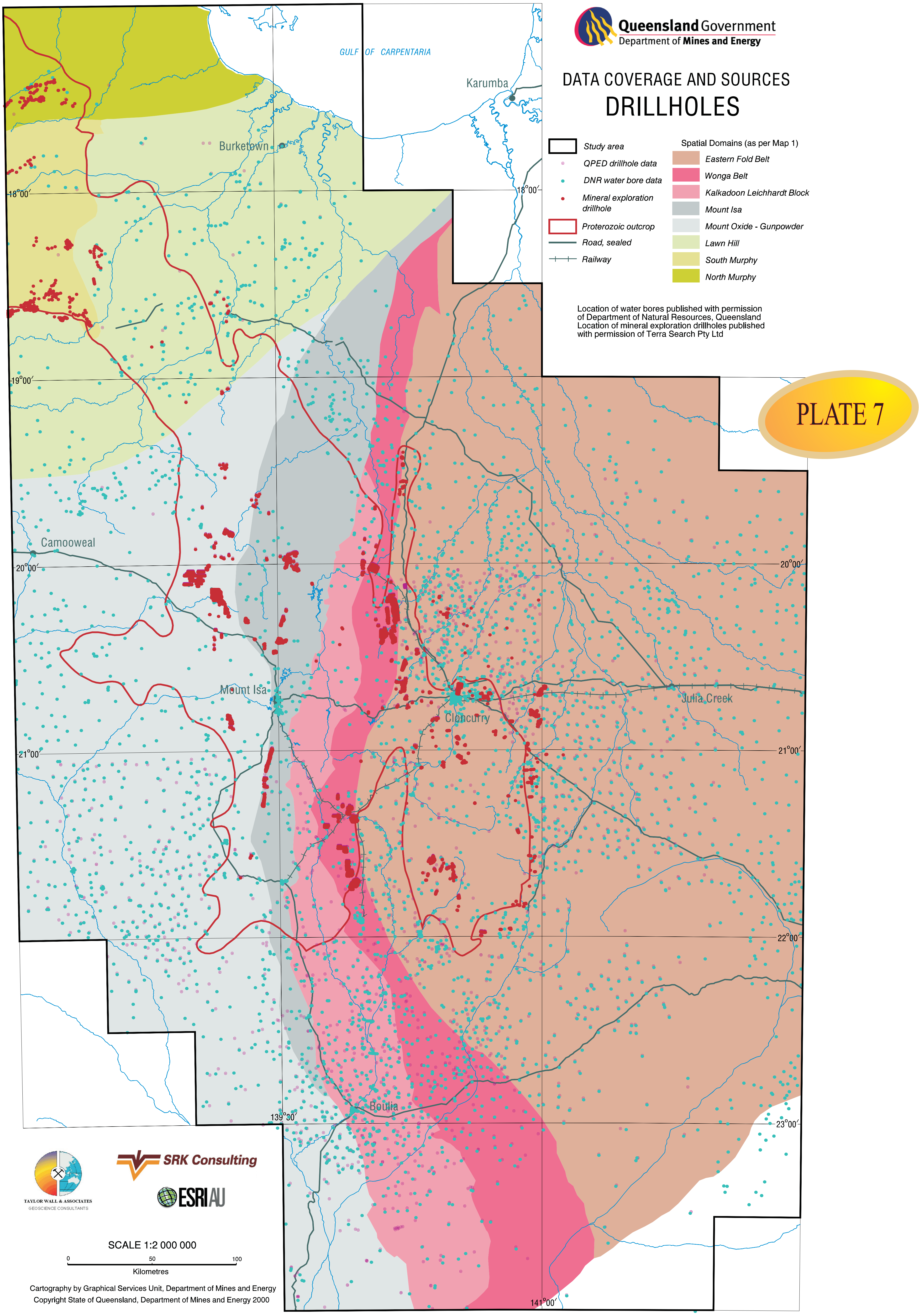
The Department of Mines and Energy, Queensland, maintains data bases of information relating to both historical and current exploration activity, including locations of exploration permits and mining tenures, summaries of exploration activity, and a comprehensive and fully indexed library of exploration reports.

Of particular interest to the exploration industry is the microfiche collection in the Department of Mines and Energy library of more than 31,000 open-file reports on exploration undertaken by companies in Queensland, dating back to the 1950s (Plate 8). In contrast to the situation in many other areas of significant exploration activity world wide, information on previous exploration in the North-west Queensland Mineral Province is well maintained, readily available and easily accessible.


Queensland Government
Department of Mines and Energy
DATA COVERAGE & SOURCES
GEOLOGY
Study area
Geological maps
1:2 500 000 scale
1:500 000 scale
1:100 000 scale
Road, sealed
Railway
Dam
Proterozoic outcrop extent
Spatial Domains (as per Map1)
Eastern Fold Belt
Wonga Belt
Kalkadoon Leichhardt Block
Mount Isa
Mount Oxide - Gunpowder
Lawn Hill
South Murphy
North Murphy
GULF OF CARPENTARIA
Karumba
Burketown
Camooweal
Mount Isa
Cloncurry
Julia Creek
Boulia
18°00′
19°00′
20°00′
21°00′
22°00′
23°00′
139°30′
141°00′
PLATE 4
TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS
SRK Consulting
ESRI AU
SCALE 1:2 000 000
0
50
100
Kilometres
Cartography by Graphical Services Unit, Department of Mines and Energy
Copyright State of Queensland, Department of Mines and Energy 2000


Queensland Government
Department of Mines and Energy
DATA COVERAGE & SOURCES
GEOCHEMISTRY
Study area
Proterozoic outcrop extent
Rock chip geochemistry
Soil geochemistry
Stream sediment geochemistry
Road, sealed
Railway
Dam
Base: AUSLIG 9 second digital elevation model data
Locations of geochemical surveys published with permission of Terra Search Pty Ltd
PLATE 5
GULF OF CARPENTARIA
Karumba
Burketown
Camooweal
Mount Isa
Cloncurry
Julia Creek
Boulia
18°00′
19°00′
20°00′
21°00′
22°00′
23°00′
139°30′
141°00′
TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS
SRK Consulting
ESRI AU
SCALE 1:2 000 000
0
50
100
Kilometres
Cartography by Graphical Services Unit, Department of Mines and Energy
Copyright State of Queensland, Department of Mines and Energy 2000


Queensland Government
Department of Mines and Energy
DATA COVERAGE AND SOURCES
GEOPHYSICS
Study area
Gravity data point
Seismic line
Proterozoic outcrop
Company aerial surveys
Government aerial surveys
Open range aerial surveys
Road, sealed
Railway
GULF OF CARPENTARIA
Karumba
Burketown
Camooweal
Mount Isa
Cloncurry
Julia Creek
Boulia
18°00′
19°00′
20°00′
21°00′
22°00′
23°00′
141°00′
PLATE 6
TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS
SRK Consulting
ESRI AU
SCALE 1:2 000 000
0
50
100
Kilometres
Cartography by Graphical Services Unit, Department of Mines and Energy
Copyright State of Queensland, Department of Mines and Energy 2000



Queensland Government
Department of Mines and Energy
DATA COVERAGE AND SOURCES
DRILLHOLES
Study area
QPED drillhole data
DNR water bore data
Mineral exploration drillhole
Proterozoic outcrop
Road, sealed
Railway
Spatial Domains (as per Map 1)
Eastern Fold Belt
Wonga Belt
Kalkadoon Leichhardt Block
Mount Isa
Mount Oxide - Gunpowder
Lawn Hill
South Murphy
North Murphy
Location of water bores published with permission of Department of Natural Resources, Queensland
Location of mineral exploration drillholes published with permission of Terra Search Pty Ltd
PLATE 7
GULF OF CARPENTARIA
Karumba
Burketown
Camooweal
Mount Isa
Cloncurry
Julia Creek
Boulia
18°00′
19°00′
20°00′
21°00′
22°00′
23°00′
139°30′
141°00′
TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS
SRK Consulting
ESRI AU
SCALE 1:2 000 000
0
50
100
Kilometres
Cartography by Graphical Services Unit, Department of Mines and Energy
Copyright State of Queensland, Department of Mines and Energy 2000

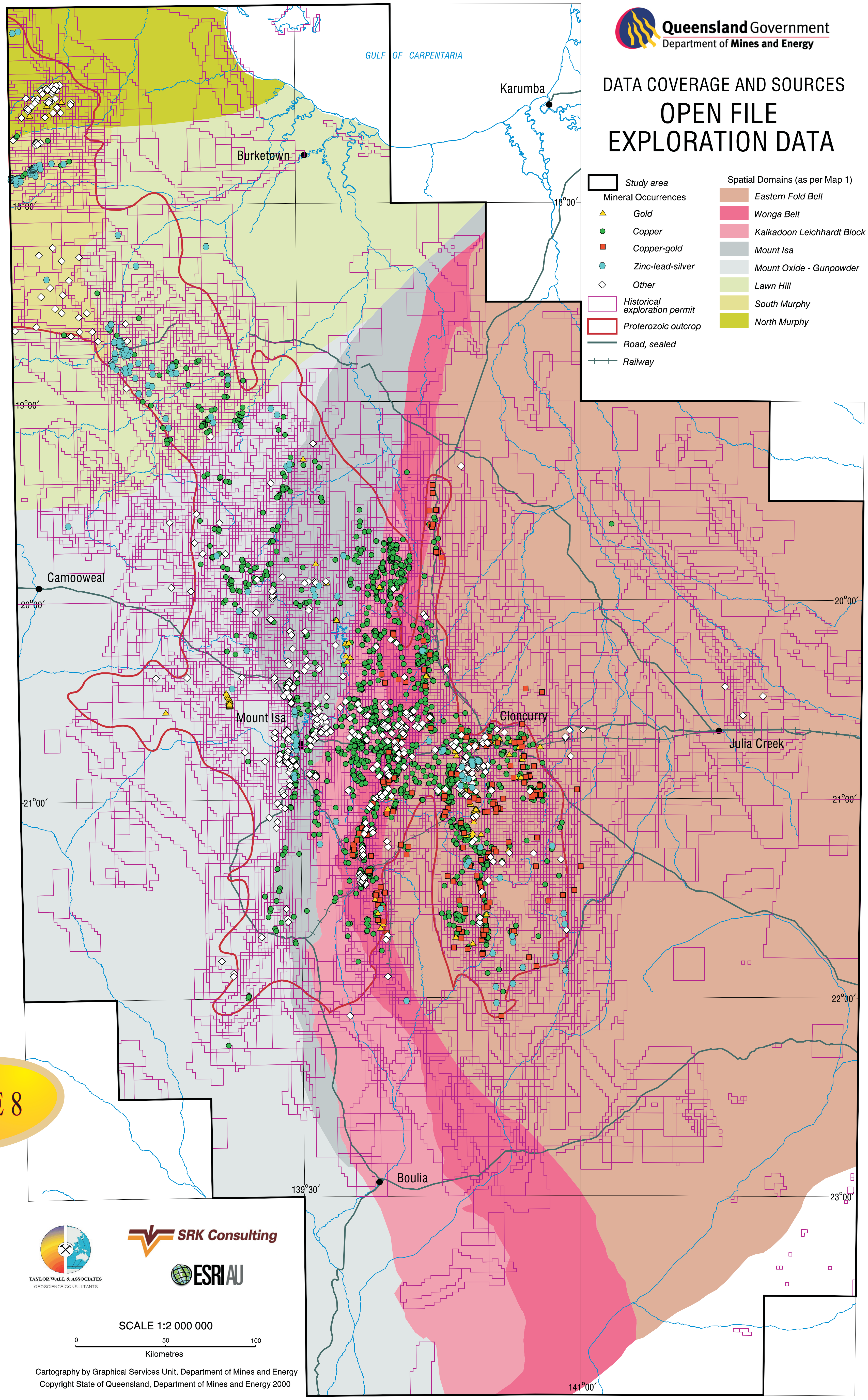

Queensland Government
Department of Mines and Energy
DATA COVERAGE AND SOURCES
OPEN FILE
EXPLORATION DATA
Study area
Mineral Occurrences
Gold
Copper
Copper-gold
Zinc-lead-silver
Other
Historical exploration permit
Proterozoic outcrop
Road, sealed
Railway
Spatial Domains (as per Map 1)
Eastern Fold Belt
Wonga Belt
Kalkadoon Leichhardt Block
Mount Isa
Mount Oxide - Gunpowder
Lawn Hill
South Murphy
North Murphy
GULF OF CARPENTARIA
Karumba
Burketown
18°00′
19°00′
Camooweal
20°00′
Mount Isa
Cloncurry
Julia Creek
21°00′
22°00′
Boulia
139°30′
23°00′
141°00′
TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS
SRK Consulting
ESRI AU
SCALE 1:2 000 000
0
50
100
Kilometres
Cartography by Graphical Services Unit, Department of Mines and Energy
Copyright State of Queensland, Department of Mines and Energy 2000

PLATE 8

5. GEOLOGY

5.1 INTRODUCTION

The core of this study has been a complete, four-dimensional re-interpretation of the geology of the North-west Queensland Mineral Province. The focus has understandably been on the richly endowed Proterozoic basement, but the Phanerozoic geology and mineral potential have also been summarised.

The geological outcomes of the study are presented in three main digital and hard copy products that are outlined and illustrated in this chapter in the following order.

- **A Time-Space Framework Chart.** The chart provides a comprehensive overview of the tectonostratigraphic evolution of the region, divided into eight major spatial domains, plus four neighbouring provinces (Davenport, Tennant Creek, southern McArthur and Georgetown). The chart includes sequence stratigraphy, litho-stratigraphy, basin forming/inversion and deformation/metamorphic events, with kinematics, intrusive events and mineralising events, all fully correlated across the Province. Lithostratigraphic units in each spatial domain are colour-coded by dominant rock-type. It also includes all of the isotopic ages and palaeomagnetic data that were used in building the sequences, correlations and event history.

- **A 1: 250 000 Proterozoic Solid Geology Map.** The geology was completely reinterpreted on the basis of the sequence stratigraphic and tectonic event framework that emerged from the construction of the above Time-Space Chart. A Proterozoic solid geology map was compiled for the exposed and covered parts of the region at 1:250 000 scale, based on existing geological maps and the comprehensive open file magnetic and gravity datasets. Most importantly, the interpretation had access for the first time in the public domain to the spectacular, high-resolution airborne magnetic and radiometric survey owned by MIM Holdings Ltd. The digital map includes attribution of all polygons by both sequence stratigraphy and dominant lithology, and of all structures by initial age/kinematics and reactivation ages/kinematics. In addition, map layers have been compiled showing the extent and thickness of major elements of the Phanerozoic cover.

- **A Tectonic and Structural Framework.** The framework is presented as a series of structural event maps compiled at 1:1 000 000 scale and a comprehensive text table. The maps and table provide a more dynamic view of the structural evolution of the region, and link the tectonic and structural history to that of the principal mineralising episodes.

This chapter does not include a comprehensive text description of the geology and evolution of the North-west Queensland Mineral Province. As the report and the digital product rely heavily on interactive visual products, it was decided not to include what would be essentially a synthesis of a widely published and readily available body of work. Instead, each section focuses on the key outcomes of the study, and Section 5.3 (Proterozoic Geology) includes a selective but comprehensive bibliographic guide to the major published works on the principal aspects of the geology and mineralisation.

5.2 TIME SPACE FRAMEWORK

Methodology and Approach

The Proterozoic Time Space 'Event Stratigraphy' chart (Map 1) is a state-of-the-art compilation of all tectono-stratigraphic relationships and sequence correlations in the North-west Queensland Mineral Province, placed within a tectonic, 'event stratigraphic' framework for the period 1900Ma–1500Ma. It highlights the obvious (to quite obscure) basin phases and the significant tectonic events that separate them. The generally familiar and, more importantly, accurately mapped (at 1:100 000 and 1:250 000 scale), lithostratigraphic units are cast within the NABRE sequence stratigraphic framework for the period 1700Ma–1590Ma (Southgate & others, 2000). For sequences outside this period, more traditional sequence terminology from the literature is used.

The chart includes, for comparison, relationships within adjacent, tectonically-linked terrains: to the west, the Tennant Creek-Davenport Provinces; to the north, the Southern McArthur Province; and to the east, the Georgetown Province. It incorporates, as far as possible, all recent (published and unpublished) geochronology, Australian Polar Wander Path (APWP) correlation and fluid overprint information, NABRE sequence stratigraphic relationships, as well as speculations of the Northern Territory Geological Survey and the current study's authors about sequence correlations. All detailed correlation relationships and the broad geometries and kinematics of tectonic events active during sequence accumulation, inversion and deformation are explicitly presented on the chart.

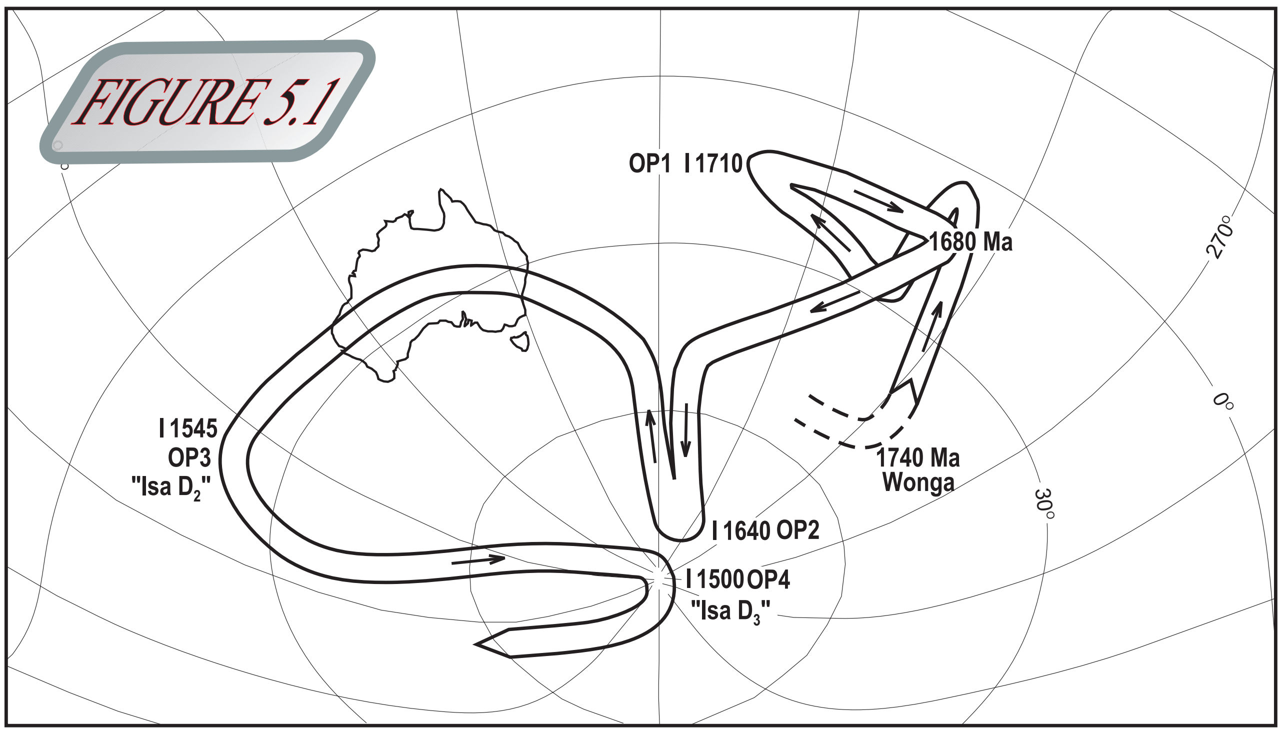
Key datasets and data sources incorporated into the Event Stratigraphy chart are:

- **NABRE Sequence Stratigraphy**

  Numerous discussions with Peter Southgate, Deb Scott and other NABRE team members have greatly helped in the assimilation of the vast volumes of detailed sequence relationships presented in the NABRE studies. These have largely been replicated on the chart within the Western Succession for the period 1700Ma–1590Ma. Key reference sources include: Australian Journal of Earth Sciences, volume 47(3), June, 2000; AGSO Records 1999/10, 1999/15, 1999/19, 1999/27; Scott & others (1998).

- **Australian Polar Wander Path (APWP) Palaeomagnetics**

  The Proterozoic APWP for Northern Australia (**Figure 5.1**) is very well defined for the interval 1740Ma–1640Ma, whereas the succeeding 1640–1500Ma period is understood in broad terms only. It is characterised by a series of Inflection points ('hairpins' and 'cusps', for example, **I1650**, **I1710**…). Because the Australian Proterozoic APWP represents the 'drift' of the entire Proterozoic continent, these inflections represent significant **inter**-plate (outside or marginal to the plate) interactions that can reasonably be assumed to result in significant **intra**-plate (within the plate) deformation or tectonic re-adjustment (Loutit & others, 1994). These events have been highlighted on the chart



Australian Proterozoic Apparent Palaeomagnetic Wander Path, showing Inflection Events (I) and Overprint (OP) clusters, as on the Event Stratigraphy Chart. (after Idnurm & Giddings,1988; Idnurm & others, 1995; Idnurm, 2000)

and are expressed either as:
(a) sequence stratigraphic events within accumulating sequences, (b) inversions or moderate deformation of basin successions, or (c) major orogenies of regions or entire terrains.

Major palaeomagnetic resetting or overprinting episodes (for example, **OP1**, **OP2**…), coincident with some APWP Inflection events, suggest major fluid flux events that have also been implicated in particular base metal mineralisation episodes. Stimulating discussions with Mart Idnurm have sharpened our understanding of the Proterozoic APWP, in particular the indirect and non-intuitive relationships between APWP Inflections and tectonic geometries and kinematics. Key references are: Idnurm & Giddings (1988); Idnurm & others (1995); Idnurm (2000); Loutit & others (1994).

- **Geochronology**

AGSO's OZCHRON (release 2) has provided a comprehensive compilation of published geochronology that has been directly incorporated into the Event Stratigraphic chart. Further details (for example, error bars, sample site, analysis technique) for geochronologic information on the chart can largely be found in OZCHRON.

Some more recent geochronology, possibly not yet incorporated into OZCHRON, can be found in NABRE publications. Direct discussions with Rod Page have clarified the significance of some of the geochronology. Isotopic dating of the Eastern Succession Cu-Au mineralisation and associated metasomatism have come direct from the literature. Key resources in the construction of the chart have been: AGSO's OZCHRON (release 2) database; Page & Laing (1992); Page & Sweet (1998); Page & Sun (1998); Page & others (2000); Perkins & Wyborn (1998).

- **Lead Isotope Model Ages**

Model ages for the formation of the Zn-Pb-Ag deposits have come exclusively from the works of Graham Carr (CSIRO) and Shen-Su Sun (ex AGSO). Numerous discussions with them have clarified the mixing options in the more complex lead systems in some of the region's base metal deposits which have been presented on the chart. Key references include Sun & others (1994) and Sun & others (1996).

Event Stratigraphy – Key Outcomes

The Event Stratigraphy Chart (Map 1) presents a comprehensive Time-Space analysis of the study region for the period 1900Ma–1500Ma and contains a number of new and important regional relationships that have been highlighted in this analysis. Some are briefly discussed below.

- **The Cover Sequence 2 volcanic-clastic pile accumulated within an extensive continental rift setting of ~NE-SW extension.** Continental volcanics and clastics have been chronologically correlated across the region and into adjacent regions during the period 1800Ma–1760Ma. The landmark studies of Stewart (1987) in the Davenport Province and recent interpretation in the study area (Map 4) support the suggested tectonic setting of this package. Regional variations in the total thicknesses and packaging of sequences in the North-west Queensland Mineral Province also conform with this architecture.

- **The establishment of a radically different N to NNW extensional architectures in the mineralisation-rich, younger sequences appears to have subtly initiated at ~1755Ma and became well established in the 1740Ma 'Wonga' event.** The ~1755Ma 'Pre-Wonga' event is evidenced by NNW extensional breakup of the Marraba Volcanics and wedged accumulation within the Mitakoodi Quartzite in the Mitakoodi Culmination (Potma, 1995). These relationships may necessitate some re-evaluation of the traditional Quilalar-Ballara-Corella-Doherty Cover Sequence 2 **sag** interpretation as these sequences may well have deposited within a newly establishing NNW extensional regime.

- **Significant ~N-S 'Wonga' extension in the Western Succession completely post-dated Cover Sequence 2 volcanics, Myally Subgroup and probably also the Quilalar Formation.** Regional large scale block tilting demonstrably affected this pile although the Quilalar Formation may, in part, have been deposited within an initiating NNW extensional regime. **Deeper levels of exposure in the Eastern Succession reveal a folded, but regionally, gently west-dipping and ramping, 'Wonga' detachment that has associated with it the syn-tectonic, bi-modal, Wonga-Burstall suite of intrusives** (Holcombe & others, 1992; Passchier, 1986). The detachment gently ramped upwards from east to west through upper Argylla Formation, Ballara Quartzite and into basal Corella Formation. Core complexes with high thermal inputs into the upper crust associated with this extensional detachment event initiated a period of uplift and probable non-deposition in the Eastern Successsion at this time. Tick Hill Au is intimately associated with this detachment-related, Wonga-Burstall suite of syn-tectonic intrusives.

- **In the Western Succession, 'Wonga' extension was followed by a complex period of deformation** (see APWP 1730–1710Ma; Figure 5.1) **that included an enigmatic transpressive, constrictional event at around 1710Ma.** Both the strength and regional extent of this shortening are controversial. However, the following relationships suggest that its overall importance to the region's tectonic evolution and mineralisation potential may have been seriously underestimated:

  - Angular unconformities beneath the Surprise Creek Formation and PRIZE Supersequence equivalents (Mount Oxide West, 306510E/7850150N; Mount Oxide North-east, 349660E/7868140N; Mellish Park Syncline, 309740E/7882960N, Betts, 1999; Paroo Range, 347190E/ 7737610N; Ardmore South-east, 344980E/7582940N); unconformable to disconformable relationships within the BIG Supersequence, and widespread transpressive reverse faulting of Cover Sequence 2 sequences with significant reverse structures terminating beneath the Surprise Creek (PRIZE Supersequence) unconformity (Ardmore South-east, 344980E/7582940N; Isa North-east, 349410E/7717390N; Paroo Range, 347190E/7737610N, Nijman & others, 1992b; Crystal Creek Block, 341790E/7790320N; Mount Oxide North-east, 349660E/7868140N; Mellish Park Syncline, 309740E/ 7882960N), suggest significant (transpressive) shortening around 1725Ma–1705Ma prior to PRIZE Supersequence deposition.

    This event is also highlighted by a pre-PRIZE Supersequence, dolerite dyke phase that exploits 1710Ma shortening structures in the Cover Sequence 2 volcanic, Myally Subgroup, and Quilalar Formation pile, within the mapped Leichhardt River Fault Trough and interpreted within the southern Lawn Hill region.

  - Topography resulting from 'Wonga' block-tilting and 1710Ma transpressive shortening is interpreted to control the depocentres of PRIZE Supersequence accumulation. If these sequences are one of the important brine aquifer facies during Isa-Century style Zn-Pb-Ag deposit formation, the 1710Ma structures clearly play a critical fluid focus role.

    The normal re-activation of particular 1710Ma reverse structures have also been interpreted, in the current study, to have played critical facies-control roles during Isa Superbasin accumulation in the Western Succession. Examples include the Mount Gordon Fault zone, which is interpreted to be a major facies divide during GUN Supersequence times (Southgate & others, 2000) and, speculatively, the Paroo-proto Mount Isa Fault zone during GUN deposition.

In addition, reverse 1710Ma structures and 'Wonga' normal faults were both reactivated normally at 1640Ma to produce the outcrop pattern of PRIZE-GUN Supersequences 'windows' within an extensive Cover Sequence 2 volcanic-Myally Subgroup pile along the Leichhardt River Fault Trough (Crystal Creek and Paroo Range) and Isa Valley regions. The 1640Ma transtensional re-activation of 1710Ma Paroo and proto Mount Isa Faults are suggested to have produced the Isa Group-basement fault relationships in the Isa Mine. (see Table 5.1).

- **PRIZE Supersequence clastic accumulation in the Western Succession appears to be a direct response to the 1710Ma inversion** (see above). It is also possible that the pre-1675Ma clastic successions in the Eastern Succession (Soldiers Cap 1) may have been deposited in response to more regional 1710Ma inversion (which remains largely unresolved), with significant rift re-activation later at 1675Ma.

- **At 1675Ma, significant tectono-stratigraphic differences existed between the Eastern and Western Successions. In the East, strong rift re-activation, within a NNW extensional regime, drove a clastic re-activation with significant bi-modal magmatic input.** *Cannington-style Ag-Pb-Zn* systems formed during this hot, rift re-activation event. **In the West, the same ~1675Ma NNW-extension focused the Sybella batholith system. It was associated with a considerable period of thermal uplift, during which, apart from minor felsic extrusion, no sedimentary accumulation occurred.** This period of non-accumulation in the West was sustained until the thermal decay of the Sybella system has run its course.

- The subsequent thermal sag is expressed very differently in the Eastern and Western Successions. **In the Eastern Succession, there was a long period (~1660Ma–1600Ma) of deep water, largely shale-facies accumulation** (Soldiers Cap 4) **while, in the Western Succession, a complex carbonate system formed in the post-1675Ma decay period, with accumulation initiating ~1690Ma.**

This carbonate system comprised both platform and slope facies with considerable basement-template tectonic control. The platform systems reached widespread sulphate-saturation to provide a source of sulphate, either directly from basinal fluids or from evaporite facies in the carbonate pile. This sulphate was a critical component of subsequent *Isa-Century style Zn-Pb-Ag* mineralizing systems.

- **In the Western Succession, this sustained period** (~1690Ma to 1600Ma) **of carbonate systems was punctuated by a number re-activations and minor inversions (I1650, I1640, D1620, Isan D_1) that re-configured the depositional system and were implicated in fluid flow events that formed the *Isa-Century style Zn-Pb-Ag* deposits.**

Depositional architectures and re-activation geometries were strongly influenced by a complex, pre-1680Ma, tectonic template (Map 4). This template plays a critical targeting role for *Isa-Century style Zn-Pb-Ag* systems and is, similarly, expected to play a critical role in the localization of *Cannington-style Ag-Pb-Zn* systems in the Eastern Succession.

However, its definition in the East is considerably more difficult due to the stronger expression of Isan inversion and the lack of facies expression in the sustained deep water sag facies (Soldiers Cap 4). These Western Succession re-activation events may be expressed in the Eastern Succession as minor clastic re-activations within the overall sag basin (for example, Tommy Creek beds).

- **Isan D_1 deformation clearly closed the depositional cycle in the Western Succession**, with changed sediment provenances becoming evident in late WIDE Supersequence times. Isan D_1 closure in the Eastern Succession, although probable, is not so clear. In the West, the South Nicholson Group accumulated in a D_1 foreland setting with unconformable relationships with D_1-folded, TERM, LAWN and WIDE Supersequences but was folded itself by ongoing D_1.

- **The Isan D_1 foreland setting of the Roper Group in the McArthur Basin, as a correlative of the South Nicholson Group, is controversial**. A post-Isan Orogeny, unpublished zircon age (~1485Ma; Rod Page, 1998) in the Mainoru Formation of the Roper Group is at odds with this foreland setting hypothesis.

However, (a) a very similar lithostratigraphy to the South Nicholson Group; (b) widespread APWP Isan D_3, **I1500-OP4** overprint effects in the Roper Group (Mart Idnurm, personal comment, 1999) and (c) the lack of a regional unconformity at the base of the Roper Group between the WIDE and DOOM Supersequences in the McArthur Basin (as would be expected had the Isan Orogeny intervened), all favour a South Nicholson–Roper Group correlation and their synchronous, Isan D_1, foreland accumulation as depicted on the chart.

5.3 PROTEROZOIC GEOLOGY

Methodology and Approach

The core of the North-west Queensland Mineral Province product is the new interpretation of the solid geology at 1:250 000 scale. This includes the areas under Phanerozoic cover as well as the outcropping Mount Isa Inlier, and is based on an integrated interpretation of the following key datasets.

- The published geology from a range of sources, but particularly from the government 1:100 000 map series and the recent sequence stratigraphic maps from the Australian Geological Survey Organisation's North Australian Basins Resource Evaluation (NABRE) project.
- A 200m grid stitch of all the key open file magnetic data, compiled by Geoimage Pty Ltd. The data in this stitch ranged in resolution from 200m line spacing to 1 500m line spacing, and approximately half of the area is covered by data flown at line spacings of 400m. The metadata for the magnetic surveys in this stitch are provided in the digital product. Image processing of this grid was undertaken by project staff and by Encom Technology Pty Ltd.
- Regional high resolution aeromagnetic and radiometric survey data acquired and owned by MIM Holdings Ltd and grided at 50m. This dataset is not included in the product.
- The gravity database compiled by DME from DME and AGSO data, which has a station spacing ranging from about 5–10km, with limited higher resolution profiles.

The polygons/rock units displayed on the digital map, that appears in the standard digital view and the 1:1 000 000 scale hard copy map, are the sequence time slices shown on the Time-Space Chart. For the period 1720–1590Ma, these are based on the NABRE sequence stratigraphy in the western part of the area (Southgate & others, 2000).

Correlative sequences have been interpreted in the remainder of the area. The polygons are also attributed with, and can be displayed by, principal rock type.

All geological structures have been attributed with the following:

- initiation age/event,
- kinematic geometric classification (that is, normal, right-lateral strike-slip, etcetera) at initiation,
- significant reactivation events, and
- kinematics for each reactivation event.

The western and eastern parts of the area, referred to herein as the Western and

Eastern Successions) and separated approximately along the Wonga Belt, were interpreted by separate teams. As the geology of the two parts is sufficiently different, particularly in terms of deformation intensity, metamorphic grade and intrusive history, separate teams with the most appropriate skill balance were justified.

- The western team, requiring strong tectonic, stratigraphic and basin analysis skills, and detailed knowledge of Mount Isa-style Ag-Pb-Zn and Cu mineralisation, comprised Mark Hinman (TWA/Hinman GeoSOLUTIONS) and Laurie Hutton (DME), with input from Vic Wall (TWA).

- The eastern team, requiring an emphasis on structural and metamorphic skills, and knowledge of iron-oxide Cu-Au and Cannington-style Ag-Pb-Zn mineralisation, comprised Roland Bartsch (SRK/Bartsch Geoscience) and Paul Donchak (DME), with input from Mike Etheridge (SRK).

This approach has led to some difference in the style of interpretation from west to east that is apparent in the maps. However, this style difference does reflect real differences in the geological patterns, and every effort has been made to ensure that there is an underlying consistency of stratigraphic, structural and event interpretation across the province. In particular, sequence stratigraphic correlations and attribution of the major structures were widely discussed and debated.

Key Bibliographic References

The emphasis of this product is on new knowledge and adding value to mineral exploration, and on highly visual products that can be interrogated in the digital GIS environment. As a result, it does not include a systematic, detailed description of all facets of the geology of the North-west Queensland Mineral Province. There are a number of excellent publications from government, research and industry geoscientists that provide comprehensive coverage of most aspects of the geology and evolution of the province.

The following publications are recommended for newcomers to the region and to refresh those who need an update:

- **Overall description of Proterozoic geology** – Blake (1987); Blake & others (1990); Stewart & Blake (1992);

- **1:100 000 scale geological maps and explanatory notes** – Alsace (Derrick & Wilson, 1982); Ardmore (Bultitude, 1982); Cloncurry (Ryburn & others, 1983); Coolullah (Wilson & Grimes, 1986); Dajarra (Blake & others, 1982); Duchess Region (Bultitude & others, 1982); Hedleys Creek (Sweet & others, 1981); Kennedy Gap (Wilson & others, 1979a); Kuridala Region (Donchak & others, 1983); Lawn Hill Region (Sweet & Hutton, 1982); Mammoth Mines Region (Hutton & Wilson, 1985); Marraba (Derrick, 1980); Mary Kathleen (Derrick & others, 1977); Mount Isa (Hill & others, 1975); Mount Oxide Region (Hutton & Wilson, 1984); Myally (Wilson & Grimes, 1984); Prospector (Wilson & others, 1977); Quamby (Wilson & others, 1979b); Selwyn Region (Blake & others, 1983);

- **Sequence stratigraphy and basin analysis** – Southgate & others (2000); Stewart & Blake (1992);

- **Geochronology** – Page & others (2000); Page & Sun (1998); Page & Sweet (1998); Perkins & Wyborn (1998);

- **Structure and metamorphism** – Drummond & others (1998); Etheridge & Wall (1994); Holcombe & others (1991); Laing (1998); O'Dea & others (1997); Pearson & others (1992); Scott & others (2000); Stewart & Blake (1992);

- **Igneous geology and geochemistry** – Wyborn (1998); Wyborn & others (1997);

- **Mineralisation** – Papers on individual deposits as listed in the References, plus other papers in the following recent publications:

Australian Journal of Earth Sciences, Volume 45(1), February 1998: Thematic Papers – Geology and mineralization in the Proterozoic 'Carpentaria Zinc Belt' of northern Australia,

Australian Journal of Earth Sciences, Volume 45(3), June 1998: Thematic Issue – Geological framework and mineralization in the Mt Isa Eastern Succession, north-west Queensland

Economic Geology, Volume 93(8), December 1998: A special issue on the McArthur River–Mount Isa–Cloncurry Minerals Province

Geology of Australian and Papua New Guinean Mineral Deposits. The Australasian Institute of Mining and Metallurgy, Monograph 22 (1998).

Proterozoic Geology – Key Outcomes

Construction of the 1:250 000 Proterozoic geology was by far the largest component of the study. It was considered to be an essential basis for systematic and reliable targeting and, most importantly, it enables the user to thoroughly evaluate the targeting criteria and target choices by providing a transparent and systematic basis for those choices. Because of the extensive mapping, research and exploration history in the region, the value added by this product is incremental in the outcropping areas, but is substantial in the covered areas where much of the discovery potential lies.

The following outcomes are considered to be the most significant, and to be of particular interest and potential value to the exploration industry:

- **The 1:250 000 Proterozoic geology is the first contiguous, four-dimensional solid geology interpretation of the outcropping and covered areas of this world-class mineral province**. It correlates stratigraphic sequences, unconformities, structural/tectonic events, igneous episodes and mineral-ising events and processes across a region of more than 290 000km^2. In particular, it provides the fundamental geological backdrop to reducing the inherent risk of targeting and exploring in the extensive and highly prospective covered parts of the Proterozoic.

- It extends the excellent work of AGSO's NABRE project (Southgate & others, 2000) in aggregating and correlating a complex and somewhat confusing lithostratigraphic framework and nomenclature into **a systematic set of time-stratigraphic sequences across the region, while retaining the essential lithological information**. In combination with the Time-Space Chart and the Tectonic and Structural Framework, it then provides a dynamic picture of the evolution of the North-west Queensland Mineral Province through a complex history of basin formation and inversion events.

- ·**It provides the first systematic, specific and detailed geological connection between the western and eastern parts of the province**. This is particularly so for the economically critical post-1700Ma period.

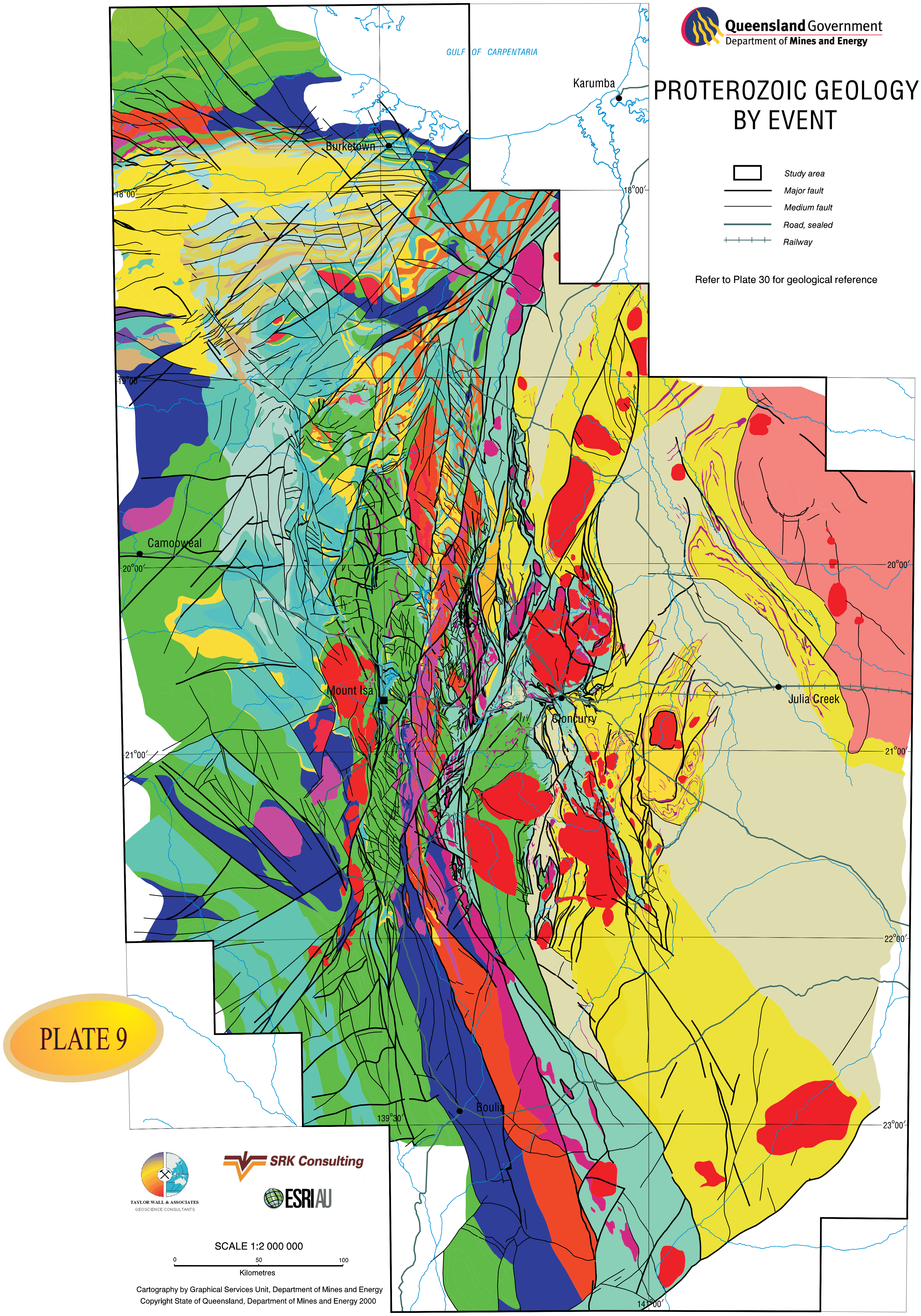
- **In the eastern part of the province, the solid geology provides, for the first time, an internally consistent interpretation of the sequence stratigraphy of the Soldiers Cap Group and correlatives**, which links the previously mapped outcropping areas with the extensive covered areas. Both Cannington and Broken Hill arguably occur at a specific level in the Cover Sequence 3 or equivalent tectonostratigraphy (that is, at or just above the break between syn-rift and post-rift). The map interprets the location of that boundary throughout the covered and outcropping areas, providing a key component for targeting Broken Hill-Cannington style Ag-Pb-Zn deposits.

- **In the western part of the province, a newly rationalized understanding of the tectonostratigraphic architectures and inversion architectures of the sequences that underlie the Isa Superbasin provide a tighter framework for targeting in the Isa Superbasin (Cover Sequence 3) sequences.** In particular, rock relationships (in part mapped in the 1:100 000 Geology map series) have been highlighted to emphasise the importance of a new transpressive constrictional event around 1710Ma which, coupled with the preceding 'Wonga'-aged extensional block tilting, both defines compartments and creates topography, which is filled by the sequences regarded as critical aquifer facies for later base metal mineralisation. This transpressive constrictional event at Big Supersequence times, which has been mapped and interpreted throughout the Western Succession in the current study, is consistent with previous observations below the Surprise Creek unconformity in the Paroo Range area by Nijman & others (1992), and relationships in the Mellish Park Syncline of Betts (1999), but conflicts with suggestions by O'Dea & others (1997).

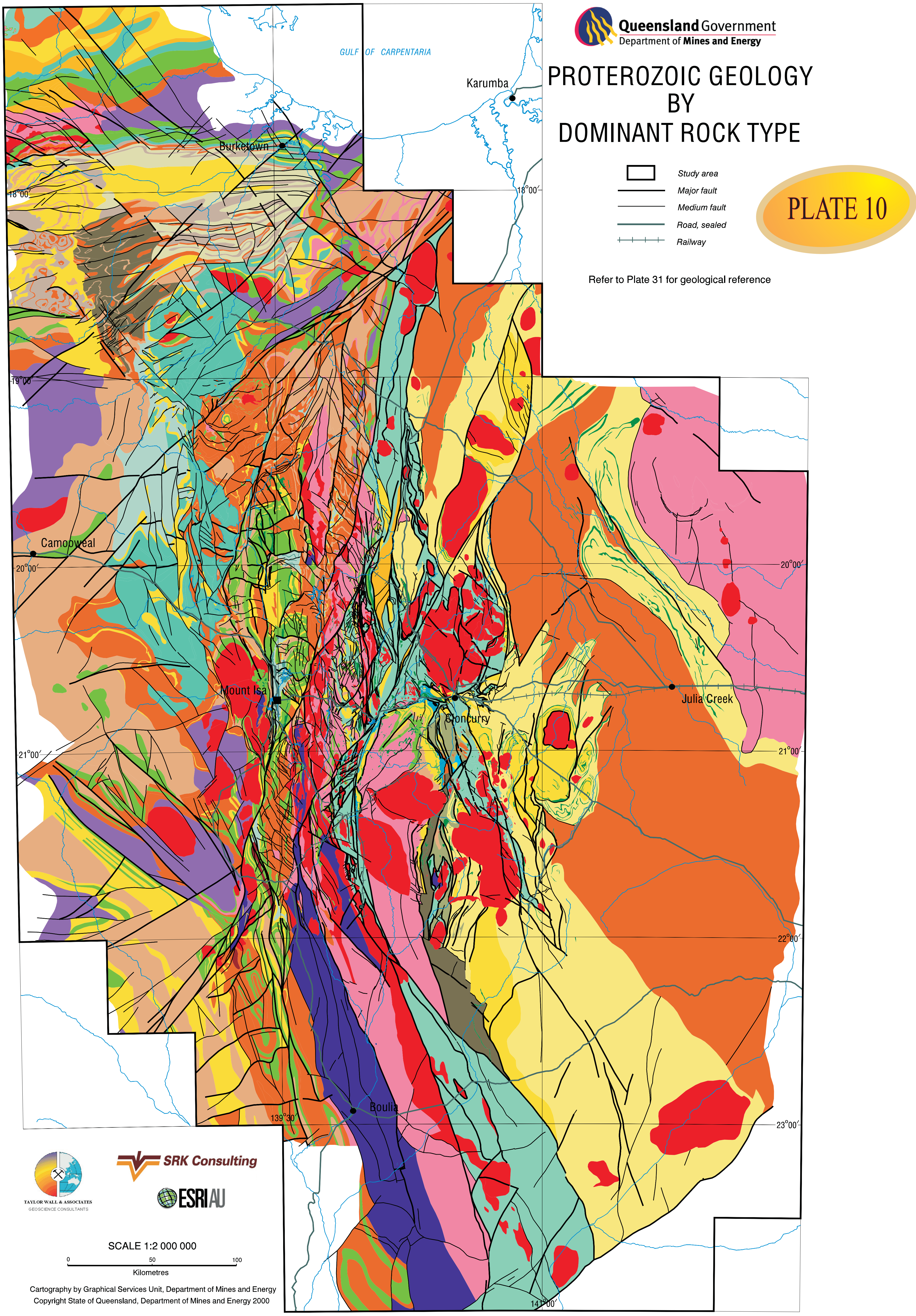
- In addition, in the western part of the province, an improved understanding of both the geometry and kinematics of structures active during Isa Superbasin deposition, in particular those at 1640Ma, has defined sidewall-accommodation and normal fault compartmentalisation of these sequences. These architectural elements are among the fundamental geometric controls on (1) the facies distribution of base metal host sequences, and (2) the synchronous or subsequent fluid flow focus that formed base metal deposits within the Isa Superbasin.

- **Virtually every mapped structure is attributed with its age, geometry and kinematics at initiation and throughout its reactivation history**. Therefore, the structural evolution of the area can be extracted and analysed, and cross-sections constructed that reflect the three-dimensional geometry and movements event by event. In this way, structural interactions and kinematics that may have influenced localisation of fluid flow and mineralisation can be extracted from the product. The structural complexity of the area, with grossly different kinematics during each of the significant events, means that it is very difficult to construct meaningful and accurate cross-sections. For this reason, a conscious decision was made in the study not to include regional cross-sections. However, users of this report should be able to construct local cross-sections that illustrate particular details of one or more structural events from the maps and digital data.

- **The solid geology includes interpretation from the geophysical data of buried felsic intrusives**. In the covered areas, this refers to intrusives that do not subcrop the base-Phanerozoic unconformity. Since a key targeting criterion for Cu-Au deposits is the roof zone of felsic intrusives of a particular suite/age, this information is of significant value to exploration and has been incorporated into target definition in this product.


Queensland Government
Department of Mines and Energy
PROTEROZOIC GEOLOGY BY EVENT
Study area
Major fault
Medium fault
Road, sealed
Railway
Refer to Plate 30 for geological reference
GULF OF CARPENTARIA
Karumba
Burketown
Camooweal
Mount Isa
Cloncurry
Julia Creek
Boulia
18°00′
19°00′
20°00′
21°00′
22°00′
23°00′
139°30′
141°00′
PLATE 9
TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS
SRK Consulting
ESRI AU
SCALE 1:2 000 000
0
50
100
Kilometres
Cartography by Graphical Services Unit, Department of Mines and Energy
Copyright State of Queensland, Department of Mines and Energy 2000

PROTEROZOIC GEOLOGY BY DOMINANT ROCK TYPE



5.4 PHANEROZOIC GEOLOGY

Neoproterozoic to Palaeozoic Events and Sequences

These rocks, ranging in age from Neoproterozoic to Devonian, include sequences in and overlying the Georgina Basin (also including outliers such as the Burke River Structural Belt and Kajabbi Formation). Key aspects of the depositional episodes, architecture, and tectonics are summarised in dot point form below.

Neoproterozoic to Palaeozoic Depositional Episodes

Neoproterozoic to Early Cambrian sedimentation

- The ages of units are poorly constrained.
- Sequences are part of the Centralian Superbasin, which covers much of Central Australia (Walter & others, 1995).
- Earliest sediments deposited as a uniform sheet of marine and fluvial sandstone overlain by carbonates, evaporites and fine siliclastics (Yakah beds ~800–750Ma).
- Sturtian glaciogene sediments (Yardida Tillite) occur in the Toko Syncline.
- Coarse arkose (Black Stump Arkose, Sun Hill Arkose) may be glacial outwash deposits related to a glaciation at about 600Ma.
- Glauconitic sandstone (Grant Bluff Formation) occurs in the Late Neoproterozoic.
- Marine sandstone and siltstone (upper Elkera Formation) mark a marine transgression near the end of the Proterozoic.
- Basalts (Colless Volcanics, Peaker Piker Volcanics) may be Neoproterozoic, or may be equivalents of the Early Cambrian Antrim Plateau Volcanics.
- Red sandstone, siltstone, shale and dolomite (Adam Shale, Red Heart Dolomite) are interpreted as Early Cambrian in age (Shergold & Druce, 1980). The Mount Birnie beds represent this episode in the Burke River Structural Belt.

Early to Middle Cambrian rift phase

- There was continental-scale north-west – south-east continental extension in the Early to Middle Cambrian (Shaw, 1991), with initiation of widespread sedimentation in the Georgina Basin.
- The Georgina Basin sequence contains coarse and fine grained clastic sediments, chert and some limestone, with local phosphatic and organic-rich sediments.
- The deposition of phosphates is related to gradual marine transgression of an irregular palaeotopography (Southgate, 1988).
- Deposition in the rift phase ceased with relative sea-level fall and the development of a subaerial exposure surface (Southgate & Shergold, 1991).

Middle Cambrian to Ordovician sag phase

- Middle to Late Cambrian carbonates make up most of the outcrop area of the Georgina Basin in the study area.
- Carbonates are deposited in intertidal and supratidal environments over a large area in north-west Queensland (Camooweal Dolomite, Thorntonia Limestone, Georgina Limestone).
- The Kajabbi Formation north of Cloncurry probably spans both the rift and sag phases in the Georgina Basin.
- The Ninmaroo Formation is a carbonate-dominated sequence deposited in two main areas of subsidence, the Burke River Structural Belt and the Toko Syncline. The Ninmaroo Formation defines the top of the Georgina Basin sequence in much of the study area. It is overlain by the Toko Group in the Toko Syncline (Shergold & Druce 1980).

Devonian sedimentation

- The Devonian Cravens Peak beds contain clasts from Neoproterozoic tillites and are considered coeval with the Alice Springs Orogeny.

Palaeozoic Tectonics

- The north-west – south-east extensional rifting phase in the late Early to early Middle Cambrian extension (Shaw, 1991) is coeval with the initiation of the Eastern Australian Tasmanides rift.
- Following this rift event, sedimentation occurred on a broad, stable, intertidal to supratidal platform characterised by local downwarps with thicker sediment accumulation.
- This sag phase in the Georgina Basin is broadly coeval with the convergent phase of the Delamerian Orogeny in the Adelaide Geosyncline to the south and Arunta Complex to the south-west.
- The Cravens Peak beds are broadly coeval with the Alice Springs Orogeny in Central Australia.

Mesozoic Events and Sequences

The Mesozoic rocks include rocks assigned to the Carpentaria and northern Eromanga Basins as well as Mesozoic sedimentary rocks forming outliers on the Precambrian and Palaeozoic basement. Ages range from Triassic (some sequences may extend back into the Middle Triassic) to the early part of the Late Cretaceous (Cenomanian). Key aspects of the depositional episodes and tectonics are summarised in dot point form below.

Mesozoic Depositional Episodes

Pre-Jurassic

- The earliest sedimentation in the northern Eromanga Basin (that is, Moolayember Formation, Warang Sandstone) is Middle Triassic and is part of the Galilee Basin Sequence (Green & others, 1992).
- Unnamed strata at the base of the sequence in the Canobie Depression (Boomarra Sub-Basin) are Middle Triassic red beds and conglomerate (McConachie & others, 1997).

Jurassic to Early Cretaceous

- Jurassic quartzose sandstone, siltstone and shale (Hutton Sandstone, Birkhead Formation, Adori Sandstone and Westbourne Formation) were intersected in EAL Cork 1 bore in the northern Eromanga Basin (Green & others, 1992).
- The Longsight Sandstone in the Glenormiston/Urandangi areas is in part equivalent to the Jurassic sequence in EAL Cork 1 (Green & others, 1992).
- A quartzose sandstone-dominated sequence (Eulo Queen Group) characterises the Jurassic in the Carpentaria Basin (McConachie & others, 1997).
- Glauconitic quartzose sandstone (Gilbert River Formation) marks the top of the quartz sand-dominated sequence in the Carpentaria Basin and in outliers overlying the Proterozoic sediments in the Mount Isa Inlier. The Mullaman beds are quartz-dominated sandstones overlying the rocks of the Mount Isa Inlier to the west.

Late Early Jurassic (Albian) Sequences

- The Rolling Downs Group (Wallumbilla Formation, Toolebuc Formation, Allaru Mudstone and Normanton Formation) is a siltstone/claystone dominated sedimentary sequence in the Carpentaria Basin formed during a marine transgression.
- A similar sequence is present in the Eromanga Basin with the Mackunda and Winton Formations equivalent to the Normanton Formation in the Carpentaria Basin.
- The Normanton Formation and Mackunda/Winton Formations mark the end of Mesozoic sedimentation in the Carpentaria and northern Eromanga Basins during the Cenomanian.

Mesozoic Tectonics

- Jurassic quartz-dominated sediments are deposited in fault-controlled basins.

- A regional unconformity during the latter part of the Jurassic can be mapped in both the Carpentaria and Eromanga Basins (Draper, *in* Bain & Draper, 1997, page 525). This unconformity is coeval with the North-West Shelf breakup unconformity. Marine transgression marks the beginning of sedimentation in the Rolling Downs Group.

- Crustal extension in the Whitsunday Province in eastern Queensland occurred during the late Early Cretaceous.

- Early Cretaceous subsidence corresponded with global sea level rise (Draper, *in* Bain & Draper, 1997, page 525).

- Voluminous volcanic detritus delivered to both Carpentaria and Eromanga Basins during the Cretaceous (Draper, *in* Bain & Draper, 1997, page 525).

- Sedimentation in the whole area ceased during the Cenomanian (early Late Cretaceous).

Cenozoic Events and Sequences

There were three major cycles of sedimentation in the Cenozoic, each separated by a hiatus in sediment accumulation (Grimes, 1980). Laterite/silcrete surfaces do not correspond to breaks in sediment accumulation. Key aspects of the depositional episodes, weathering profiles and tectonics are summarised below.

Cenozoic Depositional Episodes

Bulimba Cycle

- Dominated by medium to coarse clastic deposits

- Marion Formation formed in north-south depression which was probably an erosional valley in the Early Tertiary.

Wyaaba Cycle

- Carl Creek Limestone and Gregory Downs Limestone formed in a lacustrine environment. Rocks contain abundant fossils (Riversleigh fossil site). The Austral Downs Limestone is also lacustrine, formed by damming up of the ancestral Georgina River (Grimes, 1980).

- Wyaaba Cycle is coeval with eruption of the Main Range Volcanics in eastern Queensland.

Campaspe Cycle

- Cycle began with uplift and volcanism in north-east Queensland.

- Overall, the cycle represents a period of eustatic and climatic fluctuations.

- Rocks are semi-consolidated, post-dating the latest deep weathering event.

- They occur as deposits on the Carpentaria Plain in the north and Inland Plain to the south.

Cenozoic Deep Weathering Profiles

- The oldest profile occurs in the middle Eocene, is part of the Tennant Creek and Aurukun Surfaces, and postdates most of the sedimentation in the Bulimba Cycle (Grimes, 1980).

- The Featherby/Kendall Surface (Grimes, 1980) is now dated as middle Miocene, overprinting most sedimentary rocks of the Wyaaba Cycle.

- Gossan-forming events, characterised by mobility of Mn, occur during the Miocene and about the Eocene-Oligocene boundary (Anand & others, 1997).

Cenozoic Tectonics

- The Bulimba Cycle may be a response to opening of the Coral Sea and Tasman Sea (Grimes, 1980).

- Movement on the Cork Fault formed a depositional basin on its down-thrown side, resulting in deposition of the Old Cork beds. Later movements on the Cork Fault resulted in deposition of the Mueller Sandstone.

- The hiatus between the Bulimba Cycle and Wyaaba cycles is coeval with uplift of the eastern margin of the Karumba Basin to the north.

Cenozoic Regolith

- Regolith in the Mount Isa region is primarily the result of weathering and erosion since the Cretaceous. During this period, the Cambrian and Proterozoic rocks previously concealed beneath Mesozoic cover were exposed. Continued weathering and erosion of these rocks has produced a range of regolith types from weakly weathered bedrock (saprock) through to well developed sequences comprising (from the top down):

  1. Surficial duricrust
  2. Mottled zone
  3. Pallid zone
  4. Saprolite
  5. Saprock
  6. Bedrock

- The preservation of all or part of this regolith sequence at any site is dependent on the local erosional history. Variations also occur due to the nature of the parent rock, with silcrete, for example, commonly occurring in saprolite and saprock directly overlying unweathered bedrock.

- Since the Cretaceous, the landscape evolved by stream downcutting and scarp retreat, heavily influenced by variability in the mechanical strength of the underlying rocks. Flat-floored valleys parallel to bedrock strike ridges are common. The valleys typically overlie more easily eroded rocks that have also been more deeply weathered than the adjacent ridges. The effect of the differences in the strength of the substrate in controlling landscape evolution has been complicated by the development of duricrusts in the regolith. The duricrusts are also resistant to erosion, enabling topographically high regolith landforms to develop. The regolith in the Mount Isa region includes:

  1. Silcrete-capped ridges, as in the Western Succession; these comprise duricrusted former valley deposits, now high in the landscape as a result of differential erosion removing less well consolidated deposits to either side. Silcrete also develops directly on siliceous bedrock such as quartzites. Erosion of these sites produces surface gravels composed of nodular silcrete and sharp angular silcrete fragments.

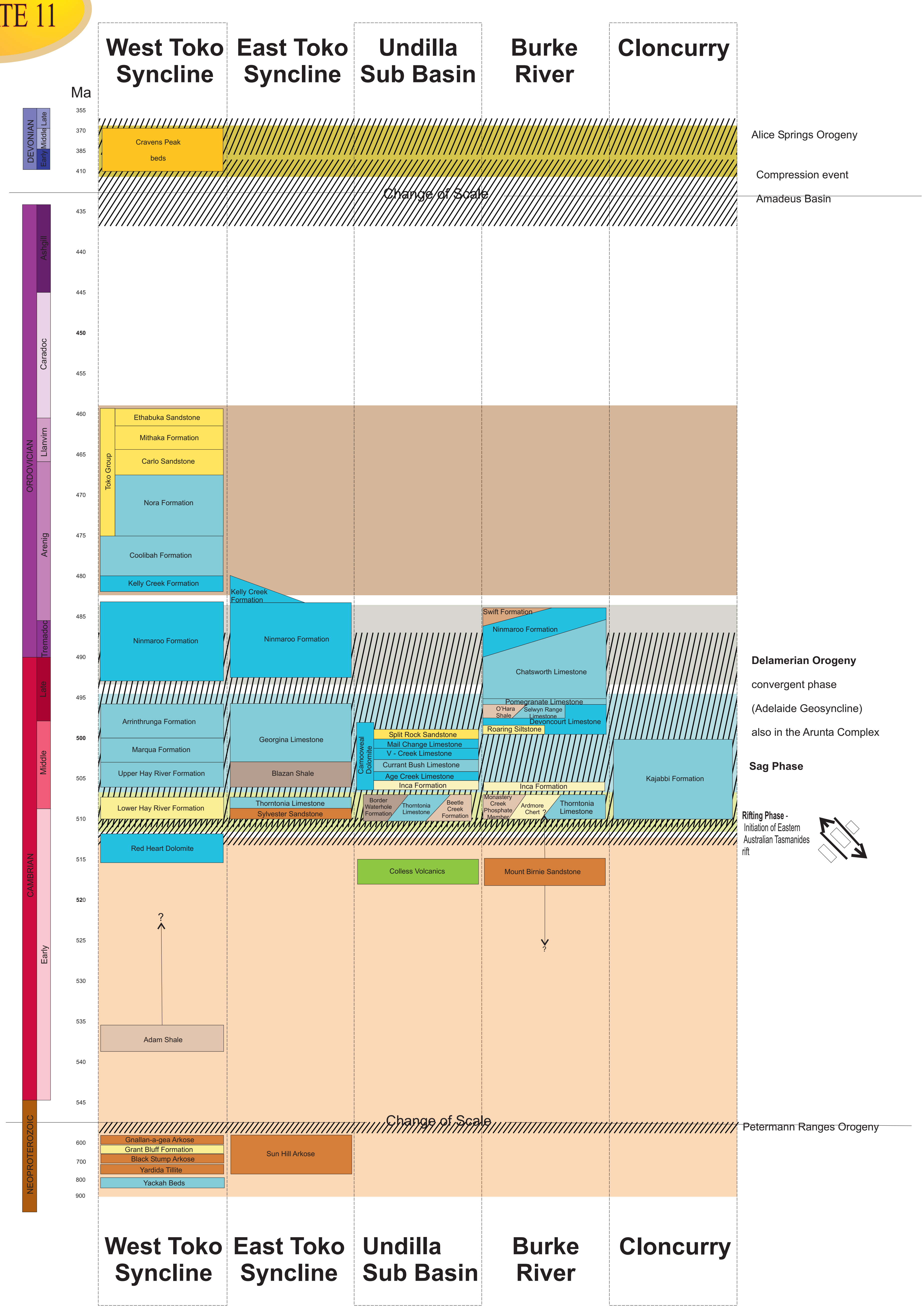
  2. Ferruginous duricrusts capping iron-rich bedrock, and forming breakaways and mesas; these occur throughout the Mount Isa region. Erosion produces angular gravels, ferruginous nodules and pisoliths.

  3. Thin (5–10 m thick) Quaternary (and Tertiary) alluvium overlying saprock or fresh bedrock beneath flat-floored valleys. Cambrian and Proterozoic bedrock underlies valleys within the Mount Isa Inlier, whereas Mesozoic sequences are preserved beneath Cenozoic alluvium around the eastern periphery of the Inlier. Cemented alluvial deposits in the lower part of the Cenozoic valley fill sequence are present in the Western Succession (Buckley River area).

NORTH-WEST QUEENSLAND MINERAL PROVINCE
PALAEOZOIC EVENT STRATIGRAPHY

Queensland Government
Department of Mines and Energy

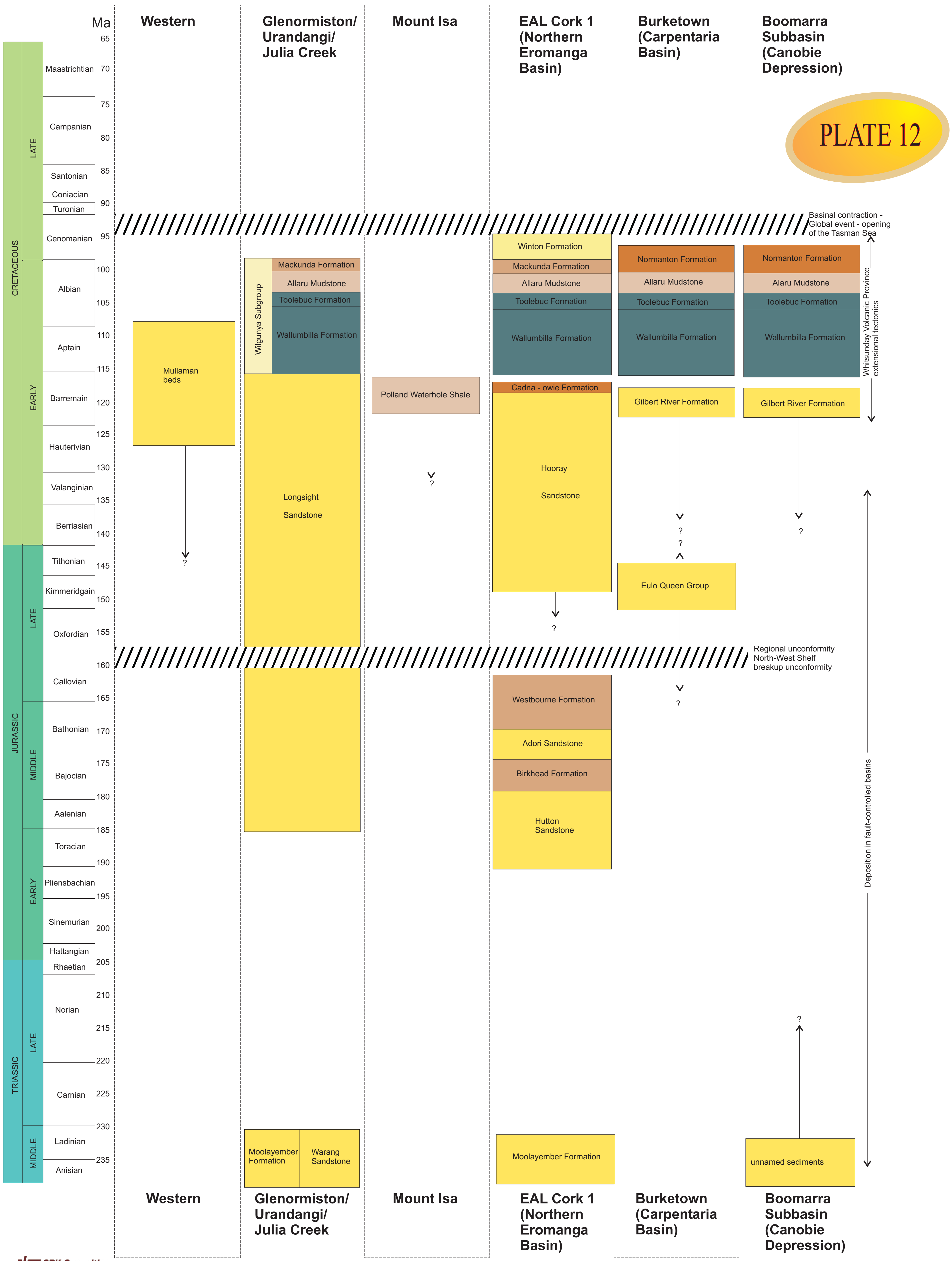
PLATE 11



TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS
SRK Consulting
ESRI AU

NORTH-WEST QUEENSLAND MINERAL PROVINCE
MESOZOIC EVENT STRATIGRAPHY

Queensland Government
Department of Mines and Energy



SRK Consulting
ESRI AU
TAYLOR WALL & ASSOCIATES GEOSCIENCE CONSULTANTS

NORTH-WEST QUEENSLAND MINERAL PROVINCE
CENOZOIC EVENT STRATIGRAPHY

Queensland Government
Department of Mines and Energy

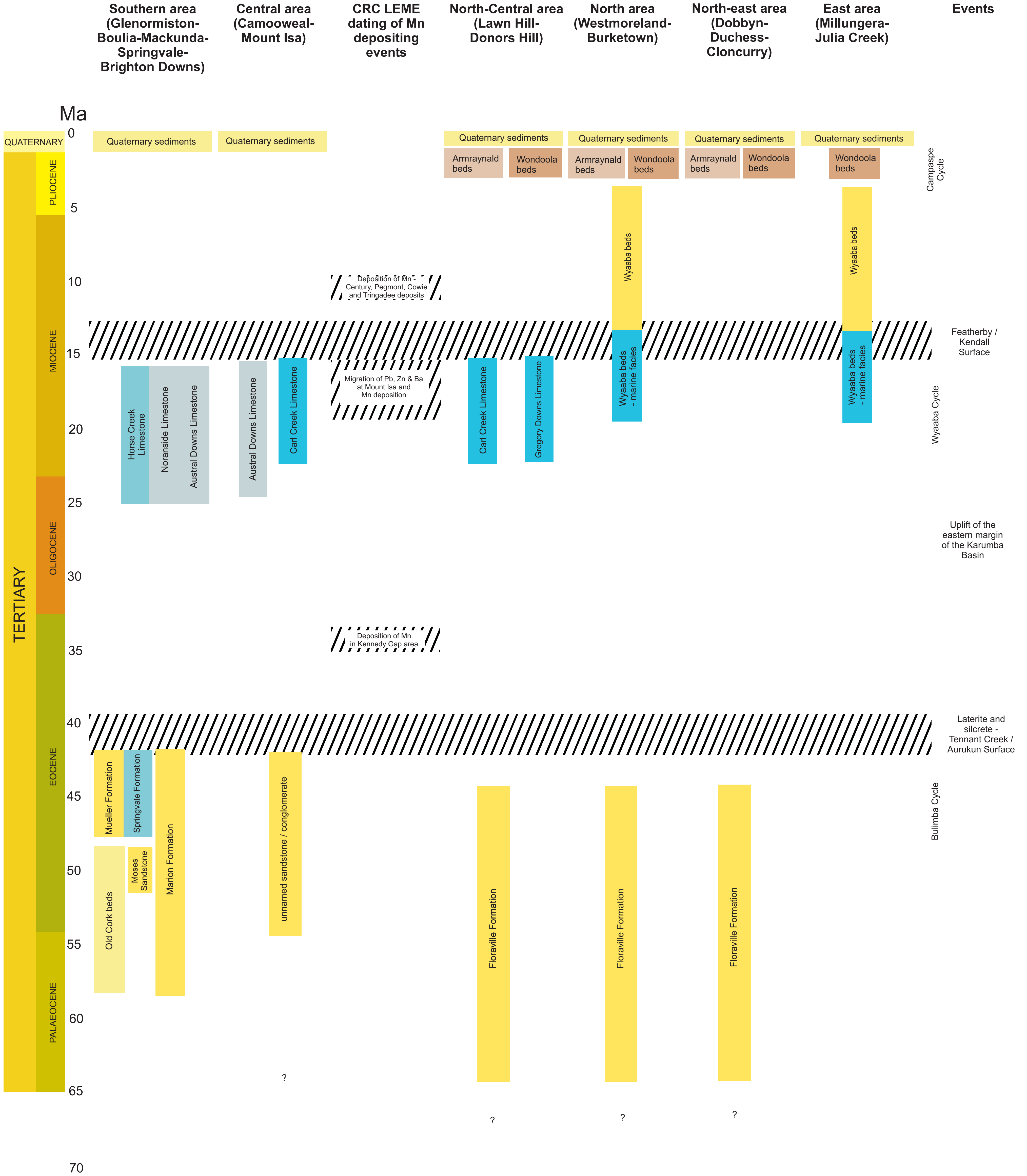
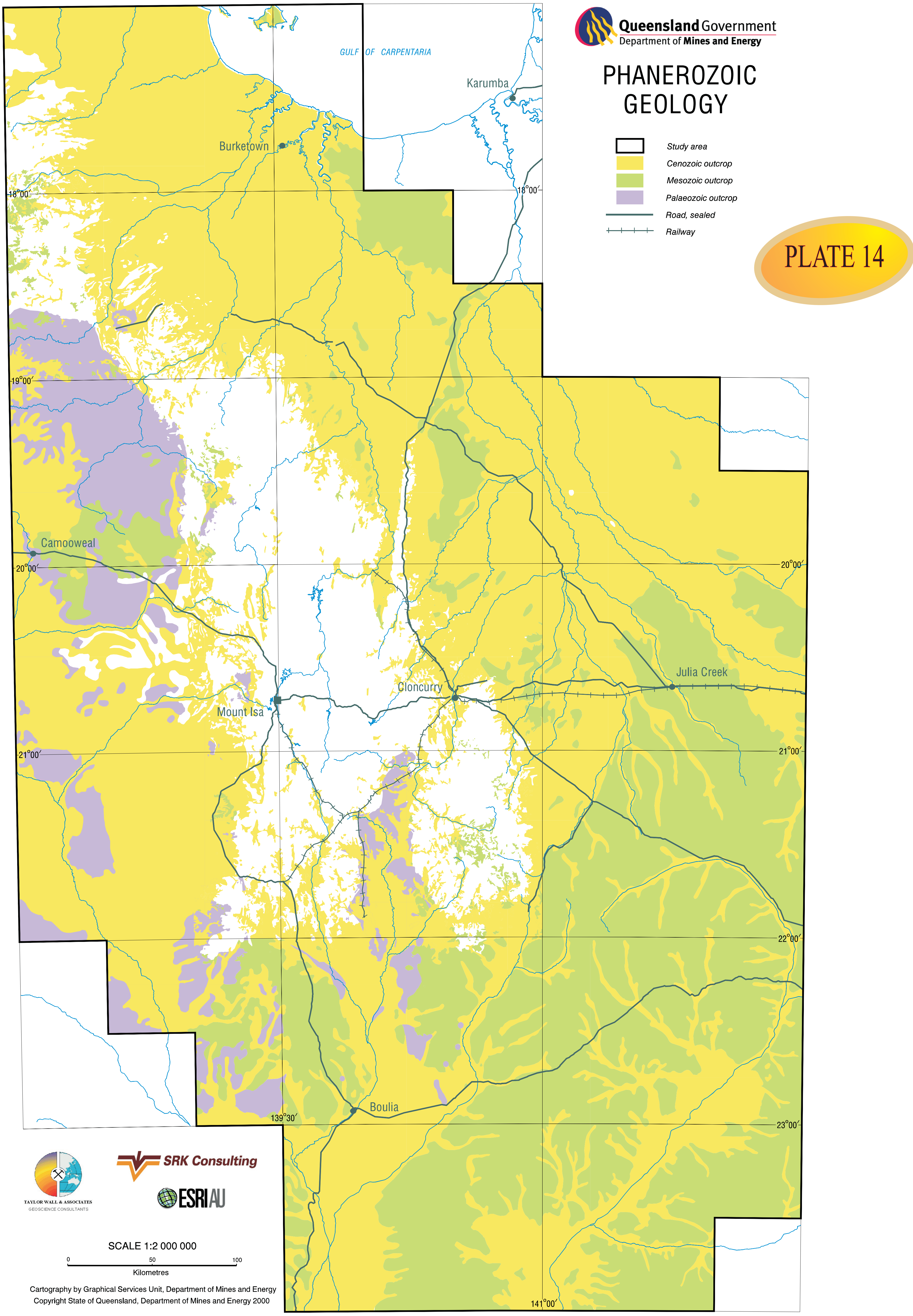


PLATE 13

TAYLOR WALL & ASSOCIATES GEOSCIENCE CONSULTANTS

SRK Consulting

ESRI AU


Queensland Government
Department of Mines and Energy
PHANEROZOIC GEOLOGY
Study area
Cenozoic outcrop
Mesozoic outcrop
Palaeozoic outcrop
Road, sealed
Railway
PLATE 14
GULF OF CARPENTARIA
Karumba
Burketown
18°00′
18°00′
19°00′
Camooweal
20°00′
20°00′
Julia Creek
Cloncurry
Mount Isa
21°00′
21°00′
22°00′
Boulia
139°30′
23°00′
141°00′
TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS
SRK Consulting
ESRI AU
SCALE 1:2 000 000
0
50
100
Kilometres
Cartography by Graphical Services Unit, Department of Mines and Energy
Copyright State of Queensland, Department of Mines and Energy 2000

5.5 SYNTHESIS OF TECTONOSTRATIGRAPHIC ELEMENTS AND MINERALISATION

The Proterozoic of the North-west Queensland Mineral Province is summarised in Table 5.1 as follows:

- nature, architecture, kinematics and initiation age of the major structural elements,
- tectonic settings in which these elements are interpreted to have initiated,
- reactivation events, their kinematics and resulting architectures,
- significance of these tectonostratigraphic elements and histories in the development of lithological packages hosting base metal and gold deposits and related hydrothermal plumbing systems, and
- the broader (continental) context of the major tectonostratigraphic elements and events.

This structural and tectonic framework is presented as a series of structural event maps (Map 4) or layers in the digital product. These maps and Table 5.1 provide a dynamic view of the structural evolution of the North-west Queensland Mineral Province, linking the tectonic and structural history of the principal mineralising episodes.

The structural event maps document the distribution and evolution of key structures interpreted to form essential elements of the hydrothermal plumbing systems responsible for base metal and gold in the northern Australian Proterozoic. As such, the event maps/layers are of special value in the targeting of these systems in the North-west Queensland Mineral Province (see Chapters 6.2 and 11.3).

NOTE: These maps and digital views are intended to illustrate the gross tectonic architecture for the regions. They were interpreted from the geophysical data (magnetic and gravity) and the new geological fault layer at 1:1 000 000 scale. Because of the inherent limits in the accuracy at this scale, this layer should not be used for interpretation at prospect scale. The new geological fault layer would be more appropriate.

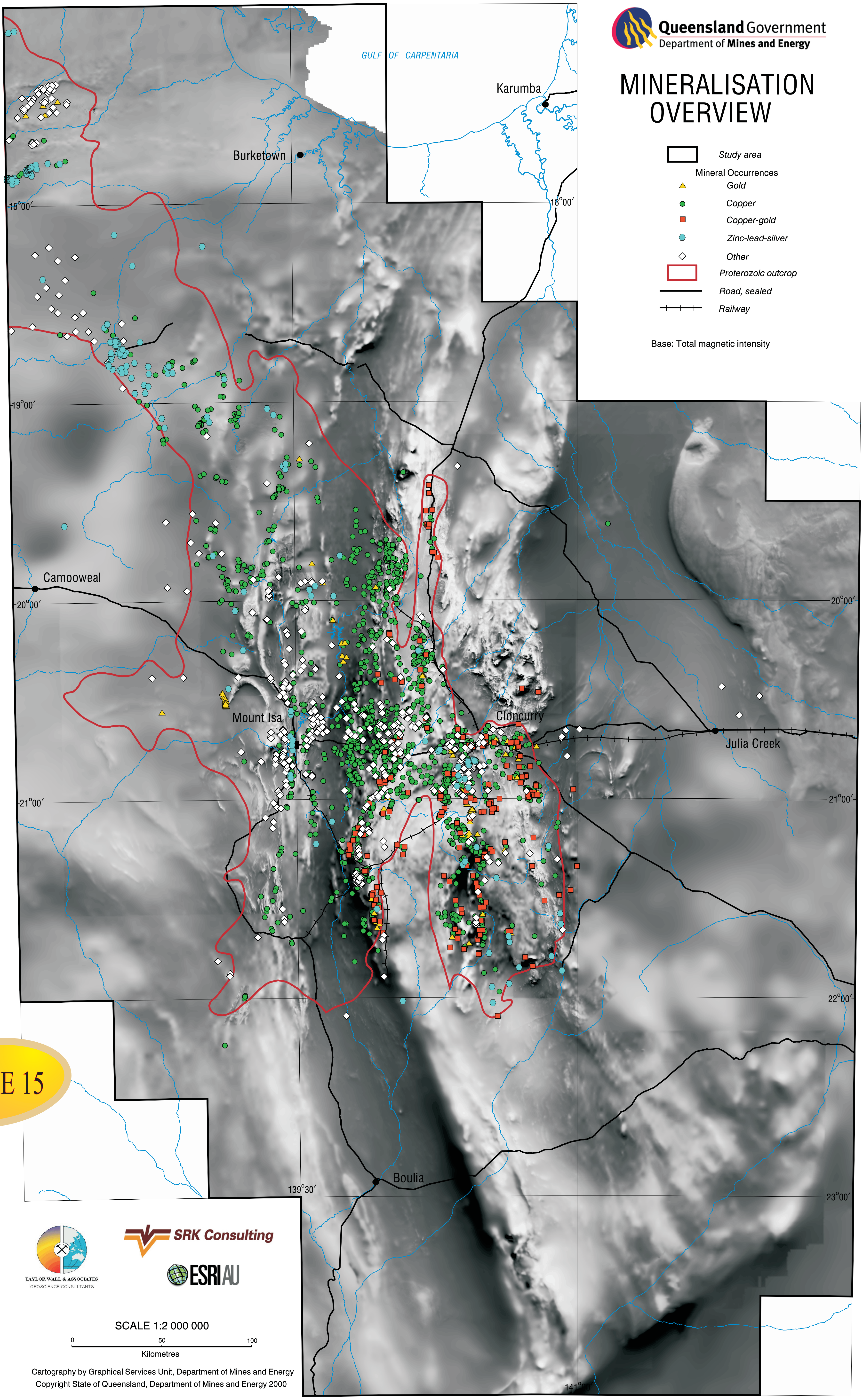

Queensland Government
Department of Mines and Energy
MINERALISATION OVERVIEW
Study area
Mineral Occurrences
Gold
Copper
Copper-gold
Zinc-lead-silver
Other
Proterozoic outcrop
Road, sealed
Railway
Base: Total magnetic intensity
GULF OF CARPENTARIA
Karumba
Burketown
Camooweal
Mount Isa
Cloncurry
Julia Creek
Boulia
18°00′
19°00′
20°00′
21°00′
22°00′
23°00′
139°30′
141°
TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS
SRK Consulting
ESRI AU
SCALE 1:2 000 000
0
50
100
Kilometres
Cartography by Graphical Services Unit, Department of Mines and Energy
Copyright State of Queensland, Department of Mines and Energy 2000

PLATE 15

Table 5.1

Fault Code	Initiating Event / Age	Tectonic Setting	Fault Components / Orientations	Reactivation History	Controls on Mineralisation	Continental Correlations
AR	Possibly inherited from Late Archaean basement ~2500Ma	Possible suture between Late Archaean to Early Proterozoic craton to the west and another, possibly more primitive terrane to the east, reactivated during the Barramundi Orogeny	Major contributor to the overall N-S structural grain of the Mt Isa Inlier	Repeatedly reactivated during all subsequent events. Localized Leichhardt River Fault Trough (LRFT) as pull-apart basin on Cover Sequence 2 (CS2) transfer step-over. Acted as major sidewall localizing Wonga extension.	No mineralisation during initiation, but had major influence on localization of all major deposit styles at regional to local scales during repeated reactivation history.	
BA seq	Barramundi basin formation ~1900Ma	Poorly constrained, possibly ENE-WSW extensional accommodation structures and NW-SE normal faults.	Broad (10-20km), poorly defined zones of ENE-trending fracture and pattern break. Some short, low displacement faults / fractures seen in magnetics	No major reactivation, but produced pattern breaks and jogs in most subsequent structures	No direct controls on mineralisation, but indirect influence by localizing jogs / complexity of younger structures	Consistent with interpreted transfer structures of Barramundi Sequence age in Pine Creek & Granites-Tanami
BA	Barramundi Orogeny → major compressional structures (and possible sutures). ~1870Ma	Poorly constrained, but probably ENE-WSW shortening reactivating AR structures as broad, east-dipping, crustal scale reverse fault zones. Possible Barramundi-reactivated suture between Late Archaean to Early Proterozoic craton to the west and another, possibly more primitive terrane to the east.	NW to N-trending, major gravity and magnetic boundaries; also define boundaries of major Barramundi basement blocks and Cover Sequence 2 (CS2), Wonga and Cover Sequence 3 (CS3) rift / basin edges.	NNW-trending segments in south of region reactivated as major, controlling strike-slip / sidewall zones during 1675Ma (CS3) transtension. Reactivated as reverse faults during ~1710Ma compression event & Isan Orogeny (D2).	No mineralisation during initiation, but had major influence on localization of all major deposit styles at regional to local scales during repeated reactivation history. Influenced patterns of faulting, rifting, subsidence, sedimentation and magmatic activity during Wonga (Tick Hill-style Au), CS3 (Isa-Century and Broken Hill-Cannington-style Zn-Pb-Ag) and Isan Orogeny (Fe-oxide Cu-Au)	~E-W compression is dominant Barramundi deformation event kinematics in Pine Creek and Arnhem Land. Weaker to absent in Davenport, Tennant Creek and Granites-Tanami provinces.
CS2	Cover Sequence 2 (Leichhardt) extensional basin-forming structures 1800Ma – 1760Ma	Intracontinental NNE-SSW extension / rifting. Part of a major array of extensional basins developed across northern and central Australia at this time. Syn-rift sequence comprises bi-modal volcanics and coarse clastics. Facies and thickness of syn-rift sequence varies between transfer-bounded compartments	Long, NNE(030º)-trending transfer / accommodation structures, compartmentalizing shorter WNW(300º)-trending normal faults. Mapped from a combination of magnetic and lesser gravity lineaments, pattern breaks, mapped faults and distribution of CS2 syn-rift facies packages. Transfer-bounded compartments range from ~30km to 60km wide. Major left-step in transfer system across BA fault zone localized LRFT	Major reactivation was during Isan Orogeny but played important compartmentalizing role during subsequent basin reactivation and inversion events. Transfer faults reactivated as strike-slip faults during D1-D3 (eg, Ballara-Corella-Mt Remarkable Fault system). Normal faults inverted as oblique reverse faults during D1-D2 (eg, Duck Ck anticline an inverted half-graben. CS3 strike-slip / sidewall faults step across both transfer and normal components, localizing extension, subsidence and inversion in Isa Superbasin times	No direct control on mineralisation during initiation. However, controls on steps / jogs on CS3 sidewall faults provided a major control on localized extension, sub-basin development, inversion and Zn-Pb-Ag mineralisation. Reactivation of CS2 faults, especially at/near intersections with other structures, is an important control on Isa-style Cu and Fe-oxide Cu-Au systems.	Very similar extensional fault architecture in Davenport, Kimberley, Granites-Tanami provinces. Also appears to be present in parts of Gawler / Stuart Shelf / Curnamona region.
Wonga	~N-S extension of regional importance, and substantial local impact. 1745Ma -1730Ma	CS2 thermal subsidence possibly interrupted by Wonga extension. Initiation of fundament change in tectonic setting of province	Two main styles / locations. 1. Narrow zone of exposure (Wonga belt) of NS zone of locally intense N to NNW extension immediately E of AR/BA fault zone. Detachment shear zone(s), core complexes and highly faulted tilt blocks in upper plate remnants. Synchronous intrusion of distinctive Wonga-Burstall Suite granitoids. 2. Broad zone west of AR/BA suture zone of upper plate EW normal faulting (20-50km spacing) localising half-graben fills of BIG-PRIZE Sequences in LRFT and to W and NW through Lawn Hill area. Local bimodal volcanics and high-level intrusives.	E-W normal faults in LRFT – Lawn Hill region compartmentalise subsequent deformation and are variably inverted during N-S compression (Isan D1).	Tick Hill high-grade gold deposit formed in ductile detachment shear zone during Wonga event. Wonga normal faults (that sole through CS2 sequences) reactivate normally during subsequent Isa Superbasin events and reversely during Isan inversion with very direct spatial control on deposition of aquifer and host facies distribution and fluid focus for both Isa-Century style Zn-Pb-Ag (eg. *Mount Isa Pb-Zn*, *Hilton-George Fisher*) and Isa-style Cu systems (eg. *Mammouth Mines*)	Poorly documented elsewhere, but possibly recorded in a number of 1720-1740Ma radiometric ages in central Australia and Gawler / Curnamona region
1710Ma compression	Enigmatic ~E-W compressional event (at present) mainly restricted to the LRFT and the areas to W and S to SW of it 1725Ma-1710Ma	Inversion, open folding/warping and transpressive reverse faulting of CS2 sequence during ~E-W compression **Structures commonly terminate beneath the Surprise Creek (PRIZE) unconformity**. These locally host a phase of dolerite dyking also not present above the unconformity. PalaeoMagnetics: **I1710**, **OP1**	Significant new ~NS reverse fault structures formed during this event restricted (at present) to the LRFT south of the Fiery Creek CS2 transfer zone and interpreted beneath the Western Fold Belt. Commonly compartmentalized by both CS2 and Wonga structures. Possible reactivation of NS AR/BA structures and probable initiation of Mt Gordon Fault system as W-vergent reverse fault (reactivated normally in GUN times). Inversion and overall anticlinal-synclinal form of LRFT and adjacent terrains partly developed in this event. May have also inverted other CS2 half-grabens (eg, Duck Creek area) in the Eastern Succession.	Amplification of folds and faults during D2, due to very similar tectonic / kinematic setting. Difficult to distinguish 1710Ma structures from D2 structures unless structural discontinuity at the Surprise Creek (PRIZE) unconformity can be demonstrated. Very difficult to identify in eastern half of region where D2 was more intense.	~N-S reverse structures formed during this event reactivate transtensionally during Isa Superbasin (CS3) formation and basin reactivation thus significantly contributing to CS3 facies and sub-basin formation (and hence Zn-Pb-Ag localization). eg. Mount Gorgon Fault zone in GUN times and the Paroo-proto Mt Isa fault zone at 1640Ma (explaining the Isa Group-basement fault geometry at Isa Mine – see below)	Poorly documented elsewhere but possibly significant sequence break at Broken Hill between Thackaringa Group and Thorndale Gneiss-Clevedale Migmatite complex

Table 5.1 (continued)

Fault Code	Initiating Event / Age	Tectonic Setting	Fault Components / Orientations	Reactivation History	Controls on Mineralisation	Continental Correlations	
1675Ma Extension	Strike-slip / transtension / extension of variable magnitude across the region. Trigger for Cover Sequence 3 basin system and some intrusion in the Eastern Succession. Extensional regime focusing Sybella intrusion and uplift (with non-deposition) in the Western Succession 1670Ma-1680Ma	Overall NW-SE extension, but fundamentally controlled by dextral strike-slip on a dominantly right-stepping set of NNW-striking faults of 100 to >1000km length. PalaeoMagnetics: **I1675**	Dominated by an array of NNW-trending, sub-vertical, dominantly dextral strike-slip faults. In the Eastern Succession, it is possible that some of these faults formed during the Wonga event. These faults are disrupted and offset where they cross major older structures, especially the AR, BA Seq, BA and CS2 structures. In general, the 1675Ma (CS3) strike-slip faults step or bend to the right at these intersections, localizing extension / transtension, subsidence and intrusion. NNE to ENE-trending normal to oblique-normal faults form at these steps / bends, and the NNW-trending segments act as 'sidewall' faults to basins and sub-basins of this age.	Minor reactivation of the fault array during deposition of CS3 sequences. This has resulted in minor local subsidence and/or uplift / inversion at steps / bends in NNW-trending fault array. Significant inversion during various phases of the Isan orogeny. Pattern of Isan Orogeny folding is strongly influenced by pattern of 1675Ma faults.	***Key controlling elements for the rift-basin systems that host the Broken Hill-Cannington style Ag-Pb-Zn deposits in the Eastern Succession.*** Deposits occur at steps / bends in the NNW-trending master faults. These steps / bends are localized at intersections between the NNW 1675Ma faults and older structures. The most common intersections that localize major deposits (eg, *Cannington*) are with CS2 transfer and normal faults. ***In the Western Succession, similar 1675Ma extensional steps/bends localize Sybella Intrusion*** which initiates a period of uplift and non-deposition. GUN sequences are subsequently deposited in response to thermal decay as broad slab-like, ramp accumulations with little apparent tectonic segmentation beside normal (hinge) reactivation of the 1710Ma Mt Gordon reverse fault system	Major NNW-trending structures are associated with 1690-1600Ma sequences and stratabound Zn-Pb-Ag mineralisation throughout eastern Australia (eg, Emu Fault / Batten Trough / HYC deposit; Bancannia Fault / Willyama Complex / Broken Hill).	
1650Ma	Enigmatic basin inversion / reactivation event disrupting Isa Superbasin accumulation.	Possible easterly rotation of extension direction towards NS applying a regional wrench to the existing 1710Ma-Wonga architecture PalaeoMagnetics: **I1650**	Regional N to NNE structures south of the Fiery Creek CS2 transfer possibly driven into transpression (eg. Mt Gordon Fault zone and AR/BA structures) resulting in uplift	unknown	Transpressive uplift along the AR/BA zone east of Mount Isa may drive mineralizing brine within PRIZE-GUN aquifers towards the strike-slipping Paroo - proto-Isa sidewall fault where rapid vertical access to GUN hosts is provided by extensionally reactivating Wonga and CS2 intersections (eg. *Hilton*, *George-Fisher* & *Mount Isa* Zn-Pb-Ag systems)		
1640Ma Extension	Major NNW-SSE extensional reactivation. Important juxtapositioning of GUN sequences in normal fault-bounded windows into CS2 sequences in the LRFT and Isa Mine/Valley regions 1640Ma	Overall NNW-SSE extension but driving variably-oriented transfer zones into transpression / transtension. Well expressed in Western Succession south of Murphy Ridge and west of AR/BA central suture zone. Obscured in Eastern Succession by deep sag facies. PalaeoMagnetics: **I1640**, **OP2**	Reactivation of earlier EW Wonga normal faults, and NW-SE CS2 & ~NS AR/BA structures as sidewall / accommodation zones. Initiation of finer scale (10-15km spacing) tilt block architecture by development of both 'sympathetic' and 'back' normals to the soling Wonga normals (eg southern Murphy seismic grid, LRFT) and new NW-SE accommodation zones. In the LRFT this extensional reactivation results in the 'dropped-in window' juxtapositioning of GUN sequences with CS2 packages (eg Paroo Range, Crystal Creek Block and northern Isa Valley). In addition, major 1710Ma reverse faults are reactivated as transtensional sidewall accommodation zones (eg, Mt Gordon fault zone, Paroo-proto-Isa faults). The GUN sequence (Isa Group) - basement fault juxtaposition geometry at Isa Mine is also attributed to this extensional reactivation event (interestingly **post** Isa Zn-Pb-Ag).	South of the Murphy Ridge and north of the Fiery Creek CS2 transfer zone, 1640Ma (RIVER) normals are variably strongly reactivated within CS2 and 1640Ma compartments in Isan D1 as reverse faults and thrusts. This locally brings Zn-Pb-Ag prospective RIVER sequences to shallow explorable depths. Minor local D1 reverse reactivation of 1640Ma, Wonga and other structures extends south to Isa within the LRFT and the KLB.	Key event for Zn-Pb-Ag mineralisation at *Walford Creek*, *?Grevillea*, *?Lady Loretta* and *HYC*. Fluid flow driven by extensional block tilting or (more likely) regional transpressive uplift on wrenching sidewall / accommodation structures driven by significant rotation of the extension direction (note **I1640-OP2** on APWP) as at 1650Ma above. Key events for localising both the pyritic shale / siltstone sub-basins / facies and the post-depositional introduction of Zn-Pb-Ag in the western part of the region	This event can certainly be traced into the McArthur Basin system to the NW, and is likely to have been widespread.	
1620Ma Compression	SW-directed inversion event well expressed on the Lawn Hill platform but possibly with some regional significance. ~1620Ma	Regionally unknown but SW-directed thrusting / reverse faulting affects GUN-LORETTA-RIVER-TERM sequences and not LAWN sequences on the Lawn Hill platform. Unconformable relationships at the base of Pmh1 near Grevillea along the Cambrian edge reflect this inversion.	SW-directed thrusts in GUN-LORETTA-RIVER-TERM sequences formed at this time. Possible formation of Termite Range Fault as SW-vergent reverse fault linking older 1640Ma sidewall faults at this time.	Subsequent transtensional reactivation of the Termite Range Fault in LAWN times accounts for facies and thickness variations in Pmh1-3.	Regional uplift driven by this SW-directed shortening probably drives Zn-Pb-Ag mineralizing brines implicated in *Grevillea* and *Lady Loretta* deposit formation	Possibly implicated in clastic reactivations of the Soldiers Cap sag (SC4) in the Eastern Succession (eg. Tommy Creek Beds)	

Table 5.1 (continued)

Fault Code	Initiating Event / Age	Tectonic Setting	Fault Components / Orientations	Reactivation History	Controls on Mineralisation	Continental Correlations
Isan Orogeny D1	Final inversion of ISA superbasin system. N-S to NW-SE compression. ~1590Ma - 1570Ma	Overall N-S to NW-SE compression interrupted CS3 WIDE accumulation. Some 'foreland'-style sediments (DOOM-South Nicholson) in the north progressively folded by ongoing Isan D1 (eg. Constance Range – Carrara Range), but otherwise the effective termination of Proterozoic sedimentation in the region.	Mainly recorded as inversion of Wonga and 1640Ma normal faults in western half of the region. Isan D1 is especially intense in the region on and to the south of the Murphy Ridge and north of the Fiery Creek CS2 transfer zone where 1640Ma (RIVER) and Wonga normal faults are variably reactivated as reverse faults and thrusts strongly compartmentalized along with folding (eg. Ploughed Mountain, Mount Caroline and Kamarga anticlines) between fundamental CS2 and 1640Ma transfer structures. Minor local D1 reverse reactivation of 1640Ma, Wonga and other structures extends south to Isa within the LRFT and the Kalkadoon-Leichhardt Belt (KLB). More extensive deformation, including probable thrust / fold nappe formation recorded as layer-parallel schistosity, mainly involving Soldiers Cap sequence, in eastern part of region. Inversion of CS2, CS3 and possibly Wonga normal faults (eg, Pumpkin Gully fold and E-W to NE-SW trending folds under cover to east).	Little or none.	Inversion associated with flow of Zn-Pb-Ag mineralizing brines. implicated in metal introduction at *Century* and possible contributions at *Walford Creek* and *Lady Loretta.* In the northern Lawn Hill - Southern Murphy region, D1 thrusting locally brings Zn-Pb-Ag prospective RIVER sequences to shallow explorable depths	Inversion of a number of Proterozoic basin systems (eg. Davenport Ranges, Carrara Range, ?Willyama and Olary.
Isan Orogeny D2	Major regional compressional deformation and metamorphic event → 'cratonisation' of Mount Isa terrane. Focused south of the Fiery Creek CS2 transfer zone ~1550Ma-~1540Ma	Collisional tectonic zone to ?east of region driving ~E-W compression (generally E-verging), thickening and uplift. This is also the major regional metamorphic event. PalaeoMagnetics: **I1645**, **OP3**	Dominant N-S fold / reverse fault structural grain in the outcropping part of the inlier. Particularly prominent in the eastern half of the region, in both outcrop and covered areas. Local deviations from N-S trends during D2 occur where inversion / reactivation of pre-existing (mainly CS2 and CS3) faults influences the fold / fault pattern. (eg. dextral strike-slip on the Fountain Range-Quamby, Ballara-Corella-Pilgrim and Mt Remarkable fault systems (CS2 transfers).	Some reactivation during D3 (see below).	Minor copper mineralisation associated with small to large (up to 100m) calcite veins in dilational sites around competent bodies, mainly in Wonga Belt.	This deformation has a weaker impact west of the Mt Isa – Mt Gordon fault system.
Isan Orogeny D3	Wrench reactivation of earlier structures in waning stages of Isan Orogeny ~1520-1495Ma	Waning stages of Isan Orogeny → wrench reactivation of earlier large scale crustal faults with associated SW-directed reverse faulting of D2-folded Isa Superbasin sequences. At least two minor events overlapping with intrusion of Williams granitoid suite. PalaeoMagnetics: **I1500**, **OP4**	Wrench reactivation of pre-existing structures of a wide variety of ages and orientations spatially confined to south of the Fiery Creek CS2 transfer zone. Dextral displacement on NNW-trending CS2 transfer faults and some N-S structures suggests ~NE-SW compression. Up to 10km on the Fountain Range-Quamby, Ballara-Corella-Pilgrim fault system, and 5km on Mt Remarkable Fault. Also evidence for a minor ~N-S compression event.	Wrench reactivation of earlier large scale crustal faults with large adjacent areas of (largely) new SW-directed reverse faulting of D2-folded Isa Superbasin sequences.	Two major deposit styles formed during this event. 1. ***Mt Isa-style Cu mineralisation***, mostly in the western part of the region. Structurally controlled largely by reactivation of pre-existing Wonga, CS2 and 1640Ma faults. 2. Key structural controls on emplacement of Williams suite granitoids and their associated ***Fe-oxide Cu-Au deposits***. Also localised much of the barren magnetite-albite-qtz+/-amphibole alteration in the eastern part of region.	unknown.

6. MINERALISATION

6.1 OVERVIEW

The North-west Queensland Mineral Province exhibits a broad range of deposit styles containing a wide range of metallic and non-metallic commodities.

Within commodity classes (groups of commodities occurring naturally, for example Ag-Pb-Zn), several styles of mineralisation are recognised based on the:

- form of the deposit or occurrence,
- mineralogy of the occurrence and apparently related alteration, and
- character of the host rocks.

Descriptions of, and exploration targeting criteria for, key styles of mineralising systems are given in the **Target Styles**: Chapter 6.2 section of this report.

Limited information on some mineral occurrences in the North-west Queensland Mineral Province has rendered uncertain their classification into appropriate mineralisation styles.

Mineralisation styles in the North-west Queensland Mineral Province are further related to one or more tectonostratigraphic events, as described in the time-space framework (Chapter 5.2; **Map 1**), based on:

- absolute isotopic dating of mineralisation, associated alteration or contemporaneous host rocks, in a few cases,
- relative timing, utilising observations on geometric, thermal or geophysical overprinting or cross cutting relationships, and
- analogies with chronologically well-established examples elsewhere.

Where temporal relationships are poorly understood or otherwise uncertain, mineralisation styles are assigned to broad or unknown tectonostratigraphic age groupings.

The main deposit styles and tectono-stratigraphic events to which they were related are listed in **Table 6.1**.

Information from the Queensland Department of Mines and Energy mineral occurrence (MINOCC) database, AGSO's MINLOC database and other sources from the literature have been utilised to classify over 3000 mineral occurrences in the North-west Queensland Mineral Province in terms of style, timing and relative size. To clarify their spatial distribution and relationships to geological domains and key structures, these data are plotted in **Map 3** and may be overlain on a broad range of lithological, stratigraphic, structural and geophysical layers, for example **Maps 5, 6, 7**.

In relation to the distribution of mineralisation in the Proterozoic:

- Stratabound Zn-Pb-Ag deposits occur in several geological domains in sediment-dominated Cover Sequence 3 blocks, but Broken Hill-Cannington styles are restricted to medium and high grade metamorphic rocks of the Eastern Fold Belt.
- Vein and breccia Ag-Pb-Zn occurrences are more broadly distributed than stratabound deposits, but tend to cluster around the same fault systems as the latter deposits.
- Copper occurrences are broadly distributed in the North-west Queensland Mineral Province but are most common in the western half of the belt. Isa-style copper mineralisation occurs mainly in greenschist facies metasedimentary hosts of Cover Sequence 3. Other vein-breccia styles are distributed through a range of lithologies and host rock ages, from subgreenschist to lower amphibolite facies metamorphic grades. However, most styles of copper mineralisation are spatially related to fault systems active/reactivated during D_2 and D_3 deformation.
- Copper-gold deposits occur mainly in amphibolite facies hosts in the eastern half of the North-west Queensland Mineral Province, in the Wonga and Eastern Fold Belt domains. In these domains, the copper-gold occurrences are mainly spatially associated with felsic plutons (they cluster around the roof zones of Williams, Naraku and some Wonga granites) and magnetically anomalous zones, as well as temporally associated with fault systems active/reactivated during Wonga extension (1740Ma) or post-D_2 deformation (in the case of the Eastern Fold Belt domain).
- Gold-dominated deposits are relatively sparsely distributed in medium-grade metamorphic hosts, mainly in the Wonga and Eastern Fold Belt domains. In the former, gold occurrences appear to be spatially associated with Wonga age (circa 1740Ma) plutons, and localised around fault systems that were deformed (folded, reactivated) during regional deformation (Chapter 5.2, 5.5). Gold occurrences in the Eastern Fold Belt domain, however, are spatially associated with fault systems active/reactivated post-D_2 and Williams age (circa 1500Ma) plutons and related alteration. Auriferous systems coeval with Wonga and Williams granites overlap with the more widespread copper-gold systems.
- Uranium-rich occurrences include different styles of mineralisation hosted by low-grade metamorphic rocks in the western portion of the North-west Queensland Mineral Province. One group of vein breccia deposits is spatially associated with fault systems to which copper deposits (including Isa-styles) appear to be related. Other uranium (±gold and platinoids) deposits are localised around unconformities. Another association of deposits (including Mary Kathleen) occurs in medium-grade metamorphic rocks of the Wonga belt.
- Mineral deposit associations in the North-west Queensland Proterozoic exhibit a limited range of diagnostic, lithostratigraphic and local structural settings within restricted time periods. Individual occurrences, or clusters of occurrences of each association, are spatially related to segments of fault systems that have a history of multiple reactivation, and architectures which reflect this history (**Chapter 5.5**).

Map 3 emphasises:

- The highly mineralised character of much of the North-west Queensland outcropping Proterozoic in relation to zinc-lead-silver, copper, copper-gold and uranium.
- The continuing prospectivity of the region for several styles of deposits of these commodities, particularly in large areas of Proterozoic under relatively thin, post-mineralisation cover, under which the relative paucity of known mineral occurrences reflects limited exploration. Over the past decade major exploration successes (**Chapter 7**) have been in these areas or over otherwise largely blind targets.

Map 3 also shows that the Palaeozoic and Mesozoic sedimentary cover successions over the Proterozoic basement contain:

- major phosphorite deposits and numerous occurrences in Cambrian host rocks,
- limestone in the Georgina Basin,
- some occurrences of Zn-Pb-Ag mineralisation in carbonates near the base of the Cambrian sequences (Georgina Basin), and
- significant oil shale and vanadium deposits in Cretaceous host stratigraphy.

TABLE 6.1: MINERAL DEPOSIT STYLES, NORTH-WEST QUEENSLAND MINERAL PROVINCE

Commodities	Deposit style	Mineralising events	Potential	Examples
Zn-Pb-Ag	Sediment-hosted Isa-Century style	Gun, Loretta, River, Wide Supersequences; suprabasinal events, 1660-1590Ma; Isan D_1	Medium grade, large deposits	Century (98.5Mt at 11.6% Zn, 1.7% Pb, 43g/t Ag); Mount Isa (125Mt at 7% Zn, 6% Pb, 160g/t Ag); George Fisher/Hilton (146.2Mt at 10.5% Zn, 5.6% Pb, 110g/t Ag); Lady Loretta (13.6Mt at 7% Zn, 6% Pb, 97g/t Ag)
	Metasediment-hosted Broken Hill-Cannington style	Soldiers Cap 2 - Soldiers Cap 3; ~1675Ma extension	High grades	Cannington (43.8Mt at 11.6% Pb, 4.4% Zn, 538g/t Ag); Pegmont (8.6Mt at 7.6% Pb, 3.5% Zn, 150g/t Ag)
	Carbonate-hosted	Isan D_1, D_2, D_3; Cambrian	Medium sized, medium grades	Kamarga
	Vein breccia	Isan D_1, D_2, D_3; Maramungee; Williams; Cambrian	Small size, medium grades	Lawn Hill vein deposits
	Other	Isan ?D_1-D_3	Small size	O'Briens Soak
Cu (±Co, Au)	Metasediment-hosted Isa style	Isan D_3	High grades and large size; leachable copper	Mount Isa (255Mt at 3.3% Cu); Mount Gordon (21Mt at 4.6% Cu)
	Vein breccia (other hosts)	Isan D_2, D_3; Cambrian	Small size	Lady Fanny
	Vein breccia – Redbank style	Isan ?D_1, D_3	High grades, moderate size	None known in study area
	Vein breccia – Mount Cuthbert style	Isan D_3	Small size, high grades	Mount Cuthbert
	Other	Isan ?D_1-D_3	Small size	
Cu-Au (±Co, U, REE)	Oxidised (magnetite-rich)	Williams; Wonga	Medium grades and tonnage	Ernest Henry (127Mt at 1.1% Cu, 0.55g/t Au); Osborne (11.3Mt at 2.9% Cu, 1.18g/t Au)
	Oxidised (hematite-rich)	Williams; Wonga	Medium grades and tonnage	Selwyn
	Reduced (sulphide-rich)	Williams; Wonga; Isan D_3	High grades, medium tonnage; leachable copper	Mount Elliott; Eloise (3.1Mt at 5.5% Cu, 1.4g/t Au); Mount Roseby (62.3Mt at 0.75% Cu)
	Other	Various deformation events	Small size	
Au	Tick Hill style	Wonga	High grades	Tick Hill (0.71Mt at 22.5g/t Au)
	Other pluton related vein breccia	Williams; Wonga	Small size	Wynberg
	Other vein breccia	Williams; Isan D_3	Small size	Gilded Rose; May Downs Goldfield
	Alluvial	Tertiary; Quaternary	Small size	Top Camp
Others	Unconformity related uranium-gold-platinum group elements	Isan D_1, D_2, D_3	Individual deposits small size	Redtree uranium deposits (combined 12.0Mt at 1.32kg/t USO_8)
	Vein breccia uranium±copper	Isan D_3	Medium size and grade	Valhalla (4.0Mt at 1.5kg/t U_3O_8); Skal
	Mary Kathleen style uranium	D_2	Medium size and grade	Mary Kathleen (9.5Mt at 0.131% U_3O_8)
	Pluton-related lithophiles	Kalkadoon; Sybella	Uneconomic	Nicholson Granite tin deposits; Mica Creek beryl deposits
	Stratabound ironstone	South Nicholson	Uneconomic	Constance Range ironstones (combined 368Mt at 45.4% Fe, 9.1% SiO_2)
	Phosphorite	Cambrian	Large tonnage	Phosphate Hill (103Mt at 23.4% P_2O_5)
	Stratabound vanadium	Mesozoic	Large tonnage, low grade	Julia Creek Vanadium (210Mt at 0.33% V_2O_5)
	Limestone	Cover sequence 2 Sag Phase; Cambrian; Mesozoic	Small to large tonnage	
	Miscellaneous	Various deformation events; Isan D_3; Kalkadoon; Wonga; Sybella; Williams; Mesozoic; Tertiary	Economically insignificant	Miscellaneous iron, manganese, silica, uranium, cobalt, gemstone, barite, building stone and oil shale deposits

TABLE 6.2: KEY TARGET STYLES IN THE NORTH-WEST QUEENSLAND MINERAL PROVINCE

System style	Commodities	Potential	Example
Sediment-hosted base metal			
Isa-Century style	Zn, Pb, Ag	Large deposits, medium grade	Century, Mount Isa, Hilton, George Fisher, Lady Loretta
Broken Hill-Cannington style	Ag, Pb, Zn	High grades	Cannington. Broken Hill (NSW)
Carbonate-hosted	Zn, Pb, Ag	Medium sized, medium grades	Kamarga, Coxco (NT)
Metasediment-hosted copper			
Isa-style	Cu (Co)	High hypogene grades and large size	Isa 1100, Enterprise
		Leachable supergene copper	Mount Gordon
Others	Cu	High grades and leachable supergene copper	Mount Cuthbert
Copper-gold + iron oxide			
Oxidised (magnetite-rich)	Cu, Au (Co)	Medium hypogene grades and tonnages	Ernest Henry, Osborne
Oxidised (hematitic)	Cu, Au	Medium-high hypogene grades, medium tonnages	Selwyn Project, Olympic Dam (SA)
Reduced styles	Cu, Au (Co)	Medium-high hypogene grades, medium tonnage; leachable supergene copper, all styles	Mount Roseby, Eloise, Mount Dore
Pluton-related gold			
Tick Hill styles	Au	High grades	Tick Hill
Other	Au (Cu)	Large tonnage	Telfer (WA), Granites-Tanami (NT) regions

6.2 TARGET STYLES

Introduction

This section examines the key features of, and exploration models for, only those associations of deposits for which the North-west Queensland Mineral Province is considered prospective and which are regarded as having the potential to be company makers for junior groups or to provide returns compatible with major company objectives.

Targeted associations of deposits are discussed under 'styles' of mineralising system. Such styles refer to groups of deposits and exploration targets, which are commodity-based and which share key features of geological setting, timing of mineralisation, conditions of formation, etcetera. Each 'style' may accommodate a range of deposit morphologies, grades, ages, etcetera. However, exploration models, targeting criteria and exploration techniques are similar within each 'style', and are outlined below along with descriptions of the essential features of each style.

Key target associations in the North-west Queensland Mineral Province are outlined in **Table 6.2**.

Sediment-hosted Zn, Pb, Ag systems

With seven major deposits aggregating 75Mt of zinc and lead plus more than 2.2 billion ounces of contained silver (**Table 1**), the North-west Queensland Mineral Province ranks as the world's most prolific Zn-Pb-Ag province (**Chapter 8**; **Figure 8.1**). Despite more than fifty years of production and exploration, two of these deposits were found in the past decade, an indication that the Province remains prospective for world-class Zn-Pb-Ag deposits.

The North-west Queensland Mineral Province hosts two main associations of stratabound Zn-Pb-Ag deposits, which constitute prime exploration targets (**Map 3** and **Plate 18**):

- Isa-Century style systems, which include Mount Isa, Hilton, George Fisher, Lady Loretta, Dugald River, Century and others. These deposits (and also the HYC deposit in the McArthur 'Basin' region, contiguous with the North-west Queensland Mineral Province) are hosted by pyritic, carbonaceous (and variably dolomitic) siltstone-shale successions of Cover Sequence 3, and

- 'Broken Hill-Cannington' style systems, including their namesake deposits in the Broken Hill district of New South Wales and the Eastern Fold Belt of the North-west Queensland Mineral Province, respectively. These styles are also hosted by Cover Sequence 3 successions, which are metasediment-dominated but also contain abundant felsic and mafic rocks, metamorphosed under amphibolite facies conditions. These host lithostratigraphic settings, and also the relatively iron sulphide-poor and Cu-Mn-Fe-P- and F-rich compositions of Broken Hill-Cannington style mineralisation, distinguish them from Isa-Century styles.

Isa-Century styles

Among the largest Zn-Pb-Ag accumulations in the world (**Chapter 8**), Isa-Century styles of the North-west Queensland Mineral Province have been assigned to the stratabound 'shale-hosted' class, which occurs worldwide in Proterozoic and Phanerozoic successions. The following key features of Isa-Century Zn-Pb-Ag systems are drawn from major examples in the North-west Queensland Mineral Province and McArthur River (Northern Territory) regions.

- All significant occurrences are hosted by 2 to 8km thick successions of Cover Sequence 3, ranging in age from around 1670Ma (Dugald River) to 1590Ma (Century) (**Map 1**).

  These successions essentially comprise platform, slope and basinal facies, carbonate clastics and siliciclastics, with minor carbonaceous lutites and broadly developed (sulphate-, halite-) evaporitic units. The upper McNamara Group (host to Century) is dominated by siliciclastic sediments. Volcanics and penecontemporaneous intrusions are largely absent from host successions, although these may contain minor 'tuffaceous' components. The sedimentary successions were marine or had an episodic marine connection (Southgate & others, 2000) and formed partly in relatively shallow water environments.

- These Cover Sequence 3 successions are interpreted to represent the products of sedimentation related to thermal subsidence following Soldiers Cap extension and rifting associated with Sybella Batholith magmatism.

  Substrates to these sag phase basins comprise mainly older rift materials, which contain felsic and basic igneous rocks, siliciclastic and less mature sediments, plus some carbonates and evaporites.

  Although the Mount Isa-Hilton system occurs near the older Sybella Granite, there is no clear evidence (from interpretations of gravity or magnetics) for the spatial association of most of the Isa-Century style systems with 'hot' (radiogenic) underlying granites.

- Within the sag successions, Isa-Century style deposits are typically not associated with regional transgressions, namely 'maximum flooding surfaces' (Southgate & others, 2000), which are commonly manifested as regionally extensive, relatively uniform shale- siltstone units. Instead, stratabound Zn-Pb-Ag deposits are localised in districts or 'sub-basins', of 100–200km^2 area, which are characterised by:

  › marked thickening of stratigraphy over a limited interval, reflecting sub-basin foundering/rapid subsidence,

  › uncommon lithofacies, in particular thick accumulations of carbonaceous shale/siltstone accompanied by coarser clastics in one or more coarsening upward cycles, and

  › synchronous local uplift and erosion producing coarser grained facies (arenites and rudites) and local unconformities.

  These facies and thickness variations appear to have resulted from tilt-block formation, compartmentalised by episodic accommodation on intrabasinal fault systems.

- Sub-basins and contiguous uplifted compartments are systematically distributed in space and time, being are localised products of significant reorganisations of basinal architecture. In northern Australia these tectonostratigraphic events (**Map 3**; Southgate & others, 2000) are correlatable basin wide, but their effects are more pronounced in particular zones (as discussed below).

  They punctuate the general sag phase-related subsidence and sedimentation, at around the following times, resulting in locally anomalous successions that contain the following deposits:

Age (Ma)	Deposits (Isa-Century styles)
1670	Dugald River
1655–1660	Mount Isa, Hilton, George Fisher
1640	Lady Loretta, Grevillea, Walford Creek, HYC (McArthur River)
1595	Century

These represent weak basinal scale deformations that correlate with changes in the migration directions and/or rates of the northern Australian Middle Proterozoic Plate (**Map 1**).

- The effects of these deformations and Isa-Century style mineralisation were focused around north-north-west trending zones that are semi-continuous for several hundred kilometres along strike (for example, the Mount Isa-George Fisher-Lady Loretta-Grevillea-Century-Walford Creek zone in the North-west Queensland Mineral Province and the comparable HYC-Loretta (ancestral Emu Fault) in the McArthur Basin) and at the intersections of these zones with NW to WNW and NE-trending zones.

- These north-north-west-trending zones

  › are mappable because of their potential field signatures and effects on basinal sequences and also their behaviour during basin inversion or other later deformation (**Table 5.1**: **Maps 4 and 5**),

  › represent thoroughgoing regional fault systems that were mainly initiated prior to Cover Sequence 3 sag phase sedimentation, but in some cases during 1640Ma extension (**Table 5.1**; **Plate 16**),

- were reactivated during the 1670-1590Ma events noted above,
- were integral to the construction of fertile host environments for Isa-Century style mineralisation, and
- formed a major component of the hydrothermal plumbing systems responsible for this mineralisation (**Plate 16**).

• The sedimentologically anomalous zones hosting stratabound Zn-Pb-Ag mineralisation may

- occur from <1km to >6km stratigraphically above the base of the sag succession,
- be products of localised transpression (for example, around HYC, McArthur Basin; Hinman & others, 1994; Hinman, 1995) associated with fault jogs or intersections (**Plate 16**), and
- potentially be stacked in such settings, successive zones reflecting later fault reactivations corresponding to later basinal deformation events.

• Within host successions, Isa-Century style Zn-Pb-Ag mineralisation occurs:

- in stratabound zones, through 50–700m of stratigraphy,
- typically as concordant to weakly discordant lenses,
- in hosts typically exhibiting strong bedding-parallel stylolitic fabrics (Hinman, 1996),
- in thin bedded to laminated highly carbonaceous lutites, commonly spatially associated or interbedded with lutites containing abundant fine-grained pyrite-rich laminae,
- in broader stratabound envelopes of secondary ferroan carbonate (for example, siderite at Century, Broadbent & others, 1998; ankerite at McArthur River, Hinman, 1998),
- without footwall alteration zones, as commonly associated with VHMS deposits, and
- parts of local stratabound zones in which there may be evidence for anomalous maturation and degradation of kerogen reflected in the unusual organic geochemistry of host sediments (Hinman, 1998). There may be evidence even for the former presence of fluid hydrocarbons.

• Zn-Pb-Ag mineralisation post-dates early diagenetic, fine-grained pyrite and comprises:

- sphalerite, galena ± pyrite and silver sulphosalts, and
- fine pore infills and replacements of carbonate, as well as hydrothermally deposited Fe-rich (and ^{13}C-depleted) carbonates and, in some cases, precipitated carbon, for example, Century (Broadbent & others, 1998).

• Prior to base metal mineralisation and at temperatures compatible with biogenic sulphate reduction, hydrothermal infiltration of these organic-rich sediments may have resulted in the formation of the abundant stratabound iron sulphide that characterises Isa-Century style host successions (Hinman & others, 1994).

• Zn-Pb-Ag mineralisation formed during bedding sub-parallel infiltration of hydrothermal fluids after shallow burial (Hinman, 1996) and in some cases, significant compaction (Broadbent & others, 1998); it was facilitated by primary and secondary porosity, fluid overpressuring resulting from hydrocarbon generation due to the interaction of organic matter with hydrothermal fluids, and probably also by bedding plane slip.

• As Zn-Pb-Ag mineralisation demonstrably post-dates the sedimentary deposition of its rocks, there is the possibility that significant metal contributions reflect later events:

- Broadbent & others (1998) have suggested that stratabound mineralisation at Century relates to D_1, or basinal inversion,
- Pb isotope data for deposits such as Lady Loretta (for example, Carr, 1996) indicate Pb additions through a broad time interval (**Map 1**) which could encompass several basinal events, and
- Such events could potentially result in mineralisation through a range of favourable lithostratigraphic intervals. The recognition of these favourable potential hosts remains a prime exploration tool.

• The main processes contributing to Zn-Pb-Ag mineral deposition were:

- fluid cooling,
- dissolution of host rock carbonate, with consequent pH increases, and
- thermochemical sulphate reduction due to the interaction of Zn-Pb-Ag-transporting fluids with organic matter and also mingling with migrated but locally sourced hydrocarbons; inorganically precipitated carbon was also produced (Hinman & others, 1994; Hinman, 1998; Broadbent & others, 1998).

These processes emphasise the significance of organic-rich and calcareous successions as potential hosts for Isa-Century style mineralisation.

• Ore component transporting fluids are inferred to have been:

- initially at temperatures of 100° to 150°C, resulting from circulation deep into the sedimentary pile and basement followed by rapid ascent in fault systems to ore depositional environments,
- highly saline (reflecting evaporitic sources) and consequently relatively acid, particularly if the fluids were clay-carbonate buffered during circulation (for example, Heinrich & others, 1990); and hence,
- sulphate-bearing, H_2S-poor and metal enriched, namely, metals >H_2S and SO_4 >H_2S; and thus,
- barium- and copper-poor, but with relatively high Zn/Pb ratios, features reflected in the chemistry of the mineralised zones.

• The fluid circulation systems that gave rise to Isa-Century style mineralisation are poorly understood, but evidently involved (**Plate 16**):

- fault-related recharge zones that accessed evaporitic fluids from surface and/or sediment reservoirs,
- migration through rock masses at temperatures around 150 C or more (implying depths of five or more kilometres, in the absence of penecontemporaneous igneous intrusions for which there is no evidence at the time of mineralisation); this implies migration through zones of adequate permeability deep in the host sag succession and also its basement. Such aquifers could have included sandstone units and fractured basement,
- cross stratal fluid flow in fault zones connecting deeply circulated basinal fluids to discharge zones in which mineralisation could form,
- topographically related head- and thermally-driven fluid flow resulting from uplift of adjacent fault bounded compartments during transpressional deformation (for example, Hinman & others, 1994; Hinman, 1995), and
- alternatively, an episodically recharging, sealing and discharging system, related to fault movements and deformation of fault localised compartments.

These considerations emphasise the importance of fault-related compartmentalisation of Isa-Century style mineralising systems active during several weak, basin-wide deformation events in the northern Australian Middle Proterozoic.

- The essential elements of, and target criteria for, Isa-Century style Zn-Pb-Ag systems are summarised in **Plate 16**.

Exploration methods

- Key tools in the recognition of Isa-Century style systems at district scale are:
  - stratigraphic studies aimed at clarifying the distribution of critical event stratigraphy and characteristic host lithofacies,
  - geological mapping and the interpretation of geophysical data (magnetics, gravity and electromagnetics) to define the fault systems that form key parts of plumbing systems and compartmentalise lithofacies distributions, and
  - reflection seismic studies, which can also contribute significantly to fault and stratigraphic mapping.
- Electrical geophysical techniques are mainly useful as tools for mapping at district and prospect scales. In most of the North-west Queensland Mineral Province, prospective carbonaceous (and pyritic) host lithological packages are conductive, limiting the direct imaging of base metal sulphide conductors. However, in the Murphy-South Nicholson domains, organic maturation levels are comparatively low and EM methods can be used successfully to detect pyritic and/or base metal sulphide-rich conductors.
- Conventional geochemical and gossan recognition tools are applicable in areas lacking appreciable transported, post-mineralisation cover.
- Isa-Century style mineralisation may be enveloped by stratabound haloes exhibiting
  - lead and zinc anomalism and veining reflecting mobilisation of these components,
  - Fe- and Mn-enriched secondary carbonates in infiltration zones distal to mineralisation,
  - anomalous organic geochemistry resulting from hydrothermal fluid – kerogen interaction (Hinman, 1998), and
  - other anomalous trace and minor element patterns (for example, McGoldrick & Large, 1998).

Broken Hill-Cannington styles

Cannington, like other Broken Hill-style deposits, contains high grade, high net-worth ore (including silver at 500g/t levels), justifying underground development. Concealed Broken Hill-Cannington style targets may thus be sought under substantial depths of cover.

There has been much debate on the origin and timing of Broken Hill-style mineralisation, for example the cases of Cannington and Pegmont, summarised by Williams (1998). We accept the evidence put forward by Bodon (1998) and also Walters & Bailey (1998) that Cannington contains stratabound Ag-Pb-Zn mineralisation formed in sedimentary hosts prior to amphibolite facies metamorphism and deformation.

However, Cannington and other Broken Hill-style mineralisation has (in part) undergone profound metasomatic modification during deformation under prograde and retrograde metamorphic conditions (see also Webster, 1996; compare with Hobbs & others, 2000, regarding Broken Hill, New South Wales). Given a pre-metamorphic origin for Broken Hill-style mineralisation, lithostratigraphic setting and localisation are key elements of exploration models targeting such deposits:

  - Cannington and other Broken Hill-style mineralisation are hosted by interlayered, quartzofeldspathic, quartz-rich and aluminous (for example sillimanite-, garnet-rich) rocks. The layering characteristics and composition of such rocks indicate a sedimentary protolith of psammite-dominated packages with some pelites (Wall & others, 1976; Wright &others, 1987; Allen & others, 1996). The psammite-rich host metasediment packages commonly exhibit subdued magnetic signatures (for example Cannington (**Map 7**)) that may be utilised in tracing target stratigraphy under cover. In the North-west Queensland Mineral Province, the key target stratigraphy for Broken Hill-Cannington style mineralisation is correlated with the boundary between Soldiers Cap 2 and Soldiers Cap 3 packages.
  - Stratabound sulphide-rich mineralisation occurs in distinctive iron, manganese and calcium-rich hosts typically manifest as unusual Fe- and/or Mn-, Ca- rich silicates ±magnetite, calcite, fluorite, apatite, carbonate, etcetera. These host rocks may be interpreted as chemical sediments (exhalites — for example, Stanton, 1972) or calcareous- and/or quartz-rich sedimentary rocks that underwent partial replacement and/or other forms of hydrothermal alteration synchronous with and postdating mineralisation (Wright & others, 1987; Webster, 1996). The mineralogically and geochemically distinctive (Fe-, Mn- and Ca-rich) stratabound zones are spatially restricted and are a favourable indicator for Ag-Pb-Zn mineralisation.

- It is noteworthy that, although Cannington contains magnetite-rich zones, Broken Hill (New South Wales), Bergslagen (Sweden) and other Broken Hill-style mineralisation lack abundant magnetite.
- Stratabound mineralisation may be enveloped by broadly stratabound:
  - zinc anomalism, manifest as gahnite-rich spinel in aluminous compositions,
  - zones of strongly peraluminous, sodium-depleted rock compositions, interpreted to represent feldspathic psammites or felsic igneous protoliths that underwent hydrothermal sericite-clay ± chlorite, carbonate alteration prior to regional metamorphism (Wall & others, 1976),
  - zones of ^{18}O depletion interpreted to represent pre-metamorphic hydrothermal alteration (Cartwright, 1998). As in the case of the aluminous alteration zones, the stratabound ^{18}O depletion is confined mainly to the stratigraphic footwall of mineralisation.
- Beeson's (1990) model for the lithostratigraphic localisation of Broken Hill-style deposits appears to be applicable to this association in the North-west Queensland Mineral Province and worldwide. According to this model, Broken Hill-style mineralisation occurs in one or more psammite-dominated intervals stratigraphically below a thick, meta-siliciclastic-dominated sequence, and overlying or layered with calcareous units and iron formations (**Plate 17**).

In turn, these stratigraphically overlie successions that are increasingly more feldspathic (that is, less compositionally mature sediments and volcanogenic material) towards the base of sequence. These successions may include felsic and mafic volcanics and commonly concordant intrusives, later metamorphosed to felsic and mafic gneisses (**Plate 17**). The Broken Hill district (New South Wales; Hobbs & others, 1984; Stevens & others, 1984) and the Berslagen region (Sweden; Allen & others, 1996) provide good bases for these lithostratigraphic models.

- The lithological constitution, stratigraphic evolution and architecture of the Eastern Fold Belt in the North-west Queensland Mineral Province, and of other successions hosting Broken Hill-style mineralisation, are consistent with their evolution in a rift zone (Hobbs & others, 1984), followed by sag (thermal subsidence) phase sedimentation (**Plate 17**). Evidence for this includes:
  - metasedimentary protoliths become more compositionally mature up sequence,
  - the proportions of igneous-derived materials (feldspathic sediments, volcanics and penecontemporaneous intrusions) also decrease up sequence, and such materials are largely absent from the sag phase,
  - igneous activity was bimodal, comprising both felsic and mafic components, and

› broadly contemporaneous sedimentary sequences outside the inferred rift comprise thinner successions of shelf carbonates, evaporites and siliciclastics.

- In such rift settings, Broken Hill-style mineralisation is localised at the top of the rift succession/bottom of the sag phase, corresponding to the last manifestations of rift-related igneous activity.

For the Eastern Fold Belt of the North-west Queensland Mineral Province, we interpret the rift-sag boundary to correspond to the Soldiers Cap 2 – Soldiers Cap 3 boundary (**Map 1**), units above this stratigraphic level representing sedimentation related to thermal subsidence. Where the Soldiers Cap rocks crop out, Soldiers Cap 2 includes the Mount Norna Quartzite, whereas Soldiers Cap 3 contains the Toole Creek Volcanics.

- The inferred rift environments of sequences hosting Broken Hill-style mineralisation contrast strongly with host environments of Isa-Century style mineralisation, but may exhibit some parallels with VHMS settings (**Plate 17**):

› subvolcanic (rift stage) intrusions may play a significant role in driving fluid circulation systems involved in forming early stratabound mineralisation,

› the most effective heat sources to drive large circulation systems are gently dipping sills (Cathles & others, 1997), and

› the chemical character and metal ratios of Broken Hill lodes, which differ from those of many VHMS deposits, may partly reflect an evaporite fluid source and fluid path history through the relatively oxidised rift succession (Plate 17).

Stratabound zones of metadolerite sills in Soldiers Cap 2, and massive felsic gneisses in this and underlying units in the Eastern Fold Belt of the North-west Queensland Mineral Province, may represent subvolcanic (rift stage) intrusions involved in mineralising hydrothermal systems (**Plate 17**). The Broken Hill (New South Wales), Bergslagen (Sweden) and Sullivan (Canada) districts all exhibit major subvolcanic intrusions in the stratigraphic footwalls of ore zones. Identification of similar features in the North-west Queensland Mineral Province may assist in targeting Broken Hill-Cannington style mineralisation.

- The Cannington deposit lies on a prominent north-north-west-trending lineament in an intersection with west-south-west- and also north-east-trending features. We interpret these elements, respectively, as sidewall or transfer systems, rift normals and reactivated (Cover Sequence 2) structures, reflecting north-north-west extension during the Soldiers Cap rift event (**Map 1; Table 5.1**).

We infer that these fault systems controlled rift stage basinal architectures and compartmentalised sedimentation. They provided the main cross stratal fairways for hydrothermal fluids, as well as focusing these fluids into potential host sedimentary compartments.

On these or empirical grounds, these fault systems, particularly around intersection zones, are key target zones for Broken Hill-Cannington style deposits in the North-west Queensland Mineral Province. Prime targets are where these fault systems intersect the Soldiers Cap 2-Soldiers Cap 3 boundary, particularly where this boundary is within about 500m of the surface.

- The essential elements of, and target criteria for, Broken Hill-Cannington style systems in the North-west Queensland Mineral Province are outlined in **Plate 17**.

Exploration Methods

- Most of the key Soldiers Cap target stratigraphy is under post-mineralisation cover. Useful exploration tools are:

› detailed interpretation of high resolution magnetics aimed at distinguishing and mapping key lithostratigraphy as well as structure. The interpretation of magnetic data can be complicated by metasomatic (and related magnetic) effects of alteration in the roof zones of Williams-Naraku age plutons,

› EM datasets may also be useful in mapping Soldiers Cap lithological packages; carbonaceous units in Soldiers Cap 3 and overlying stratigraphy are commonly good conductors,

› EM can also be useful in identifying sulphide lenses, which can be strongly conductive in Broken Hill-style environments,

› lithogeochemistry and petrological studies aimed at recognition of the distinctive Fe-, Mn- and Ca-rich and Pb-Zn anomalous rocks that are characteristic of mineralised psammitic packages. Alteration related to Williams-Naraku and Maramungee age pluton suites may complicate interpretations (for example, Bodon, 1998; Chapman & Williams, 1998),

› at prospect and somewhat broader scales, detailed gravity may be useful in identifying dense zones that could relate to massive sulphide lenses, and

› more effective targeting of Broken Hill-Cannington style systems will result from refinement of mapping of the key sets of linears/fault systems through continued interpretation of gravity and magnetic datasets, integrated with structural and lithostratigraphic studies.

Other Sediment-hosted Zn-Pb-Ag

- Other sediment-hosted Ag-Pb-Zn occurrences in the North-west Queensland Mineral Province may include veins, breccias and replacements, or composites of these styles in both Proterozoic and Palaeozoic hosts (**Map 3**). Although some districts (such as Lawn Hill) had significant but small-scale production, individual deposits contain small to very small resources.

- Composite styles, particularly those hosted by carbonates or carbonate-cemented sandstones may have greater exploration potential and may present metallurgically clean, zinc-rich resources. Examples in the northern Australian Proterozoic include the Coxco system near McArthur River, as well as some mineralisation at the Walford Creek and Kamarga prospects.

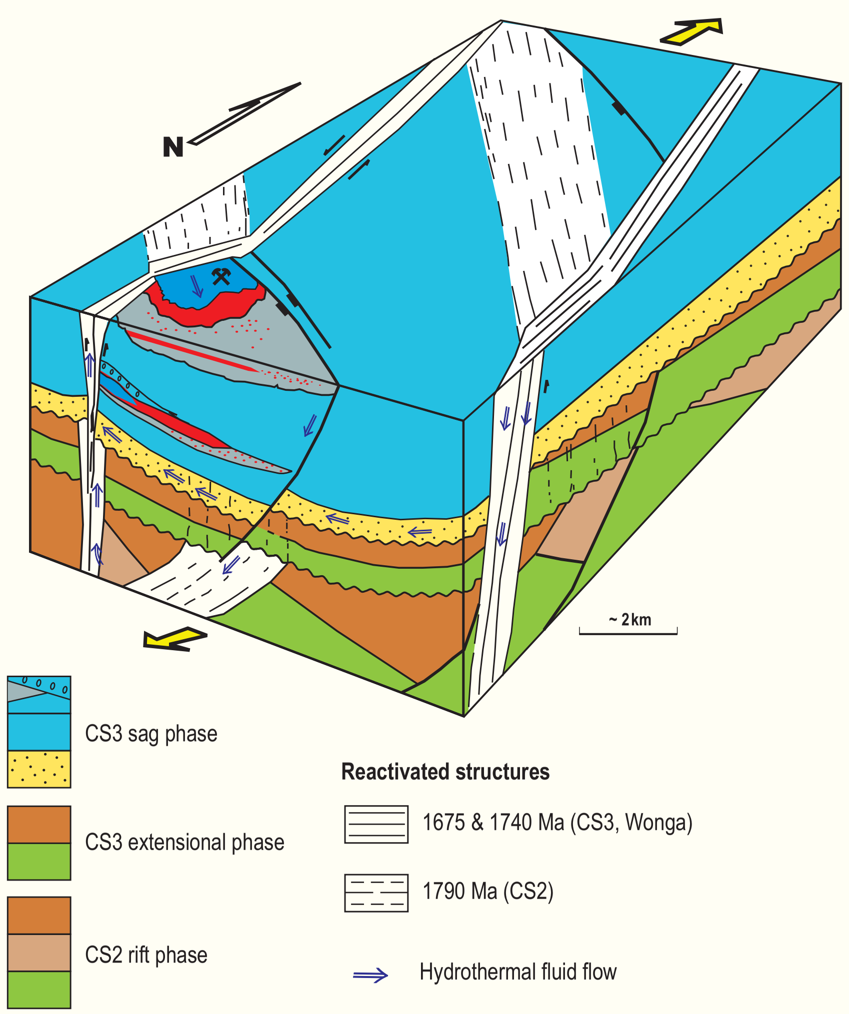
- Although some carbonate-hosted occurrences are known in the Eastern Fold Belt, the main potential is thought to be in Cover Sequence 3, carbonate-rich sequences in the western half of the North-west Queensland Mineral Province where these potential hosts interact with the fault systems to which Isa-Century style mineralisation is related; and where these fault systems have been appropriately oriented to reactivate during the main stage of D_1 basin inversion and later deformational events.

- Carbonate-hosted base metal mineralisation may also be sought in the Cambrian units of the Palaeozoic cover; near the unconformity with the Proterozoic; and in the vicinity of fault systems active during the main Palaeozoic deformation (**Chapter 5.4; Plate 11**).

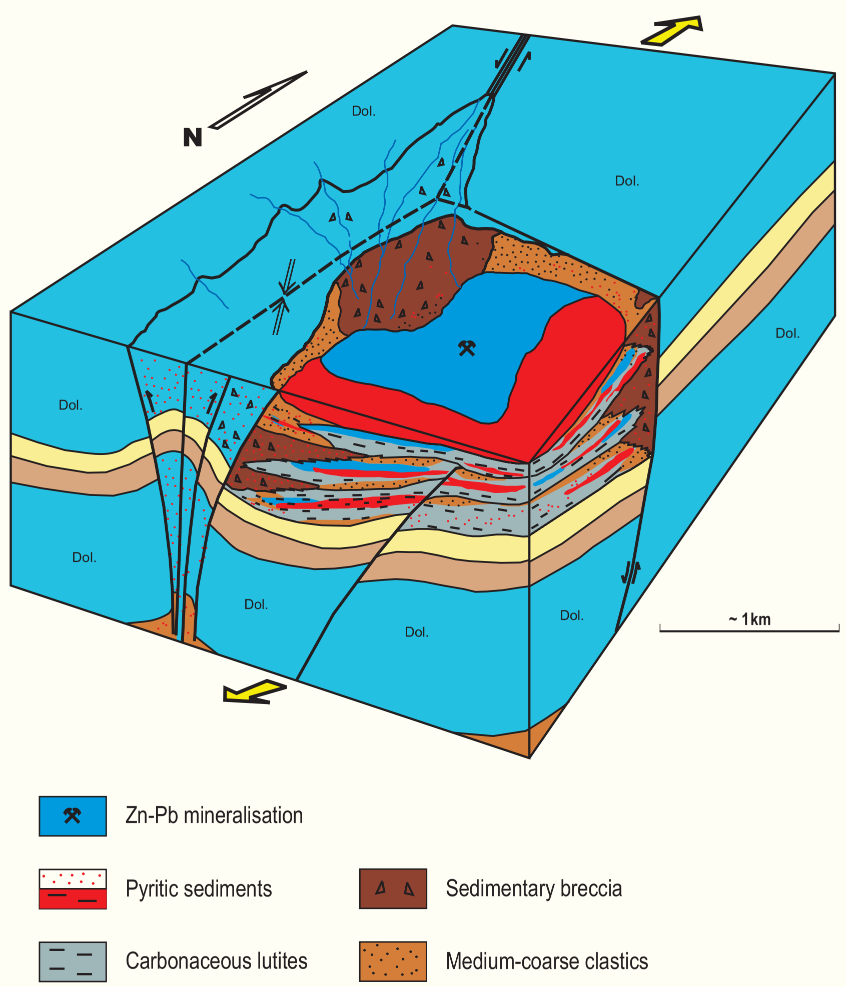
TARGET MODELS

STRATABOUND Zn-Pb-Ag: ISA-CENTURY-STYLES

REGIONAL TECTONOSTRATIGRAPHIC MODEL



STRUCTURAL AND LITHOSTRATIGRAPHIC LOCALISATION



ESSENTIAL ELEMENTS	
	▪ Brine, high SO_4^{2-} / H_2S, 100-200°C - evaporite source - acid fluid (? clay-carbonate buffer) ▪ Fault system – related fluid circulation system connecting - fluid recharge zone - faulted basement and basal sandstone aquifer - fluid discharge fault zone ▪ Fault system active/reactivated episodically during one or more mineralizing events and sedimentation ▪ Related foundering sedimentation compartments (sub-basins) - accumulating organic-rich sediments and coarser clastics - related to accommodation zones of fault systems ▪ Fluid infiltration zones - fed by discordant fault systems - in organic-rich sedimentary packages ▪ Ore deposition in infiltration zones - interaction with kerogen, and/or mixing with reduced fluids effecting thermochemical sulphate reduction - host rock carbonate dissolution and acid neutralisation - fluid cooling

TARGET CRITERIA

Mineralisation: Supersequences and event(s)	▪ Gun, Loretta, River, Wide; - suprabasinal events 1660-1590Ma - Isan D_1
Tectonostratigraphic domains	▪ South Murphy, Lawn Hill, Mount Oxide-Gunpowder, Mount Isa, Wonga Belt
Regional structural settings	▪ NNW trending zones active during above events - reactivated Cover Sequence 3 (and ?Wonga) accommodation systems: sidewalls/transfer systems ▪ at intersections with NW-, EW-, NE-, trending basement fault systems - reactivated earlier rift structures of Cover Sequence 2, Wonga ages
Local structural settings	▪ Associated with syn-sedimentation fault systems - NS to EW orientations ▪ Fault bound compartments exhibiting block tilting and anomalous sedimentation
Host lithostratigraphic settings	▪ Sag phase sedimentary successions - Cover Sequence 3, as above ▪ Carbonate- and siliceous clastic packages containing - carbonaceous lutites - interbedded with coarser clastics ▪ Anomalous thickness distributions of these sedimentary facies in fault-related sub-basins
Mineralisation indicators	▪ Abundant stratabound fine-grained (diagenetic) pyrite ▪ Ferroan carbonate alteration envelope and stylo-laminated lutites ▪ Zn and Pb anomalism – stratabound and in early and late vein systems ▪ EM conductors reflecting abundant sulphides as well as carbonaceous metasediments

PLATE 16

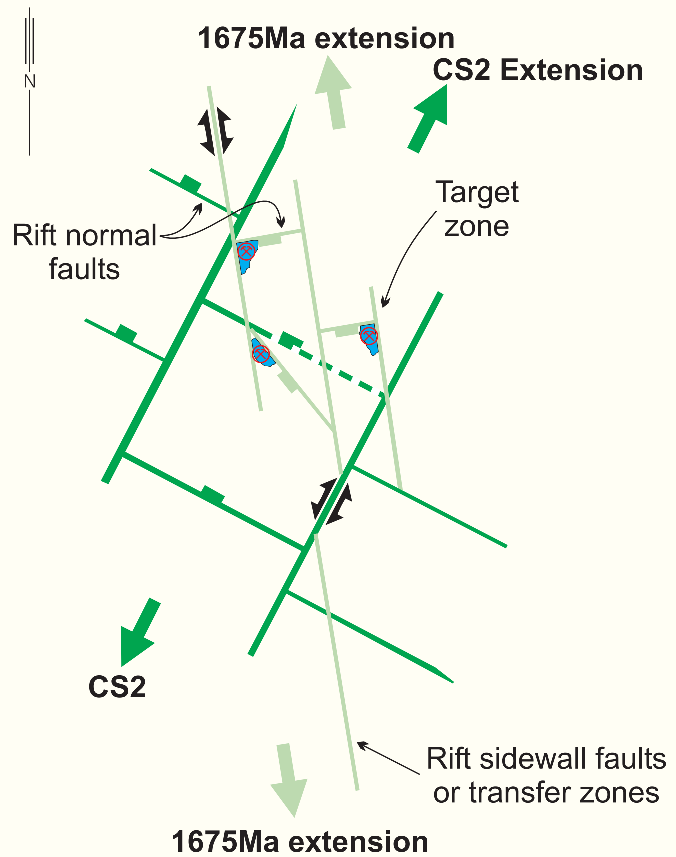
2000B/TD-09-00/NWQld/IsaCentStrata.cdr

PLATE 17

TARGET MODELS

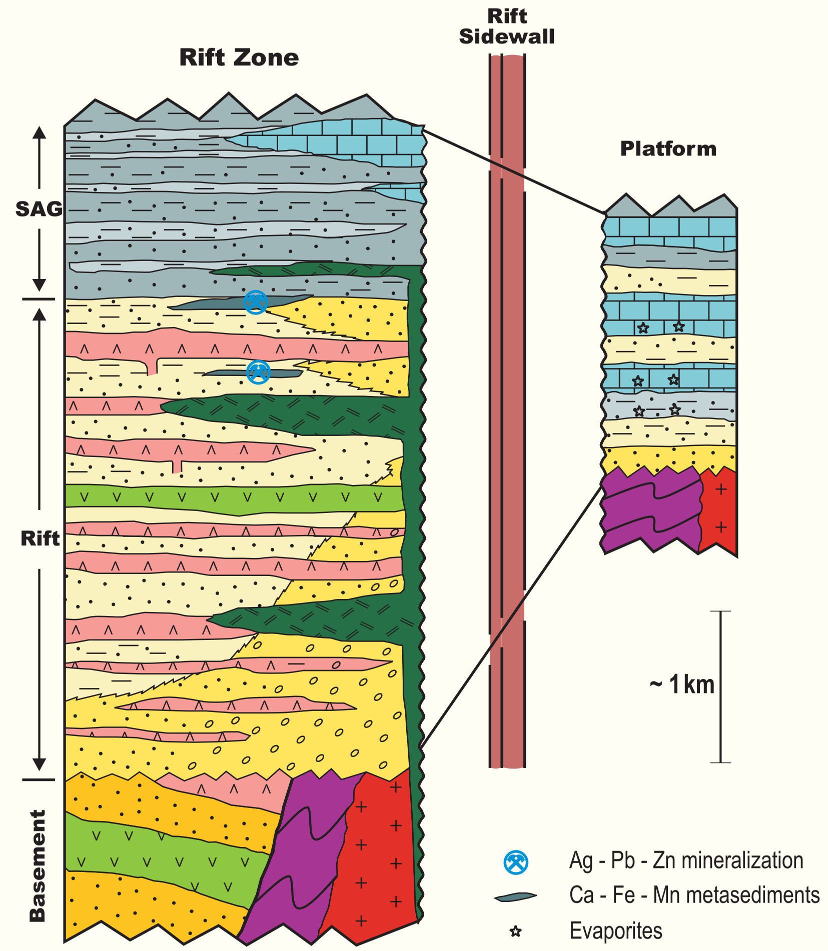
STRATABOUND Ag-Pb-Zn: CANNINGTON-BROKEN HILL STYLES

TECTONIC SETTING: 1680Ma RIFT ZONE



Stratabound Ag - Pb - Zn mineralization is interpreted to be localised by sedimentary packages and hydrothermal systems controlled by 1675Ma rift structures, and also reactivated fault systems

LITHOSTRATIGRAPHIC MODEL



This model emphasises the importance of near rift top host stratigraphic packages, contiguous platform evaporate-bearing successions and footwall sills.

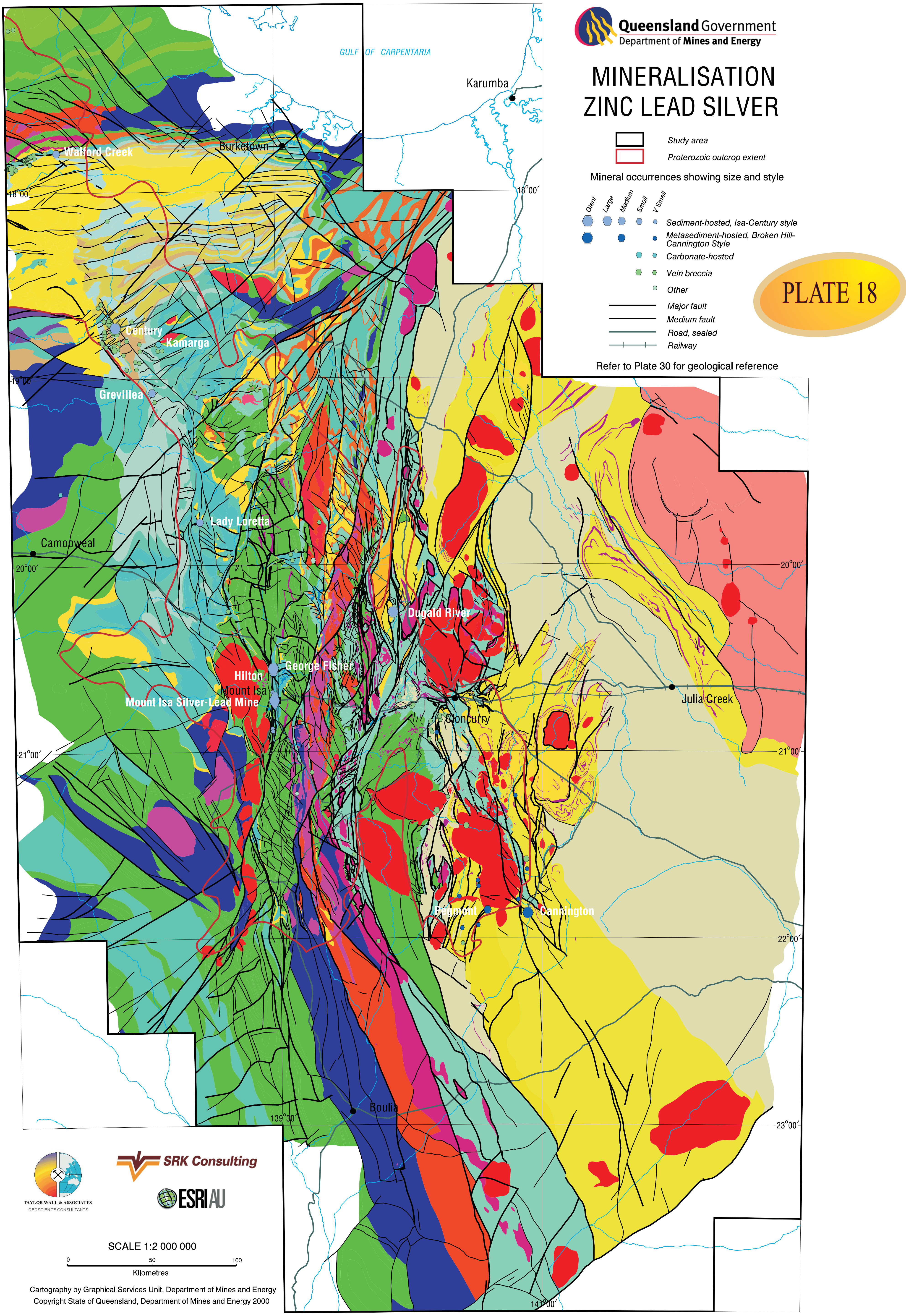
ESSENTIAL ELEMENTS

- Analogies with both VHMS and clastic sediment-hosted Zn-Pb-Ag systems
- Late rift phase clastic sedimentation
  - near cessation of bimodal igneous activity
  - immediately prior to commencement of sag phase sedimentation
- Contiguous evaporitic shelf succession, source of brines
- Fault-related fluid circulation system, active during
  - host succession sedimentation
  - igneous intrusion into rift succession
- Mineralisation: exhalative and/or subseafloor replacement of calcareous lithologies

TARGET CRITERIA

Mineralising event(s)	▪ Soldiers Cap rift (1690-1670Ma)
Tectonostratigraphic domains	▪ Eastern Fold Belt ▪ Wonga Belt
Regional structural settings	▪ Rift sidewall faults or transfer zones - NNW-trending ▪ at intersections with rift normal faults and/or reactivated basement structures - EW- to NW-trending
Local structural settings	▪ Mafic and/or felsic sills structurally/stratigraphically underlying target region
Host lithostratigraphic settings	▪ Top-of-rift stratigraphy - upper Soldiers Cap unit SC2 - lower Sc3 (subdued magnetics, psammite-dominated metasedimentary succession) ▪ stratigraphically below more mature siliciclastics: sag phase sediments, (Soldiers Cap unit SC3)
Mineralisation indicators	▪ Ca-Mn-Fe rich metasediments - may include BIF's ▪ Siliceous metasedimentary package - stratabound footwall alteration zone ▪ associated, stratabound Pb-Zn anomalism - eg gahnite-bearing metasediments

2000B/TD-09-00/NWQld/Cann_BrokHill AgPbZn.cdr


Queensland Government
Department of Mines and Energy
MINERALISATION
ZINC LEAD SILVER
Study area
Proterozoic outcrop extent
Mineral occurrences showing size and style
Giant
Large
Medium
Small
V Small
Sediment-hosted, Isa-Century style
Metasediment-hosted, Broken Hill-Cannington Style
Carbonate-hosted
Vein breccia
Other
Major fault
Medium fault
Road, sealed
Railway
Refer to Plate 30 for geological reference
PLATE 18
GULF OF CARPENTARIA
Karumba
Burketown
Walford Creek
Century
Kamarga
Grevillea
Lady Loretta
Camooweal
Dugald River
George Fisher
Hilton
Mount Isa
Mount Isa Silver-Lead Mine
Cloncurry
Julia Creek
Pegmont
Cannington
Boulia
18°00′
19°00′
20°00′
21°00′
22°00′
23°00′
139°30′
141°00′
TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS
SRK Consulting
ESRI AU
SCALE 1:2 000 000
0
50
100
Kilometres
Cartography by Graphical Services Unit, Department of Mines and Energy
Copyright State of Queensland, Department of Mines and Energy 2000

Metasediment-hosted copper: Isa-style

- These systems contain deposits that are notable for their high copper grades (>3 to 4% copper) and include world-class deposits, such as those at Mount Isa, with copper metal contents aggregating in excess of 10Mt at these grades (**Table 1**).

- Hypogene Isa-style mineralisation is typically chalcopyrite-dominated, with potential by-product cobalt and low, but anomalous gold. Ores are commonly metallurgically 'clean' and straightforward.

- The high sulphide content of hypogene Isa-style mineralisation may result in substantial supergene copper resources. For example, the Mount Gordon Project (Esperanza, Esperanza South and Mammoth deposits) has a resource of around 1Mt contained copper (**Table 1**), much of this in the form of high-grade chalcocite ore, amenable to pressure leach, solvent extraction and electro-winning of copper metal. Western Metals Ltd production from Mount Gordon is approaching 50 000tpa copper at cash costs of around US$0.31/lb, with project capital costs under US$150 million.

- Given their high grades and metallurgical characteristics, Isa-style copper systems are major exploration targets in Proterozoic rocks of the North-west Queensland Mineral Province, and also offer potential for medium-to-large tonnages.

- Isa-style deposits are archetypes of the sediment-hosted breccia copper association that is uncommon but is widely distributed in space and time, with examples known from Proterozoic to Mesozoic ages on at least five continents (Waring & others, 1998; Wall, 1999). The ore-forming systems involve similar chemical processes to other sediment-hosted copper systems, but represent the relatively high temperature end of the spectrum of syn-diagenetic to low-grade metamorphic ore-forming environ-ments.

- Mineralisation is hosted by, or spatially associated with carbonaceous, pyritic and dolomitic metasediments, and is associated with diagnostic dolomitic/ferroan carbonate and siliceous alteration ('silica-dolomite') in the form of breccias, vein networks and replacements (for example, **Figure 6.1**; **Plate 19**). These alteration systems are associated with fault-fold systems and commonly form relatively late in the low grade metamorphic and deformation history of the host metasediments.

- The giant deposits of the Isa-Hilton zone, similar smaller deposits and numerous other occurrences are confined to the low-grade metamorphic domains in the west of the North-west Queensland Mineral Province (**Map 3; Plate 20**). However, similar lithological settings in more easterly domains may host related styles.

The essential elements of Isa-style copper systems (Waring & others, 1998) are summarised as follows:

- Saline, H_2S-poor, relatively oxidised fluids ($SO_{4\ total}$ H_2S), are required for the mobilisation and transport of copper, sulphur and other ore-forming components. Under subgreenschist to greenschist facies (200° to 400°C) conditions, such brines can transport potentially ore-forming concentrations of copper and other components (Co, Ni, As) characteristic of Isa-style deposits (Heinrich & others, 1995).

  These fluids may represent evolved basin brines, sourced in or above Cover Sequence 3 evaporitic environments (evidenced by high Br/Cl fluid inclusions, Heinrich & others, 1995), and these were further modified by interaction with rock masses of relatively low redox capacity (for example, oxidised and/or sulphide-poor lithologies).

- Pyritic, carbonaceous and (preferably) dolomitic metasedimentary successions are the favoured potential hosts for mineralisation. Such rocks are:

  › if calcareous (or dolomitic), effective sinks for acid by carbonate dissolution accompanying silicification and thereby contributing to copper sulphide precipitation by increase of fluid pH,

  › highly reduced compared with ore-forming fluids and also oxidised rock masses, and

  › localised sources of reductants (CH_4) by hydrothermal fluid rock interaction associated with fluid infiltration through carbonaceous and pyritic rocks, for example:

  $$2C + 2H_2O = CO_2 + CH_4$$

  and also of H_2S.

  Mixing of these fluids with oxidised brines may contribute to the precipitation of copper and iron sulphides (Heinrich and others, 1995) or pyrite replacement, namely:

  $$8Cu^+ + 8FeS_2 + CH_4 + 2H_2O = 8CuFeS_2 + CO_2 + 8H^+$$

  or, at an earlier stage than copper mineralisation, the formation of hydrothermal that may be later replaced by chalcopyrite pyrite (for example at Mount Gordon, Richardson & Moy, 1999).

  Each of the above mechanisms has been inferred to contribute to the formation of high grade copper ores at Mount Isa (Heinrich & others, 1995, 1998) and Mount Gordon (Wall, 1999).

- The main accumulations of pyritic carbonaceous lutites in Cover Sequence 3 are localised in sub-basins confined by accommodation zones resulting from episodic reactivation of fault systems accompanying sedimentation and also hosting stratabound Zn-Pb-Ag mineralisation (**Chapters 5.5, 6** above; **Table 5.5**).

  These tectonostratigraphic packages and structures thus potentially define target zones for Isa-style metasediment-hosted copper as well as for Zn-Pb-Ag deposits. The Mount Isa-Hilton district, in which the copper and lead-zinc mineralisation are spatially overlapping (**Figure 6.1; Map 3**), is a prime example of these relationships.

- Isa-style copper mineralisation occurs in, and is paragenetically associated with, an envelope of carbonate-quartz + magnesian silicate (chlorite, talc, phlogopite), sulphides and albite alteration, colloquially known as 'silica dolomite'. This type of alteration is most extensively developed in dolomitic metalutites, for example at Mount Isa (Figure 6.1, Plate 19) where 'silica dolomite':

  › forms broadly bedding-concordant to somewhat discordant, steeply dipping, shallow plunging zones,

  › comprises zones of carbonate grain-coarsening, ferroan carbonate-quartz veining, brecciation and replacement that are synchronous with shear zones, subparallel to layering, accompanied by Mg-rich alteration in footwall metabasics, part of a district scale (>10km long by up to 2km wide by >1km high) envelope of systematic ^{18}O and ^{13}C depletion, manifested in alteration carbonate (Waring 1990, Waring & others, 1998; **Figure 6.1**), and represent dilational infill and fracture-bedding controlled replacement (Perkins, 1984),

  › is zoned from an outer envelope of sparse dolomitic (chalcopyrite) veins, downwards and inwards through a more intense network of dolomitic-quartz-chalcopyrite veins and associated coarse dolomite growth, to a replacive (veined and brecciated) siliceous core. With advancing alteration, the latter progressively overprints dolomitic veining and replacement; copper grade correlates with intensity of silicification (Waring, 1990; Waring & others, 1998) (**Figure 6.1**). Quartz deposition is accompanied by carbonate replacement, and may also reflect fluid cooling and dilatancy-induced fluid pressure drops,

  › has mineral assemblage zoning and isotopic patterns that reflect progressive interaction of hydrothermal fluid with infiltrated host rocks at ~300° to 350° C (Heinrich & others, 1989; Waring & others, 1998),

- has stable isotopic, alteration and ore patterns that define a north-trending zone of fluid infiltration into the Mount Isa Group that is localised above the shallow dipping and plunging contact with metabasic volcanic contacts (**Figure 6.1; Plate 19**), and is spatially associated with the north-trending Mount Isa and related fault systems (**Plate 19**),

- overprints the stratabound Zn-Pb-Ag mineralisation (Perkins, 1984; Valenta, 1994) resulting in partial to complete dissolution of the latter, high Ag/Zn and Pb/Zn proximal to 'silica dolomite', and 'downstream' formation of late Pb-Zn sulphide veins and replacements (Perkins, 1997; Wall, 1999).

• In carbonate-poor host sediments, for example at Mount Gordon, copper mineralisation is accompanied by less extensive alteration, which takes the form of silicification and quartz and quartz-carbonate veining (Richardson & Moy, 1999).

• 'Silica-dolomite' alteration and Isa-style copper formed late to post D_2 regional deformation and

- associated with D_3 shortening (Perkins, 1984; Bell & others, 1988; Valenta, 1994), locally manifested as fault-fold systems,

- with absolute ages circa 1520Ma (Perkins & others, 1999),

- under peak to somewhat metamorphic regional metamorphic conditions, ranging from sub- to upper greenschist facies, as evidenced by alteration assemblages and fluid inclusion data (Heinrich & others, 1998).

• In Isa-style systems, infiltration of ore-forming fluids into and through metasedimentary, potential host packages is fracture-controlled and localised by:

- fault-fold systems and shear zones (for example, Mount Isa-Hilton and Mount Gordon systems; Plate 19),

- dilation at zones associated with fault jogs, stepovers and intersections (for example Mount Gordon; Van Dijk, 1991; Richardson & Moy, 1998; Plate 19),

- at finer scales, mechanical contrasts among host metasediments reflecting bedding controlled and alteration-related heterogeneities (Valenta, 1994; Wall, 1999).

• Giant Isa-copper style alteration and mineralisation systems form where fluid infiltration was subparallel to the stratigraphic layering of chemically receptive hosts, for example at Mount Isa where infiltration was facilitated by dilation of the basement metavolcanic/Mount Isa Group contact, and shallow-dipping extension fracturing in response to east to north-easterly oriented shortening and related steep extension directions (Bell & others, 1988; Valenta, 1994).

Large Isa-style targets (**Plate 19**) may also be anticipated where appropriate metasediments are relatively shallow dipping in fold/fault systems, and in fold hinge zones and/or around thrust fault systems that were active/reactivated during D_3 deformation.

• Cover Sequence 2 metabasic volcanics, commonly basement to Cover Sequence 3, have undergone extensive oxidised and magnesian alteration in the vicinity of Isa-style copper mineralisation, for example below the 'silica dolomite' system at Mount Isa (Figure 6.1; Plate 19). This alteration:

- forms kilometre scale zones of carbonate-albite-Fe oxide ± biotite, chlorite assemblages, with local uranium + copper mineralisation (for example the Valhalla deposit, Chapter 6.2; Map 3; Plate 25 below) and overprints peak regional greenschist facies grade oxidised assemblages,

- is localised by N-S fracture/shear zones cross cutting/overprinting D_2 fabrics and structures and kinematically consistent with D_3 deformation and dated around 1530Ma (Perkins & others, 1999),

- involves fluids similar to those forming the Isa copper systems (Heinrich & others, 1995), having similar ^{18}O and D/H isotopic signatures, similar salinities and high Br/Cl, and which were relatively oxidised (that is, SO_4 dominant); the latter implies passage of sulphate-bearing brines (presumably sourced in/above Cover Sequence 3) through the basement metavolcanics.

• At broader scales, Isa-style copper systems are associated with regional fault sets active/reactivated during D_2-D_3 deformation. These fault systems may (for example, **Plate 19**):

- transect Cover Sequence 3 (potential host) stratigraphy and basement,

- effect cross-formational fluid flow, and connect fluid and solute sources with ore depositional regions,

- include reactivated segments of fault systems that localised pyritic carbonaceous lutite sub-basins that may also host stratabound Zn-Pb-Ag deposits,

- juxtapose reduced metasediments with more oxidised/sulphide-poor rock masses (for example, basement metavolcanics and rift phase sediments),

- provide locally dilatant environments facilitating throughgoing fluid flow and also fluid mixing where appropriately oriented with respect to layered host successions, local mechanical discontinuities and the regional stress field,

- involve combinations of fault segments that were initiated or reactivated during Cover Sequence 2 extension, Wonga, D1710 shortening and Cover Sequence 3 extensions and inversions (for example or as portrayed in Plate 19).

• The essentials of and targeting criteria for Isa-style copper systems are highlighted in **Plate 19**.

Exploration Methods

• Several geophysical techniques may be useful in targeting Isa-style copper systems and deposits:

- electrical methods can be utilised to map subsurface conductors (for example, sulphide-rich zones). However, such methods may map carbonaceous and pyritic potential hosts, but may not directly distinguish copper mineralisation within these rock packages.

  In the northernmost North-west Queensland Mineral Province (for example north of Century) carbonaceous rocks of Cover Sequence 3 may not be conductive due to relatively low degrees of organic maturation. In such areas EM methods may be utilised to map highly pyritic strata or hydrothermal pyrite zones, which are key targets for copper exploration,

- interpretation of aeromagnetic data, when integrated with geology, can indicate first-pass, structurally and lithologically favourable strata. Apart from the elucidation of structure, magnetics may also be useful in the recognition of hydrothermal alteration zones (magnetic lows) in basement metavolcanics, and

- district and regional scale gravity data, integrated with interpretation of magnetics and geology, can be useful in clarifying metavolcanic basement depths and structure.

• Targeting and exploring Isa-style copper systems requires:

- understanding of the structure and lithological distribution in three dimensions, and

- recognition of the distribution of, and mineralogical and geochemical variations in, 'silica dolomite'-style alteration and its distinction from other styles of alteration.

In these regards, at district and mineralised system scales, carbonate stable isotope data can be utilised in evaluating the scale of Isa-style copper systems and vectoring in on prospect level targets (Waring & others, 1998). However, such techniques require fresh hypogene carbonate, normally only available from drilling below the zone of weathering, and

› evaluation of regolith geochemical responses in areas of deep weathering/younger cover.

Other Copper System styles

Carbonate vein systems

- In the Kalkadoon, Ewen and Wonga domains of the North-west Queensland Mineral Province, there are numerous copper (± Au, Co) deposits (for example, Mount Cuthbert, Kajabbi) and occurrences (**Map 3**; **Plate 20**) that are broadly similar to Isa copper styles but could, in some cases, also be related to pluton-related copper-gold systems of the Eastern Fold Belt.

  Although known deposits typically hold small copper resources, oxide and supergene enrichment zones may have relatively high grades and potential for small-to-medium sized solvent extraction-electrowinning (SX-EW) operations, such as the Mount Cuthbert Copper Project.

- Copper mineralisation is typically

  › in the form of carbonate-rich veins and replacements,

  › spatially associated with fault/shear systems, commonly NNE to NNW striking and steeply dipping (Map 3),

  › post D_2 timing, overlapping with greenschist facies retrograde metamorphism, and

  › localised around fault intersections with more competent units or other faults.

- Wall rocks are variable and include metasediments, but are more commonly metafelsic volcanics and metabasics.

- Exploration guides include:

  › mapping of fault systems active syn-post-D_2 and potential intersections with more competent (for example, feldspathic) rock units, and

  › surface expressions and anomalous (Cu, Au + Mo, Bi) geochemistry.

Other stratabound copper styles

- These include deposits variously labelled as ‘sandstone copper’, ‘shale copper’, ‘red bed copper’, etcetera. This group includes major deposits in Zambia, Zaire, Poland and elsewhere.

  Although much exploration in the North-west Queensland Mineral Province has been conceptually driven by models developed for the above regions, few occurrences of unequivocally similar mineralisation are known in the region.

- However, the Redbank deposits in the Northern Territory adjacent to the North-west Queensland Mineral Province, although locally discordant, are stratabound on the district scale, and may indicate the operation of systems and processes similar to those of ‘red bed’ copper systems (Wall & Heinrich, 1990).

- Key factors in the formation of ‘red bed’ copper deposits are thought to be:

  › oxidised, H_2S-poor fluids sourced in evaporitic environments,

  › migration (circulation) of this fluid through an underlying basement that is oxidised and/or has a low redox capacity, for example continental arkosic sediments, granitoids, felsic volcanics,

  › throughgoing fault systems, commonly reactivated rift zone structures, and

  › a highly reduced, commonly carbonaceous and pyritic cover succession, which constitutes the potential host for stratabound copper deposits.

Although most of these elements are present in parts of the North-west Queensland Mineral Province, basements to the reductant-bearing cover successions are unlike those in regions best noted for ‘red bed’ copper.

- Some major systems in Zambia and Zaire, however, may have much more in common with Isa-style copper systems (and vice versa) and, in some cases, even with copper-gold ± iron oxide systems than is generally recognised. Perhaps:

  › some as yet undiscovered copper systems formed relatively early in the deformation and burial history of the North-west Queensland Mineral Province, particularly in the north-west of the region,

  › some systems in Zambian/Zairian copper belts and other metasediment-hosted systems may prove to have formed late in the metamorphic-deformation histories of such terranes (for example Hitzman & others, 2000), like Isa-style systems, and

  › companies active, or considering exploration, in such copper belts would do well to examine and explore for the Isa-style copper systems of the North-west Queensland Mineral Province.

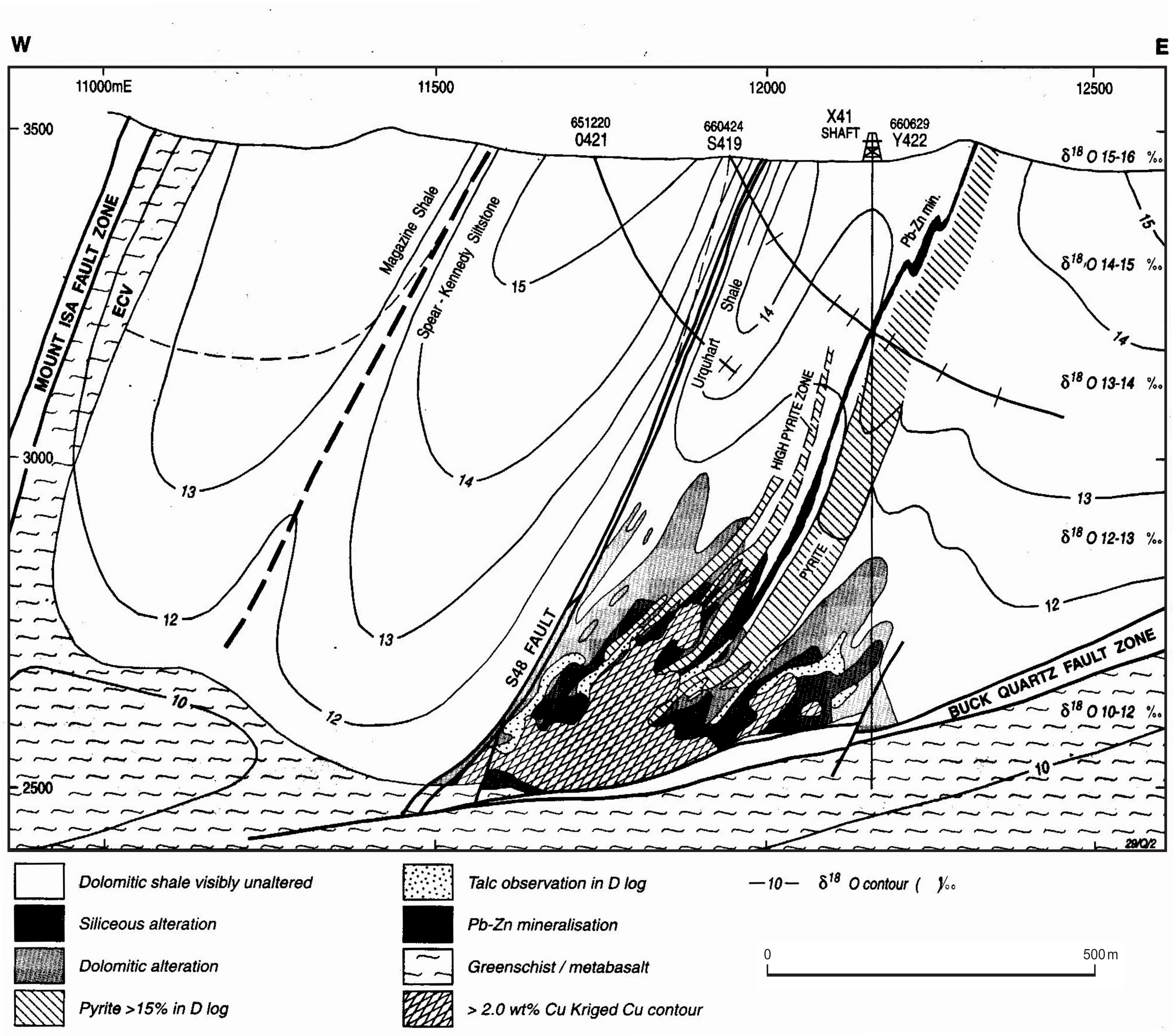
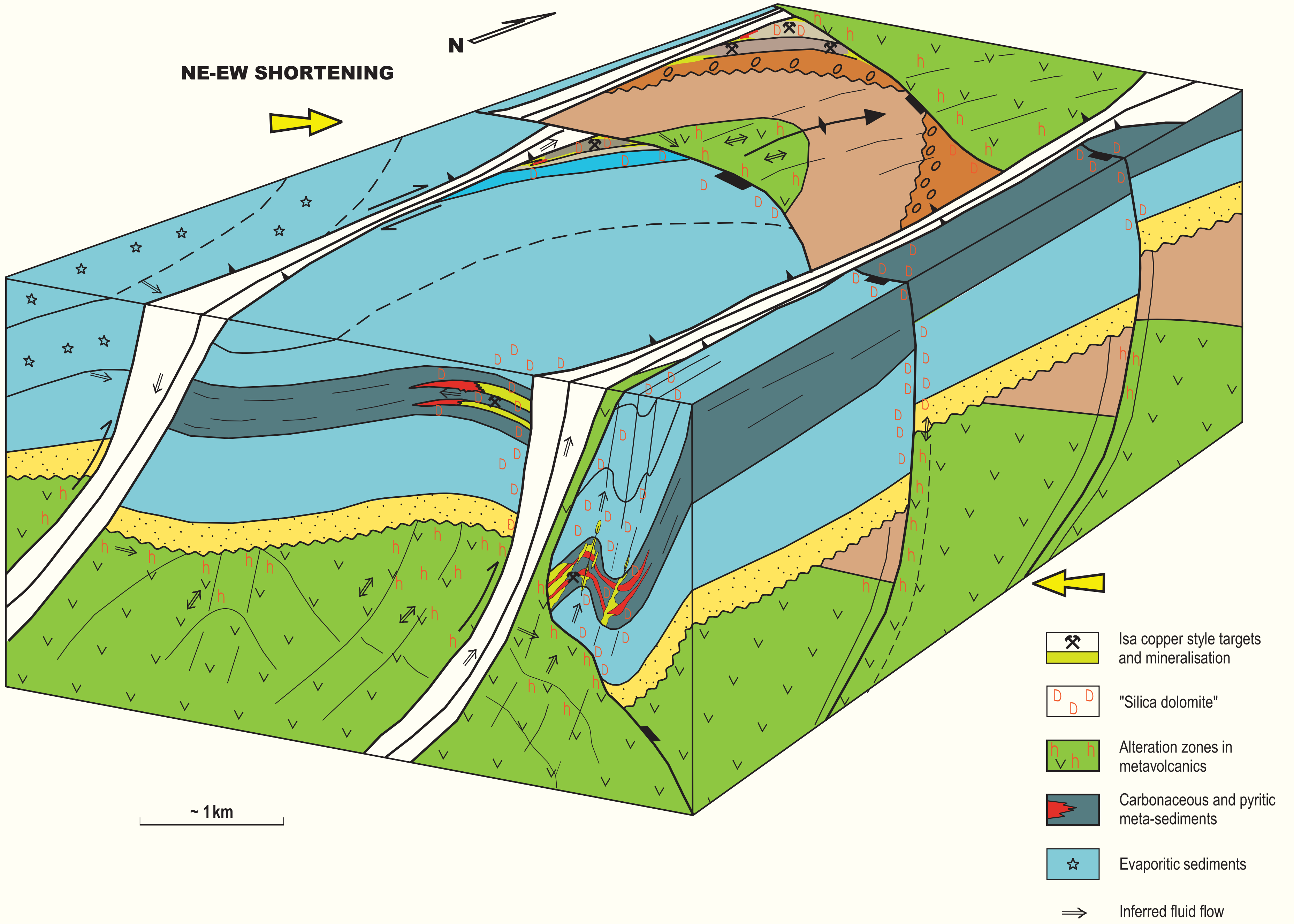


Figure 6.1 Section 34200m N through the Mount Isa copper orebody, showing the distribution of 'silica dolomite' alteration, Pb-Zn mineralisation, stratabound pyritic zones and copper grades. Dolomite oxygen isotope contours are also presented. From Waring & others, 1998.

PLATE 19

METASEDIMENT-HOSTED COPPER: ISA-STYLE

TECTONOSTRATIGRAPHIC MODEL

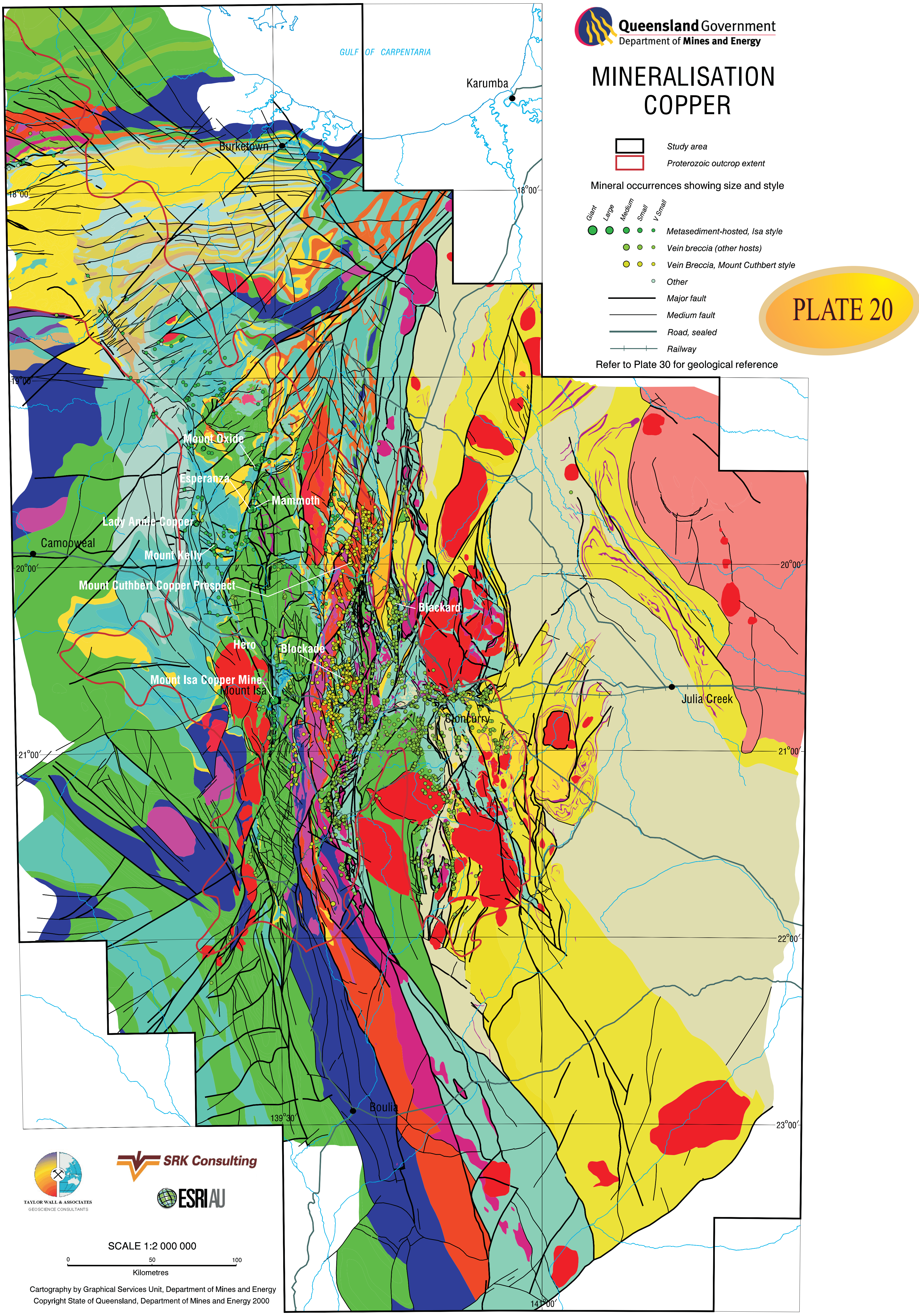


ESSENTIAL ELEMENTS

- Saline, H_2S-poor, high SO_4^{2-} / H_2S fluids 200-400°C
  - path history involving evaporite environments and oxidised rock masses
- Syn-metamorphic, fault-related fluid circulation system
  - connecting fluid source, oxidised rocks and host metasediments
- Strongly reducing and reactive, low grade metamorphosed sedimentary host succession
- Dilational zones in these metasediments

TARGET CRITERIA

Mineralising event(s)	▪ Isan D_3 deformation
Tectonostratigraphic domains	▪ Mount Isa, Mount Oxide-Gunpowder, Lawn Hill, South Murphy, North Murphy, Wonga Belt
Regional structural settings	▪ Along broadly N-trending fault systems, active during D_3 - reactivated segments of earlier fault systems ▪ at intersections of these with E-W, WNW trending reactivated fault systems ▪ Fault juxtaposition of basement metavolcanics and host metasediments
Local structural settings	▪ Shallow plunging host metasediment – (metavolcanic) basement (fault) contact ▪ D_3 fold-fault system - subvertical extension - faults subparallel to metasediment stratigraphy
Host lithostratigraphic settings	▪ Cover Sequence 3 metasediments - carbonaceous and preferably dolomitic siltstones - pyritic diagenetic facies or pyritic alteration ▪ Mechanical contrasts in metasediment package ▪ Greenschist facies metamorphic grade
Mineralisation indicators	▪ 'Silica dolomite': quartz-carbonate-sulphide veining and alteration, D_3 age - related ^{18}O depletion zone ▪ Pyritic and Zn-Pb-Ag mineralization ▪ Altered, demagnetized basement metavolcanics ▪ Cu ± Co, As anomalism


Queensland Government
Department of Mines and Energy
MINERALISATION
COPPER
PLATE 20
Study area
Proterozoic outcrop extent
Mineral occurrences showing size and style
Giant
Large
Medium
Small
V Small
Metasediment-hosted, Isa style
Vein breccia (other hosts)
Vein Breccia, Mount Cuthbert style
Other
Major fault
Medium fault
Road, sealed
Railway
Refer to Plate 30 for geological reference
GULF OF CARPENTARIA
Karumba
Burketown
18°00′
19°00′
20°00′
21°00′
22°00′
23°00′
139°30′
141°00′
Mount Oxide
Esperanza
Mammoth
Lady Annie Copper
Camooweal
Mount Kelly
Mount Cuthbert Copper Prospect
Blackard
Hero
Blockade
Mount Isa Copper Mine
Mount Isa
Cloncurry
Julia Creek
Boulia
TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS
SRK Consulting
ESRI AU
SCALE 1:2 000 000
0
50
100
Kilometres
Cartography by Graphical Services Unit, Department of Mines and Energy
Copyright State of Queensland, Department of Mines and Energy 2000

Copper- Gold ± Iron Oxide Systems

- Copper-gold deposits in these systems (**Plate 21**) are associated with relatively high temperature, iron- (commonly magnetite-) rich hydrothermal alteration systems that are spatially and temporally related to felsic plutons and have a variety of forms, including vein networks, breccias, disseminations and replacements. They are localised in dilatant zones of structures active during pluton emplacement and cooling.

- The North-west Queensland Mineral Province is well endowed with deposits that are affiliated with the iron oxide-copper-gold association (**Map 3**; **Plate 22**). This association is recognised worldwide (Hitzman & others, 1992; Wall & Gow, 1995; Barton & Johnson, 1996). Mineralisation includes:

  › magnetite-rich (for example, Ernest Henry and Osborne),

  › hematitic (for example, some ore zones in the Selwyn Project), and

  › reduced variants (for example, Mount Roseby, Eloise, Mount Dore).

  Although mineralogically and geochemically distinctive, these variants may occur in different segments of the same hydrothermal systems (**Plate 21**).

- The hypogene grade-tonnage characteristics of such deposit styles (**Table 1**) may support:

  › underground mining (for example, Osborne, Eloise, Selwyn),

  › large open pit operations (for example, Ernest Henry; Ryan, 1998), or

  › where supergene-enriched zones have developed (for example, Mount Roseby), the potential for high value concentrate, copper-leach or oxide-gold operations.

Target criteria

- Copper-gold ± iron oxide deposits are prime exploration targets in the North-west Queensland Mineral Province and are confined to:

  › the Eastern Fold Belt, associated with the late orogenic, circa 1500Ma, Williams-Naraku Batholith suites, and

  › the Wonga domain, related to syn-extensional, 1740Ma plutonism (**Map 3**; **Plate 21**).

- The Wonga and Williams-Naraku pluton suites, typical of those with which this class of iron oxide-copper-gold systems are associated (Wall & Gow, 1995), are the more silicic members of bimodal igneous associations which were the products of high temperature, hydrous magmas of crustal derivation (Wyborn, 1998), and which were relatively oxidised (magnetite series; Wyborn, 1998). They sourced magmatic hydrothermal fluids with high SO_2/H_2S (Burnham & Ohmoto, 1980), capable of transporting high concentrations of copper, gold, iron and other components (Heinrich & others, 1998; Perring & others, 2000).

- Metamorphic and alteration assemblages associated with Williams-Naraku age plutons indicate their emplacement at depths in excess of 5–6km, consistent also with the lack of preservation of pene-contemporaneous volcanic complexes in most of the North-west Queensland Mineral Province. However, major felsic volcanic-plutonic complexes, of similar age to those cropping out in the Croydon region farther to the east and also to that of the Williams-Naraku suite are interpreted under cover in the far east of this Province (**Maps 1 and 2**).

  Erosion levels of the Proterozoic in the far eastern part of the North-west Queensland Mineral Province may thus be shallower and comparable with those of the Stuart Shelf and Gawler regions of South Australia. The latter regions are underlain by major post-orogenic ash flow cauldron-pluton complexes, which host large scale iron oxide-rich alteration systems and related hematitic copper-gold-uranium deposits such as Olympic Dam (Wall & Gow, 1995). The far eastern regions of the North-west Queensland Mineral Province may be prospective for similar mineralisation.

- Copper-gold deposits are localised in alteration systems in the roof zones of laccolithic/sill-shaped Williams-Naraku and Wonga age felsic plutons (**Plate 21**) that are recognisable from (for example, Wall & Gow, 1995):

  › elliptical gravity low signatures,

  › spatially-related positive magnetic anomalies, reflecting magnetite-bearing alteration,

  › medium-to-high metamorphic grades reflecting proximity to plutons,

  › extensive related sodic (± iron oxide-bearing) metasomatism.

- These alteration systems are localised around structures (faults, high strain zones) active during pluton emplacement and cooling, above the edges of plutons and cupolas or apical zones in the pluton ceiling (**Plate 21**).

- The faults/high strain zones represent accommodation zones related to pluton emplacement or deformation during pluton cooling in response to continued regional deformation, and commonly are reactivated segments of earlier fault systems.

- At district and deposit scales, a variety of structural/mechanical settings are favourable for mineralisation (**Plate 21**):

  › For example, the Ernest Henry deposit (Ryan, 1998) is localised by the interaction of a north-east striking, 30° to 40° south-east dipping shear zone system with a massive feldspathic body (felsic sill or metavolcanic) set in ductily deformed metasediments (**Plate 21**).

  The shear zone is subparallel to the margins of the felsic body, and the stretching lineation, orebody elongation and plunge are subparallel. Mechanical contrasts between the felsic body and its more ductile country rock resulted in concentration of fracturing and brecciation in the felsic body. At a broader scale, the shear zone appears to be localised around the edges of two plutons:

  › the Selwyn/Starra iron oxide-rich rocks and copper-gold mineralisation appear to be localised in a steeply dipping north-trending ductile shear zone around a major lithological discontinuity (Adshead, 1998), and

  › at Osborne, mineralisation (Adshead & others, 1998) appears to be localised in the shallow plunging hinge zone of an antiform at the oblique intersection of the latter with a small displacement fault zone. It is noteworthy that mineralised zones, iron oxide-rich rocks and pegmatites are shallow-to-moderately dipping.

  The larger copper-gold orebodies appear to be localised in shallow to moderately dipping structural-lithological settings in which major mechanical contrasts are present, facilitating the evolution of dilatant zones (**Plate 21**). Other significant mineralised zones such as Mount Roseby exhibit major lithological-mechanical contrasts, but are related to more steeply dipping fault ± fold systems.

- Alteration systems containing Cu-Au mineralisation are characterised by Fe-rich 'calc-silicate' (calcic amphibole + pyroxene, + carbonate, scapolite) assemblages along with alkali feldspar + biotite-bearing parageneses. This alteration:

  › generally fills dilatant sites (unlike 'skarn'/carbonate replacement styles) such as veins, breccias, etcetera,

  › is commonly, though not everywhere, magnetite-rich, giving rise to strong positive magnetic anomalism (**Map 3**),

  › is indicative of relatively high temperature 400° to 600°C (Wall & Gow, 1995), pluton proximal environments,

- may form large unmineralised volumes and related magnetic anomalies, particularly in the case of 'sodic-calcic' (magnetite-amphibolite-albite) alteration (for example, Perring & others, 2000).

- Alteration paragenetically associated with Cu-Au mineralisation is distinctive and less widespread and may be:
  - magnetite-carbonate dilational infill accompanied by potassic alteration (K-feldspar, biotite) of aluminous hosts (for example, Ernest Henry and Osborne),
  - highly siliceous (for example, Osborne),
  - hematitic (that is, strongly oxidised), overprinting magnetite assemblages (for example, Selwyn) prompting analogies with Tennant Creek and Olympic Dam (Wall & Gow, 1995; Valenta & Wall, 1990), and
  - magnetite-poor and commonly pyrrhotite-rich (reduced) assemblages (for example, Mount Roseby and Eloise) typically associated with country rock packages containing carbonaceous metasediments.

Hypogene copper-gold mineralisation typically exhibits:

- chalcopyrite as the main copper phase,
- strong correlation of gold and copper grades, reflecting the grain-scale association of gold with copper-iron sulphide, but variable Cu/Au in different zones,
- anomalous to by-product grade cobalt, plus variable enrichment in bismuth, uranium, molybdenum, nickel, manganese and barium, fluorine, phosphorus (apatite) and boron (tourmaline),
- associated iron sulphides (pyrite and/or pyrrhotite), and
- less abundant quartz-rich gangue than is common in, for example, porphyry copper-gold mineralisation.

- Deep weathering in some areas of the Eastern Fold Belt and Wonga Belt has resulted in substantial, easily mineable, supergene copper resources (for example, Mount Roseby; **Table 1**), despite the commonly relatively low sulphide content and calcareous gangue of many deposits.

- A major contribution of magmatic hydrothermal fluids to the formation of copper-gold deposits in north-west Queensland is indicated by the:
  - spatial and temporal association with felsic plutons,
  - medium-to-high temperature associated alteration,
  - limited stable sulphur, carbon and oxygen isotopic data currently available (for example, Davidson & Dixon, 1992), and
  - high salinity, high temperature inclusion fluids (Williams & others, 1999; Perring & others, 2000).

- Fluid cooling and fluid mixing, both of which can effect reduction of high temperature fluids, appear to have been the main processes involved in ore deposition. The spatial association of reduced (magnetite-poor and commonly pyrrhotite-rich) mineralisation with carbonaceous metasediments is consistent with partial reduction by mixing of oxidised fluids with CH_4-bearing fluids derived from interaction with such metasediments. Such processes may also have contributed to the formation of the magnetite-bearing mineralisation that is also commonly associated with rock packages containing reduced assemblages.

- The essential features of, and target criteria for, copper-gold ± iron oxide systems are summarised in **Plate 21**.

Exploration methods

- At district and broader scales copper-gold target zones can be mapped by integrated gravity and magnetics interpretation, which can highlight pluton roof zones and related magnetically anomalous alteration. Key target areas are above the edges of plutons, and above or in cupolas, commonly defined by the intersection of structures more or less around the centre of the pluton.

- At finer scales, integration of geological and magnetic interpretations can be utilised to delineate fault-fold systems and their interaction with potential host lithological environments.

- Detailed gravity can provide further constraints on three dimensional geological interpretations and the identification of high density, low magnetic susceptibility zones which could represent hematitic targets.

- Potassic alteration and uranium anomalism, commonly associated with oxidised styles of copper gold mineralisation, can give rise to radiometric anomalies, identifiable from the interpretation of airborne or ground radiometric data, in areas lacking post-mineralisation cover.

- Electromagnetic methods can be useful in:
  - mapping the distribution of carbonaceous metasediments which are significant in the environments of reduced copper-gold mineralisation styles,
  - detecting conductive zones which may correspond to relatively massive sulphide vein sets or hypogene sulphides with a high degree of connectivity. However, carbonaceous metasediments may also be highly conductive,
  - covered supergene zones, which may also be conductive due to the distribution of native copper (for example, at Ernest Henry; Ryan, 1998), and
  - mapping the distribution of disseminated sulphides, in the case of IP chargeability data. As many copper-gold deposits contain sulphides, mainly in disseminated forms, such methods may discriminate sulphide-bearing zones among the voluminous magnetite-rich alteration.

- Copper and gold anomalism and the presence of sulphides appear to be the most direct geochemical and mineralogical signal of potential copper-gold targets. Although deposits also show strong values of elements such as Co, Mo, Ba and U, related geochemical anomalies are commonly not much more broadly developed than Cu and Au anomalism.

As noted above, sulphide-, potassic- and carbonate-bearing alteration/veining are more closely associated with mineralisation than the widespread magnetite-amphibole-albite alteration, which is typically also sulphide-poor.

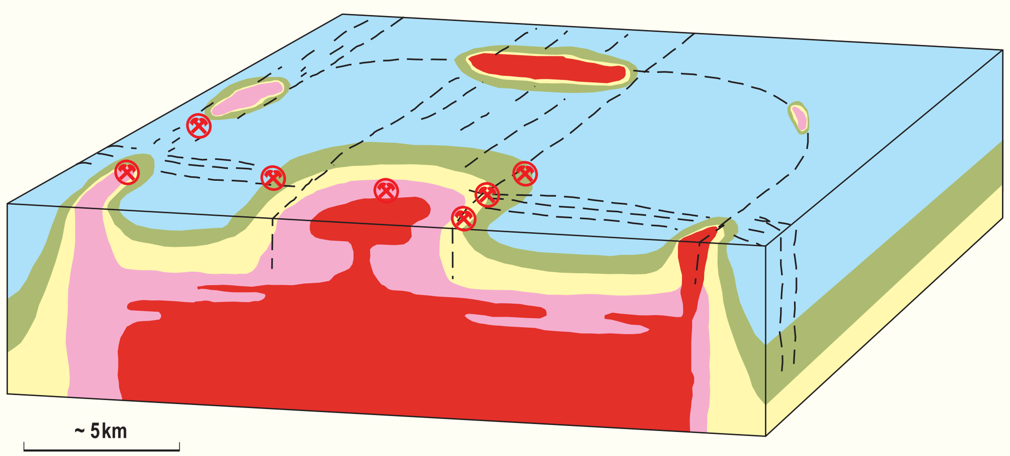
TARGET MODELS

PLATE 21

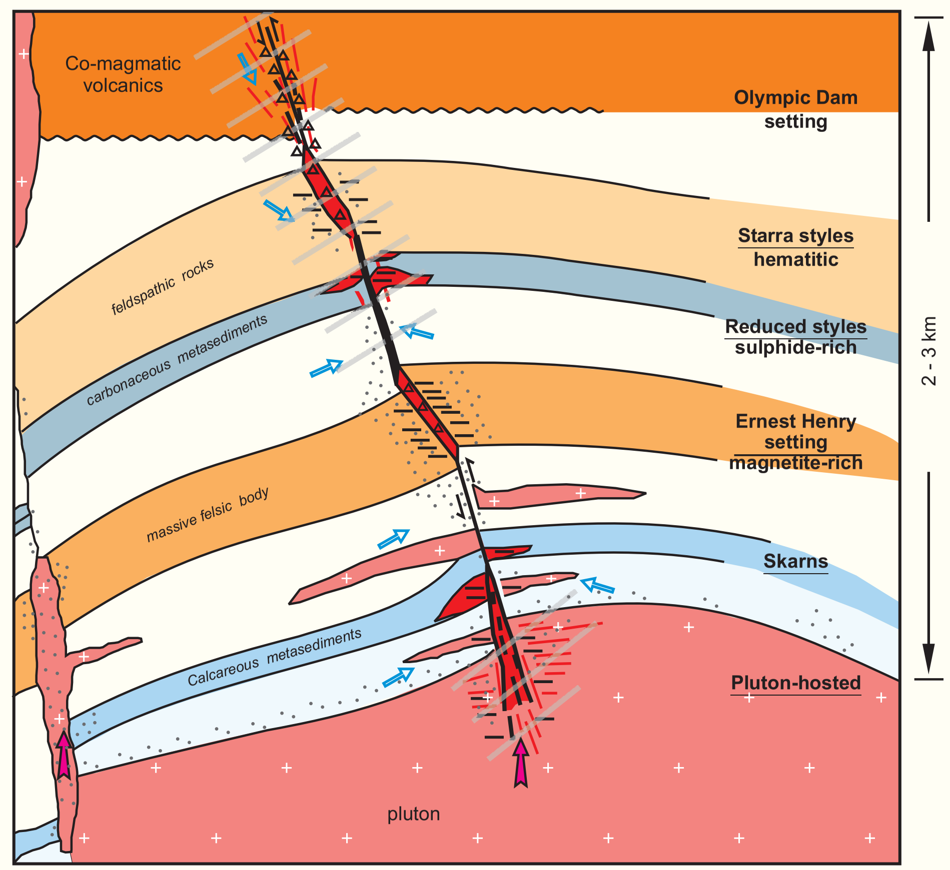
IRON OXIDE-COPPER-GOLD SYSTEMS

- magnetite-rich (eg Ernest Henry)
- hematitic (eg Selwyn; Olympic Dam)
- reduced styles (eg Eloise, Mount Roseby)

Iron oxide Cu-Au systems: pluton roof zones



The structural and lithological settings of Cu-Au targets

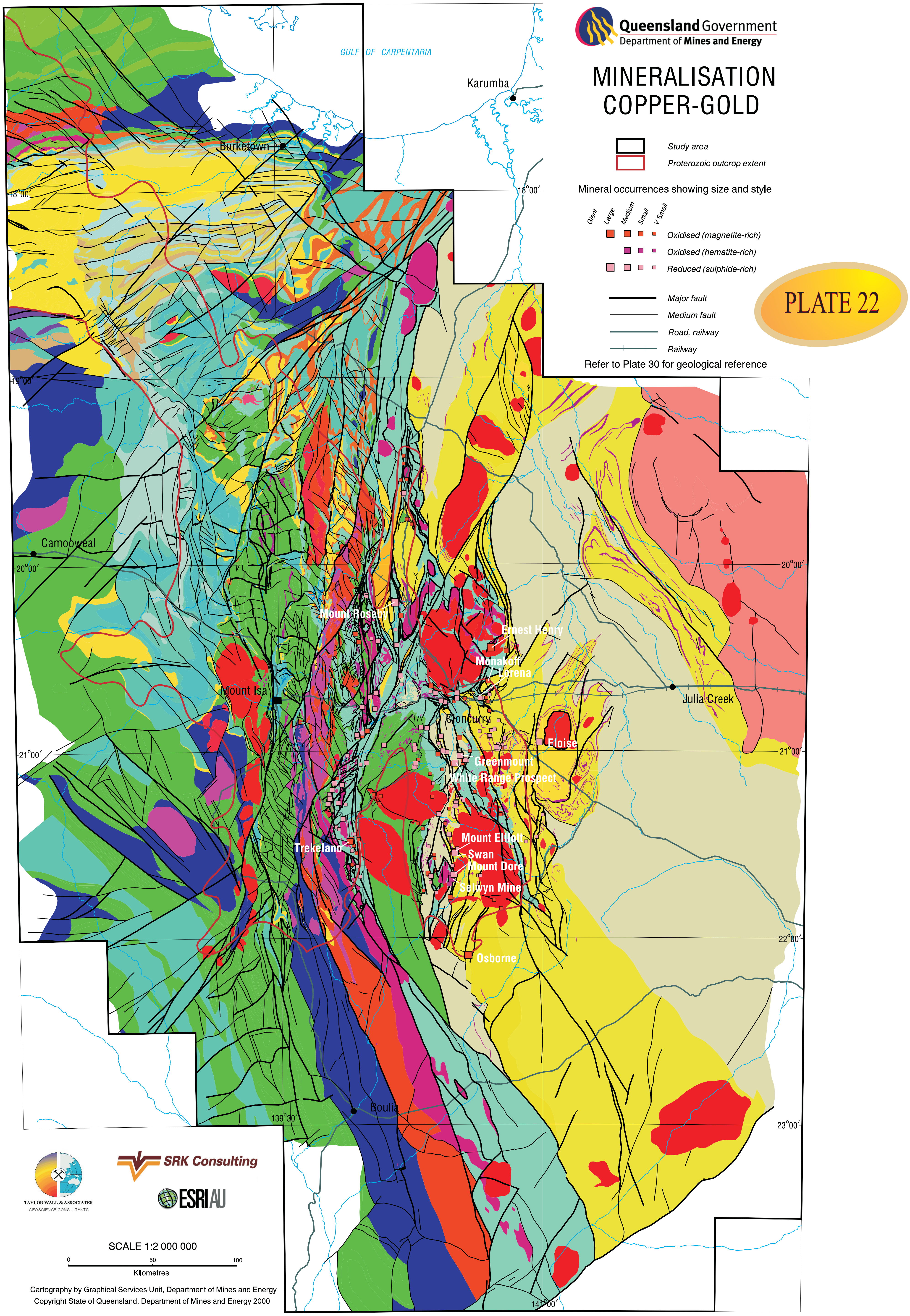


ESSENTIAL ELEMENTS

- High temperature, relatively oxidised felsic magmatism
- Pluton roof zones, above pluton margins and cupolas
- Structures active during pluton emplacement and cooling
  - pluton accommodation and reactivated fault-fold systems
- Spatially and temporally related, medium-to-high temperature metasomatic zones, commonly magnetite-rich
- Dilatant zones related to
  - fault/fold systems
  - major lithological/mechanical contrasts
- Intruded successions:
  - preferably with evaporitic components (input to hematitic mineralisation styles)
  - carbonaceous metasediments for more reduced styles

TARGET CRITERIA

Mineralising event(s)	▪ Williams-Naraku magmatism (1500-1520Ma) ▪ Wonga magmatism (~1740Ma)
Tectonostratigraphic domains	▪ Eastern Fold Belt ▪ Wonga Belt
Regional structural settings	▪ Roof zones of Williams and Wonga-age plutons ▪ Fault-fold systems reactivated during and after pluton emplacement
Local structural settings	▪ Wonga age: - fault jogs, intersections in upper plate fault systems - dilatant irregularities in extensional detachment ▪ Williams age: - reverse thrust-faulted, antiformal zones ▪ Magnetite alteration related to these structures
Host lithostratigraphic settings	▪ Feldspathic potential hosts (volcanics, sills, pluton tops) in more ductile metasediment envelope ▪ Carbonaceous metasedimentary packages (reduced styles) ▪ Pre-existing magnetite-rich zones (hematitic styles)
Mineralisation indicators	▪ Magnetite-bearing alteration systems and their less magnetic extensions ▪ Potassic (biotite-K-feldspar) wall rock alteration contemporaneous with hydrothermal carbonate + magnetite-rich infill ▪ Hematitic overprint on hydrothermal magnetite ▪ Copper-gold ($\pm$U, As)


Queensland Government
Department of Mines and Energy
MINERALISATION
COPPER-GOLD
Study area
Proterozoic outcrop extent
Mineral occurrences showing size and style
Giant
Large
Medium
Small
V Small
Oxidised (magnetite-rich)
Oxidised (hematite-rich)
Reduced (sulphide-rich)
Major fault
Medium fault
Road, railway
Railway
Refer to Plate 30 for geological reference
PLATE 22
GULF OF CARPENTARIA
Karumba
Burketown
18°00′
19°00′
Camooweal
20°00′
Mount Isa
Mount Isa
Mount Rosebery
Ernest Henry
Monakoff
Lorena
Julia Creek
Cloncurry
Eloise
21°00′
Greenmount
White Range Prospect
Mount Elliott
Swan
Mount Dore
Selwyn Mine
Trekelano
Osborne
22°00′
Boulia
139°30′
23°00′
141°00′
TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS
SRK Consulting
ESRI AU
SCALE 1:2 000 000
0
50
100
Kilometres
Cartography by Graphical Services Unit, Department of Mines and Energy
Copyright State of Queensland, Department of Mines and Energy 2000

Pluton-related gold systems

In view of its history of production and discovery, the North-west Queensland Mineral Province has generally been viewed as relatively unprospective for significant gold deposits. However:

- the high grade Tick Hill mine produced about 20t (>0.5Moz) of gold over three years at cash costs of around US$60 per ounce, with low capital outlays,
- the Starra-Selwyn gold-copper mines have recorded production, plus remaining resources, of more than 30t (1Moz) of gold, and
- the Ernest Henry, Osborne and Eloise copper-gold operations account for more than 4.8t (149 000oz) gold per annum co-product.

Significant gold deposits in the North-west Queensland Mineral Province (**Map 3**; **Plate 24**):

- are confined to the Wonga and Eastern Fold Belt domains,
- exhibit similar patterns of distribution to those of copper-gold occurrences, and hence
- may be targeted utilising similar exploration models to pluton-related copper-gold deposits.

Tick Hill and other potential pluton-related target styles are outlined below.

Tick Hill styles

High grade gold mineralisation at Tick Hill (Forrestal & others, 1998) is localised in:

- foliated quartz-sodic feldspar rocks that resemble protomylonitised pegmatites and quartzofeldspathic veins, accompanied by intense silicification and quartz veining,
- an envelope of quartz-rich rocks with a metasomatic magnetite-rich hanging wall zone (compare with copper-gold occurrences),
- a high strain zone, with local strong foliation and lineation,
- a narrow, hornfelsed belt containing numerous deformed segmented bodies and quartzofeldspathic veins, and
- around the contact of well bedded Corella calc-silicates and more massive Argylla Formation metavolcanics.

The nature of veining and alteration at Tick Hill is consistent with relatively high temperature mineralisation similar to that of other sulphide-poor, high-grade deposits (for example, Pogo, Alaska; Thompson & others, 1999). The abundance of pegmatoid bodies, the hornfelsed character of surrounding Tick Hill rocks, and proximity to the 1740Ma Saint Mungo Granite are also compatible with the Tick Hill system having been localised in a pluton-proximal environment.

The 50m wide high strain zone which hosts Tick Hill:

- is folded around a D_2 synform and hence predates the main regional EW shortening and amphibolite faces metamorphism,
- forms part of a major extensional detachment mapped through the Wonga Belt, and broadly synchronous with 1740Ma felsic plutonism and mafic intrusion (Holcombe & others, 1991), and
- occurs in an area where the broadly stratabound detachment shear zone ramps up-section from the Argylla Formation to Corella Formation, and has been interpreted as a lateral ramp in the detachment (Forrestal & others, 1998).

Syn-detachment deformation emplacement of pegmatoids, quartzofeldspathic veins, magnetite and sodic alteration appear to have been localised in dilational zones associated with this irregularity in the detachment fault.

Tick Hill ore zones were (Forrestal & others, 1998):

- of relatively small dimensions (200m strike length by 200–300m down dip extensions and up to 20m widths),
- high grade to very high grade (15–100g/t gold), but with sharp cutoffs and subtle geological expression,
- enveloped by >10ppb gold soil anomalies that extend for >1km along strike, and
- initially located by soil sampling follow-up of prominent bulk leach extractable gold (BLEG) anomalies shed from a zone showing weak, patchy copper anomalism.

The essential elements of and target criteria for Tick Hill-style gold systems are outlined in **Plate 23**.

Exploration methods

Tick Hill style target zones may be delineated by:

- surface and geophysical mapping of detachment zones and intersecting structures,
- recognition of related alteration and veining by surface mapping, detailed magnetics and radiometrics, and
- surface geochemical prospecting for gold and copper.

Other pluton-related styles

The roof zones and tops of felsic plutons may host major gold deposits formed in systems temporally related to the emplacement and cooling of the underlying plutons (Wall & Taylor, 1990). This "Thermal Aureole Gold" (TAG) association includes numerous world-class and many giant gold deposits – for example Muruntau, Telfer, Pogo, Vasilkovskoye and more (Wall, 1999; Sillitoe & others, 1999). TAG deposits range from pluton-proximal, relatively high temperature styles to more distal, lower temperature types exhibiting characteristic paragenetic and geochemical signatures (Wall, 1999). The plumbing systems responsible for TAG deposits are systematically related to structures formed or reactivated during pluton emplacement and cooling, similar to those of some copper-gold systems (**Plate 21**).

In the Wonga and Eastern Fold Belt domains of the North-west Queensland Mineral Province' there are large areas comprising roof zones of partially unroofed or concealed plutons of Wonga, Sybella, Maramungee and Williams ages (**Maps 2 and 7**). These roof zones commonly exhibit copper-gold mineralisation, but also contain high gold-low copper deposits. Granitoid-hosted gold deposits, apparently related to circa 1500Ma (Williams) age plutons, also occur in the Croydon Province, which adjoins the North-west Queensland Mineral Province to the east.

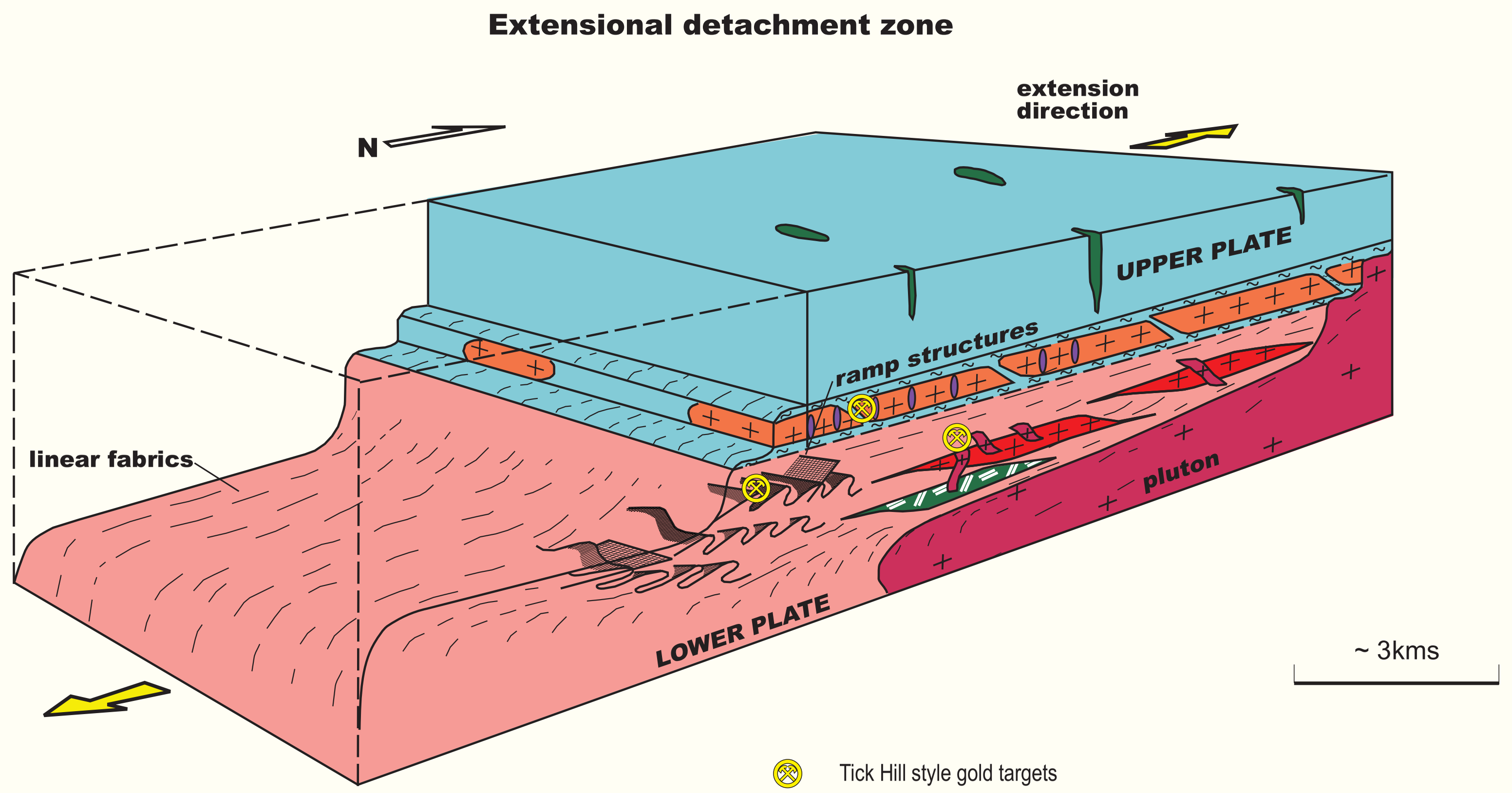
Some covered areas in the western North-west Queensland Mineral Province are underlain by Barramundi age metasedimentary successions intruded by 1800 to 1850Ma felsic plutons (**Map 2**). Similarly aged metasedimentary-plutonic associations host the Pine Creek and Granites-Tanami goldfields' as well as the Tennant Creek copper-gold camp.

TAG target styles in these areas of the North-west Queensland Mineral Province include

- pluton tops,
- pluton-proximal variants, for example, Pogo styles in massive/gneissic rocks and metasediment-hosted deposits, high strain zones and fold-fault systems around pluton edges, and
- more distal, metasediment-hosted (for example, Telfer) styles in multiply plunging antiforms containing carbonaceous sediments.

TARGET MODELS

TICK HILL-STYLE GOLD



Tick Hill style gold targets

- Upper plate lower grade rocks showing mainly brittle deformation (e.g. Corella Formation)
- Upper plate weakly to moderately deformed granitic sills (e.g. Burstall-type granitoids)
- Upper plate mafic bodies intruded into dilational zones (e.g. Lunch Creek Gabbro-type bodies)
- Lower plate high grade rocks showing ductile deformation (e.g. lower Argylla Formation sequence)
- Lower plate syn-kinematic metabasic sills
- Lower plate syn-kinematic meta-granitic rocks (e.g. Wonga-type granitoids)
- Syn to post-kinematic extension-related granitic plutons and smaller intrusions (e.g. Sybella Granite-type intrusions)

(modified from Holcombe & others, 1993)

ESSENTIAL ELEMENTS

- High temperature auriferous fluids (pluton-related)
- High strain zone exhibiting deformation synchronous with pluton emplacement and cooling
- Dilatant segment of high strain zone

TARGET CRITERIA

Mineralising event(s)	▪ Wonga extension (~1740Ma) ▪ Soldiers Cap extension ?(1670-1700Ma)
Tectonostratigraphic domains	▪ Wonga ▪ Eastern Fold Belt
Regional structural settings	▪ Extensional detachment zone
Local structural settings	▪ Syn-extensional dilatant irregularity in detachment - jog - lateral ramp - intersection of detachment with · reactivated basement structure (NE-ENE trending) · upper plate fault system
Host lithostratigraphic settings	▪ Roof zone of syn-extension felsic pluton ▪ Major lithological/mechanical discontinuity, for example, Corella/Argylla contact
Mineralisation indicators	▪ Pre-D2 - quartzofeldspathic veining - spatially associated pegmatoid bodies - magnetite-bearing metasomatic zones ▪ Gold ± copper anomalism

PLATE 23

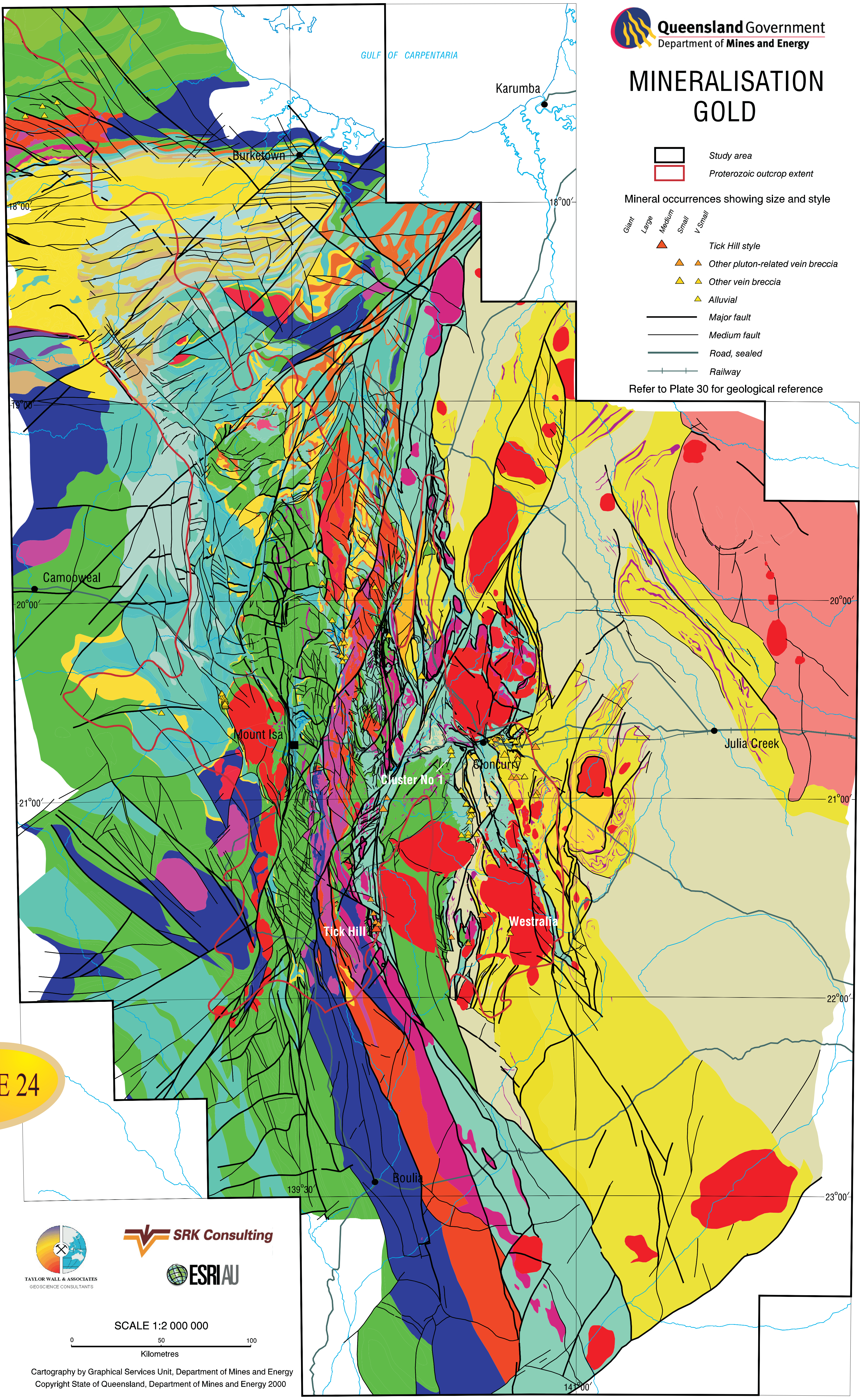

Queensland Government
Department of Mines and Energy
MINERALISATION
GOLD
Study area
Proterozoic outcrop extent
Mineral occurrences showing size and style
Giant
Large
Medium
Small
V Small
Tick Hill style
Other pluton-related vein breccia
Other vein breccia
Alluvial
Major fault
Medium fault
Road, sealed
Railway
Refer to Plate 30 for geological reference
GULF OF CARPENTARIA
Karumba
Burketown
Camooweal
Mount Isa
Cloncurry
Cluster No 1
Julia Creek
Tick Hill
Westralia
Boulia
18°00′
19°00′
20°00′
21°00′
22°00′
23°00′
139°30′
141°00′
TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS
SRK Consulting
ESRI AU
SCALE 1:2 000 000
0
50
100
Kilometres
Cartography by Graphical Services Unit, Department of Mines and Energy
Copyright State of Queensland, Department of Mines and Energy 2000

PLATE 24

Other Commodities and styles of mineralisation

Uranium-gold-platinum group elements: Unconformity-related

Uranium±gold deposits are hosted by Palaeoproterozoic fluvial sediments and volcanics of the south-eastern margin of the McArthur Basin where it unconformably overlaps onto volcanics and granite of the Murphy Inlier.

Almost all occurrences are spatially related to either:

- north-east-trending structures with proven or suspected tholeiitic dyke filling,
- north-east- and north-west-trending structures,
- volcanic sills,
- east-trending structures with volcanic dyke filling,
- quartz breccias of north-west-trending regional faults, and/or
- the proximity of the contact between the uppermost unit of the Westmoreland Conglomerate and the overlying Seigal Volcanics.

Faults at deposit scale may be related to larger strike-slip fracture zones extending for tens of kilometres. Mineralised zones do not show any signs of pervasive deformation but are displaced by later faulting.

Mineralisation in the principal deposits is present as horizontal, vertical or hybrid styles. Horizontal style mineralisation is relatively extensive and sheet like, up to 20m thick, within the uppermost portion of Unit 4 of the Westmoreland Conglomerate and close to the Seigal Volcanics contact. This style of mineralisation flanks the north-east-trending Redtree Dyke and is best developed immediately adjacent to and on one side of the dyke only. Vertical style mineralisation forms subvertical, relatively irregular lenses to 30m thick that are hosted by Unit 4 sandstone of the Westmoreland Conglomerate, although some mineralisation extends into the dolerite dykes. These lenses are adjacent to the Redtree dykes and their geometry closely mimics that of the dyke-joint system. Hybrid mineralisation is developed in the overlap zone between the horizontal and vertical styles of mineralisation and is, in detail, a combination of both styles. The overlap zone can be up to 50m thick.

Individual ore zones contain resources of 9170t to 5.4Mt at grades of 0.1 to 0.28% U_3O_8. The most significant group of deposits occurs at Redtree, with a combined inferred resource of 12.0Mt at 1.32kg/t U_3O_8.

Pitchblende is the main ore mineral and occurs in both the Westmoreland Conglomerate and altered basic dyke rocks. In the sandstones, it occurs interstitial to detrital grains, along fractures, and in veins up to 10mm thick. It is present as massive, structureless, or rarely euhedral grains, as colloform masses and as thin films of sooty pitchblende. Pitchblende in the dyke rocks occurs as fine aggregates, as thin films and as veins. Secondary uranium minerals occur as fine disseminations and filling pore spaces. The most abundant secondary uranium minerals are torbernite, metatorbernite and carnotite. The upper, weathered parts of mineralised systems contain uraninite, torbernite and carnotite, with traces of autunite, bassetite, ningyoite and coffinite. The deeper and unweathered portions of the deposits contain uraninite, autunite, ningyoite, bassetite and coffinite, and minor brannerite. Other ore minerals include pyrite, marcasite, chalcopyrite, galena, sphalerite, Co-Ni sulpharsenides, bismuth, bismuthinite, bornite, chalcocite, digenite, covellite and gold. Thorium is present only in alteration products of detrital Th minerals (in heavy mineral layers) as thorogummite and florencite. Hematite is abundantly present as the specular type or as a finely disseminated earthy variety and is intimately associated with the primary mineralisation.

Gold has been noted as small grains up to 10 microns, either as inclusions in pitchblende or in the associated gangue minerals in both the sandstone-hosted and the dyke-hosted mineralisation. Grades are up to 80g/t but are generally more of the order of 0.2–7g/t. There appears to be a general spatial relationship between uranium and gold mineralisation, to the extent that high-grade uranium intersections in or near the dykes frequently carry high gold contents. However, high uranium is also known to occur without appreciable gold contents, and vice versa.

The uranium mineralisation followed regional sericite, illite-chlorite and hematite alteration and generally involved silica dissolution. The alteration envelope is variably enriched in Mg, P, REE and a variety of metals. Alkali elements are depleted.

The dolerite dykes and the faults along which the deposits have been emplaced have acted as channelways for later mineralising solutions. Uraninite deposition was preceded by phyllosilicate alteration and even earlier silicification, and followed by uraninite dissolution and additional phyllosilicate alteration. The initial stages of fluid mixing in the deeper parts of the system are associated with a higher temperature, more oxidised alteration and a mineralisation assemblage comprising quartz+sericite   kaolinite+hematite+ uranium gold. As the ore fluids progressively moved upwards and outwards from the dykes and were progressively cooled and neutralised, the alteration-mineralisation assemblage changed to a lower temperature, less oxidised assemblage comprising chlorite+uranium with only minor gold (Rheinberger & others, 1998). The source rocks may have been uraniferous granitic gneiss, granite and associated volcanics, or basaltic volcanic members of host formations.

Uranium emplacement is not only related to vertical structures, which could have acted as passageways for ascending fluids, but also to horizontal geological boundaries such as basic sills, unconformities, lithological boundaries and the overlying Seigal Volcanics.

Uranium ± copper: Vein breccia

Lenticular to tabular, stratabound uraniferous beds and zones are hosted by metamorphosed basic volcanics and pelitic and psammitic sediments of the Eastern Creek Volcanics in the Leichhardt River Fault Trough in the Calton Hills-Paroo Creek and Spear Creek-Mica Creek areas. Secondary uranium mineralisation is generally not readily discernible at the surface of the known deposits, which were located with radioactivity detectors. Most deposits are uneconomic to subeconomic, but some such as Valhalla, Skal, Anderson's Lode (Counter) and Warwei-Watta represent significant uranium resources. Valhalla has a "Global Mineral Resource" of 32Mt at 790g/t U_3O_8, including a measured resource of 4.016Mt at 1500g/t U_3O_8, with a 800g/t U_3O_8 cut-off.

Known hosts include quartzite, amphibolite, tuff, siltstone, greywacke, hornblende, biotite, quartz and allanite schists and basalt. Individual deposits are localised in particular horizons of the Eastern Creek Volcanics. Quartzites of the Cromwell Metabasalt Member are the preferred host, particularly adjacent to sheared and faulted metabasalt. Some minor occurrences are found in the underlying Leander Quartzite and in the Myally Subgroup and the Surprise Creek Formation in the Calton Hills-Gunpowder Creek area. There are no obvious relationships with intrusive igneous activity, although some deposits in the Spear Creek area have a spatial association with pegmatitic dykes of the Sybella Granite. Strong north-north-east strike faults are associated with most deposits. Mineralisation is probably associated with Isan D_3 deformation.

Ore shoots tend to dip and pitch steeply and to exhibit an irregular tabular to pipe-like form. They are associated with zones of fracturing and brecciation that trend north-north-west to north-north-east and dip subvertically. The largest deposits extend to >150m depth.

Generally, only limited supergene alteration of primary mineralisation has occurred. Primary mineralisation comprises very fine-grained disseminated brannerite (>50% U_3O_8), commonly in close association with uraniferous magnetite and/or hematite and, in places, uraninite, allanite, sphene, biotite, rutile, ilmenite and metamict zircon (with 7–8% U). There is a strong association of hematite, magnetite and calcite alteration with uranium.

Minor copper mineralisation may be present in the form of chalcopyrite-silica-dolomite veining and secondary copper minerals Secondary calcite and dolomite are present in the gangue and are of economic significance with respect to the leaching characteristics of the ore. The Valhalla deposit contains vanadium (1315g/t V_2O_5), weak lead and zinc mineralisation and low-level anomalous gold (Eggers, 1998).

Uranium: Mary Kathleen style

The Mary Kathleen uranium deposit lies south of the D_3, north-east-trending Cameron Fault, and is sited in the axial surface of a tight, slightly asymmetrical D_2 syncline (the Mary Kathleen Syncline) that can be traced southward for >5km. The western limb of this structure is cut off by the Mary Kathleen Shear, and the eastern limb by the 1737±15Ma Burstall Granite. Slightly younger rhyolite dykes west of the granite have similar compositions and an identical radiometric age (Solomon & others, 1994). The Burstall Granite and associated rhyolite dykes also have elevated U-Th contents (granites average 7ppm U and dykes average 12ppm U).

The orebody is hosted by a reduced (magnetite-poor) calcic exoskarn formed by replacement of calcareous rocks of the Corella Formation. The ore comprises fine-grained uraninite disseminated through allanite-apatite enriched rocks that cross-cut the garnet-diopside skarn.

The main uranium-bearing minerals in the orebody are allanite and stillwellite. Uraninite occurs as fine disseminations enclosed within apatite and allanite, which usually replaces garnet. The uraninite occurs as ovoid grains of 0.01–0.1mm diameter enclosed within a silica shell that separates the uraninite from the allanite or stillwellite host minerals. In the surface oxidised zone, uraninite was replaced by gummite. Rare earth oxides (particularly Ce and La) occur in allanite and stillwellite. Yttrium occurs within the garnet lattice and is essentially non-recoverable. Minor minerals in the deposit include ferrohastingsite, quartz, epidote, sphene (titanite), hematite, chalcopyrite, pyrite, pyrrhotite and galena (Solomon & others, 1994).

The orebody consists of elongate lensoidal ore shoots that are up to 50m thick and roughly parallel the margins of a broader garnet mineralised zone. The relationship of the ore shoots to stratigraphy is obscured by garnetisation in the upper part of the orebody but the ore lenses are broadly stratiform at depth. In cross section, the ore zone consists of a 30° to 50° westerly dipping upper section and a vertically dipping lower section. In longitudinal section from south to north, the base of mineralisation plunges steeply north for 150m, then flattens for 150m before plunging steeply north again. The deepest mineralisation is ~450m below ground surface. Strong surface oxidation extended to 15m depth, whereas semi-oxidised ore continued to 35m depth (Hawkins, 1975).

The ore zone narrows at depth and ore distribution exhibits fracture and chemical (lithological) controls. The ore is largely a replacive breccia with clasts of early skarn breccia in an allanite-garnet ore matrix. The larger-scale distribution is as an irregular lens that may represent an original tensile vein or shear network.

The spatial relationships between ore, the Mary Kathleen Shear and the axial trace of the Mary Kathleen Syncline indicate that ore formation postdated major folding and was synchronous with shearing under amphibolite facies conditions, consistent with a syn-regional metamorphic age for ore genesis.

The primary structural control on ore formation was the development of ore in and around tensile veins and/or secondary shears in a competent skarn host, along a major boundary between skarn-dominated rocks to the east and regionally metamorphosed, 'un-skarned' metasediments and Wonga Granite to the west (Oliver & others, 1986). Uraninite-bearing ore at Mary Kathleen has a U-Pb age of 1550 to 1500Ma (late D_2-D_3), compared with 1737±15Ma for the Burstall Granite, 1700±60Ma for banded skarn and 1620 to 1500Ma for the main regional metamorphism and deformation.

U-REE enrichment is related to reaction of highly saline and oxidised fluids (Isan Orogeny) with earlier, slightly reduced (magnetite-poor) skarn (Oliver & others, 1986 and 1990).

Lithophiles: Pluton-related

There are two main types of pluton-related lithophile mineralisation in the study area that are associated with two different mineralising events.

Quartz-greisen vein deposits

The Motor Car, One Hen and Stonewall Jackson prospects comprise cassiterite and/or copper mineralisation in quartz-greisen veins in the 1850Ma Nicholson Granite in the Murphy Inlier. The Motor Car deposit, a target of former mining activity, is in an altered mafic-rich diorite intruding a greisenised granitic/volcanic environment. Rock chip samples of the quartz vein at the One Hen deposit assayed up to 8.1% Sn and the greisen assayed up to 6.1% Sn. Tin mineralisation also occurs as cassiterite-quartz veins and quartz-muscovite greisen lodes, lenses and pods in the Cliffdale Volcanics and Nicholson Granite Complex at Crystal Hill, Tracy's Table and Dry Creek in the Northern Territory.

Greisenisation, silicification and kaolinisation are the main recognised alteration styles. All known deposits in the Murphy Inlier are very small in size and are not economic. Some eluvium was worked historically at Crystal Hill.

Beryl-mica pegmatites

Segregated granite pegmatite dykes and veins of the 'Mica Creek Pegmatite' (a phase of the Sybella Granite) intrude hornblende schist and amphibolite of the Eastern Creek Volcanics in the Mica Creek area to the south-west of Mount Isa. The dykes and veins occur in a narrow, north-north-west-trending, 14.4km long by 3.2km wide belt near the eastern contact of the Sybella Granite. They have been a source of beryl and mica and also contain monazite, feldspar, cassiterite, tantalite-columbite, quartz, tourmaline, magnetite, hematite, ilmenite, rutile, bertrandite (Mn-Fe-Ca phosphate), manganese oxides, rhodonite, native bismuth, bismutite, uraniferous columbite, garnet, fluorite, apatite, epidote and topaz, but not in mineable quantities (Hill & others, 1975). Isolated beryl crystals have also been reported from some pegmatites along the western margin of the Sybella Granite, 16km west of the Mica Creek area (Brooks & Shipway, 1960).

The productive pegmatites are zoned from albite or albite-muscovite rock at their margins to a quartz core. Beryl is commonly present in the albitised feldspar or felspar-muscovite zone and is concentrated near the quartz core, where it forms euhedral, pale yellowish green, green, blue and amber crystals up to 300mm across and more than 1m long. Muscovite and biotite mica occur as imperfect sheets up to 0.1m^2 in area (Hill & others, 1975).

Ironstone: Stratabound

Oolitic iron formations occur in the Mesoproterozoic South Nicholson Group of the South Nicholson Basin in the Constance Range area. Up to 10 (generally <4) lenticular, iron-rich beds occur in the 45–180m thick Train Range Ironstone Member, some 275–520m above the base of the Mullera Formation. The Train Range Ironstone Member also contains thinly bedded, alternating dark grey shales, siltstones and sandstones. One to four ironstone beds are present at any one place and the potentially economic ore occurs in the 'Main Ironstone Member' — the lowest iron-bearing unit of significant thickness (Harms, 1965).

The iron formations crop out around the rims of two major and several minor structural basins that are complicated by folding and faulting. Dips range from 0° to 30°, except near faults where dips are locally up to 90°. The iron formations are resistant to erosion and form hog-back ridges and mesas. Dip slopes tend to be formed by low-grade ironstone and sandstone, reducing the available tonnages of overburden-free ironstone of good grade. Local relief is generally less than 100m.

Outcropping ironstones are a variable mixture of ochrous red hematite, finely crystalline blue-black hematite, limonite, quartz grains, quartz cement, shale and clay minerals, and rare relict siderite. The ironstones vary in appearance from oolitic forms to a quartz sandstone with a hematite matrix, and have been derived from primary ironstone by surface weathering. Grades range from 20–62% Fe, depending on the silica content of the parent rock (Harms, 1965). Oxidised ironstone extends to 12–30m vertically. The transition zone appears to have some iron enrichment, and the near-surface zone has probably been enriched in silica.

Below the water table, the ironstones contain oolites of ochrous or finely crystalline hematite, siderite and/or chamosite, and silica grains in a matrix of siderite, hematite, minor microcrystalline quartz and carbon. Oolites range from 0.2–3mm in diameter and successive shells may consist of different iron minerals. Veins of quartz-pyrite, siderite-pyrite and calcite cut the ironstones. Disseminated syngenetic pyrite occurs along bedding planes, especially in carbonaceous shales associated with the ironstone beds, and in siderite-rich bands. Siderite partially or completely replaces some or all of the other iron minerals. It also replaces quartz grains and appears to have formed late in the deposition or diagenesis.

The highest grade beds are oolitic and contain 50–55% Fe at the surface. Lower grade beds contain <20 to 25% Fe and are siliceous. Fifteen individual deposits have been investigated by the Broken Hill Pty Company Ltd and resources were calculated for three deposits, which contain a total resource of 368Mt at 45.4% Fe and 9.1% SiO_2, including 40Mt of oxidised ore at 57.0% Fe and 10.0% SiO_2.

Phosphorite

Phosphorite deposits in the Georgina Basin have been described by de Keyser & Cook (1972), Southgate (1988), Southgate & Shergold (1991) and Draper (1996).

The deposits in the Mount Isa region are in the Beetle Creek Formation, Border Waterhole Formation and Thorntonia Limestone. They consist of beds of consolidated pelletal phosphorites interbedded with chert, carbonate, shale, siltstone and volcanic materials. The phosphorite beds average 11m thick but range up to 36m thick and consist of dense pellets of apatite in a cherty and carbonate matrix. The phosphorites range from dense pelletal rocks consisting almost exclusively of francolite (one of the collophane group minerals) to siliceous and calcareous phosphorite, phosphatic chert and phosphatic siltstone, and grade into fossiliferous limestone. Chert (silica) and clay are the main dilutants and the deposits have comparatively low levels of heavy metals (for example, <5ppm Cd). The phosphorites comprise apatite + fluorapatite + francolite + dolomite + calcite + quartz + clays (montmorillonite or illite) ± halite ± gypsum ± iron oxides ± siderite ± pyrite ± carnotite.

Structural compartments appear to play a major role in facies distribution (Draper, 1996). The deposits formed in shallow water environments in areas of more rapid sedimentation. Basement topography had a controlling influence on current circulation patterns and phosphate deposition was greatest on the flanks of palaeobathymetric highs.

Known resources (Draper, 1996) include:

- Phosphate Hill-Duchess (plus Ardmore): demonstrated resources of 1115Mt at 17.2% P_2O_5 and inferred resources of 304Mt at 18.7% P_2O_5,
- Lady Annie-Lady Jane: demonstrated resources of 486Mt at 17.0% P_2O_5,
- Babbling Brooke Hill: measured reserve of 176Mt at 14.7% P_2O_5. Demonstrated resource of 38Mt at 16.8% P_2O_5,
- Quita Creek - 30Mt at 17.0% P_2O_5,
- D-Tree - 339Mt at 16.0% P_2O_5,
- Sherrin Creek - 175Mt at 16.5% P_2O_5,
- Lily Creek - 191Mt at 14.9% P_2O_5,
- Riversleigh - 11Mt at 14.4% P_2O_5,
- Phantom Hills - 46Mt at 16.0% P_2O_5,
- Mount Jennifer - 20Mt at 15.3% P_2O_5,
- Mount O'Connor - 42Mt at 17.4% P_2O_5,
- Highland Plains - 84Mt at 13.4% P_2O_5.

The majority of these deposits are in remote areas with difficult access and little infrastructure. However, the two most significant deposits (Lady Annie-Lady Jane and Phosphate Hill-Duchess) are closer to Mount Isa and have been subject to extensive exploration, including mining and beneficiation studies. Tenure over both of these deposits is held by WMC Ltd (through its subsidiary WMC Fertilizers Ltd). Production of high analysis phosphate fertilisers began from WMC's Phosphate Hill mine and chemical plant early in 2000. The deposit contains a measured and indicated resource of 103Mt of phosphate rock at 23.4% P_2O_5, which includes reserves of 70Mt at 23.8% P_2O_5 (Wallis, 1998).

Vanadium: Stratabound

Vanadium mineralisation occurs in oil shales of the Cretaceous Toolebuc Formation, which consists of an upper unit of mixed coarse fossiliferous limestone, oil kerogens and clays (known geologically as coquina or shelly limestone) and a lower black calcareous oil-rich shale unit.

The Toolebuc Formation crops out over hundreds of square kilometres in the Julia Creek region and carries high vanadium contents wherever tested. Fimiston Mining NL is currently investigating the feasibility of vanadium production from their tenements in this area. Total resources are of the order of 210Mt at 0.33% V_2O_5 at Julia Creek and 170Mt at 0.46% V_2O_5 at the Linfield deposit (Fimiston Mining NL, 1999).

The vanadium deposit comprises the supergene oxidised portion of the oil shale in the Toolebuc Formation; the prospective horizon is a gently dipping to subhorizontal unit averaging 5–15m thick. The vanadium resource is oxidised to an average depth of 15m. The focus of the current exploration is the upper soft oxide coquina, which averages 5m thick, is flat lying, and crops out over extensive areas. The soft oxide coquina consists of ~85% coarse shelly limestone and 15% clays and goethite and is covered by up to 5m of clays.

The vanadium occurs in a number of different mineral species, including clays, organic compounds (including kerogen and vanadyl porphyrins), pyrite in the fresh rock, and goethite in the oxidised rock. Weathering processes have resulted in vanadium being released from the organic compounds, enhancing metallurgical recovery and giving excellent soft mining and beneficiation properties to the rocks.

Limestone

Deposits in Proterozoic rocks

According to Carter & others (1961), at least 660 000t of 'limestone' (crystalline calcite in veins and lenses) has been produced from the North-west Queensland Mineral Province for use as a flux in base metal smelting, mainly at the Hampden, Mount Elliott, Mount Cuthbert and Mount Isa smelters. There are no major limestone quarries, and production has come from a large number of small quarries. Historically, proximity to rail transport was a determining factor in the development of known deposits (Carter & others, 1961).

Almost all of the limestone deposits are in the Corella Formation, in a belt stretching from Dobbyn in the north to near Duchess in the south. They are thought to have formed by mobilisation of $CaCO_3$ from the Corella Formation into dilatant zones during metamorphism. A common site is on the contacts of dolerite sills and plugs with the Corella Formation. Production has mainly been from lenses of coarsely crystalline calcite. The value of many of the deposits as smelter flux was enhanced by the presence of appreciable copper as disseminated chalcopyrite (Carter & others, 1961).

Deposits in the Georgina Basin

High-grade limestone resources occur in the V-Creek Limestone in the Undilla area in the Camooweal 1:250 000 Sheet area. This formation comprises hard and massive limestone interbedded with earthy marls. The beds are flat to gently dipping and the area has limited topographic relief.

Westgold Resources NL have been investigating the feasibility of constructing a major cement and lime plant at Mount Isa, based on these high-grade limestone resources. Other applications being considered include limestone for smelter flux and mine run-off neutraliser and lime for a metallurgical reagent and waste water neutraliser. Peak production could reach 500 000tpa of limestone, 45 000tpa of lime and 225 000tpa of cement. If it goes ahead, the project will service the major base metal mining developments expected in the Mount Isa region.

Lawlor Contracting Pty Ltd currently carries out crushing on its 'Third One' mining lease (ML 5564) in the Undilla area to provide limestone for acid neutralisation at the Mount Gordon copper mine.

Deposits in the Eromanga Basin

The Cretaceous Toolebuc Formation is also a source of limestone. Significant prospects include Arrolla and Greenwood, east of Cloncurry.

Miscellaneous

Hematite-magnetite gossan iron ore deposits

Several hematite-magnetite gossans in the Mount Isa region have historically been worked for, or viewed as, potential sources of ironstone flux. These deposits comprise ironstone gossans associated with fault zones. The most significant deposits are Mount Philp, Mount Oxide, Lochness, Black Mountain (Leviathan) and Hematite Siding.

Oil shale

Georgina Basin

The Cambrian sediments of the Georgina Basin include bituminous limestones and kerogenous shales.

Thin oil shale, bituminous limestone and bituminous shale units were intersected in the V-Creek and Currant Bush Limestones in two AGSO stratigraphic drillholes in the Thorntonia area. A percussion/core hole drilled by Eastern Copper Mines NL in 1980 intersected traces of hydrocarbons at various depths, including a small amount of oil in a 'spar-lined' cavity at 125.35m depth and in a thin fracture at 113.6m depth (Evans, 1980). Further drilling in 1981 returned a thickest oil shale intersection of 0.7m at 55.96m depth and a highest oil yield of 69L/t by Fischer Assay (Barraclough, 1981).

Exploration in the Yelvertoft area has returned yields averaging 26L/t over 28m but no economic deposits have been delineated.

Carpentaria and Eromanga Basins

The Cretaceous Toolebuc Formation of the Rolling Downs Group is a thin (5–20m) shallow marine stratigraphic unit that is widespread in the Eromanga and southern Carpentaria Basins. It comprises carbonaceous and bituminous shale and interbedded bioclastic and micritic limestone (Day, 1983) and contains inferred shale oil resources totalling 230 000Mm^3 (Ozimic, 1981). Exploration has indicated a yield of 20L/t. Most of these resources are too deeply buried to be economic, given current technology. The oil shales crop out in an area west of Julia Creek, where they are being investigated as a source of vanadium.

Bituminous shales and limestones also occur in the lower part of the Mesozoic Wallumbilla Formation and Allaru Mudstone.

Silica

Deposits of quartz are common in Proterozoic rocks throughout the mineral province, mainly as fault infillings. The quartz varies in purity.

Many of the copper deposits in the region have cappings of low-grade siliceous copper ore that were mined and sold to Mount Isa Mines Ltd for use as flux at the Mount Isa copper smelter in the 1950s to 1970s.

Deposits of high purity quartz occur as narrow, discontinuous quartz veins, pipes and blows in the Leichhardt River Fault Trough. They form prominent outcrops of buck quartz, mainly in the Eastern Creek Volcanics, but also in the Myally Subgroup and Mount Isa Group. The quartz is white to milky in colour, buck to laminated in texture, and is suitable for use as silica flux. It may also be suitable for ornamental purposes.

Barite

In the Carrier area in the Camooweal 1:250 000 Sheet area, minor barite occurs as lenses and veins in association with copper, lead and zinc mineralisation at the Barite Blow and Carrier prospects in the Lady Loretta and Paradise Creek Formations, close to the Termite Range Fault. Smaller barite veins up to 1m wide are common along the fault zone along a strike length of 2km. Mineralisation occurs in a massive, ferruginous brecciated chert unit that occurs as a series of northerly trending en echelon lenses along the north-eastern side of the fault. This chert may be stromatolitic. Samples assayed up to 32.7% $BaSO_4$, 210ppm Cu, 3700ppm Pb, 2.8% Zn, 2.77% Fe_2O_3 and 62.8% SiO_2 (Marlow, 1975). Minor barite has been noted also at the nearby Tinmad prospects.

Barite Blow contains an inferred resource of 101 600t at 20% $BaSO_4$ for a total barite content of 20 320t (Carpentaria Exploration Company Pty Ltd, 1971).

Manganese

Deposits in Proterozoic rocks

Several small manganese deposits, some of which have been mined historically, occur in the Overhang Jaspilite and overlying Marimo Slate south-west of Cloncurry (Blake, 1987). The deposits comprise siliceous manganese oxides (psilomelane and pyrolusite) produced by supergene enrichment of manganiferous jaspilite along strike faults and shear zones. Iron oxides and quartz are commonly associated with the manganese; assay results have indicated small amounts of cobalt, nickel, lead and zinc (Carter & others, 1961). The manganiferous unit in the Overhang Jaspilite can be traced for several kilometres. The Overhang deposit produced 8225t of ore (for use in the Mary Kathleen acid leach uranium treatment plant) at average grades of about 48.3% MnO_2, 18.6% SiO_2 and 4.5% Fe_2O_3.

Manganese is commonly associated with cobalt deposits and with some copper deposits. Asbolite has been reported from the Kajabbi, Dugald River and Soldiers Cap areas (Carter & others, 1961).

Deposits in Mesozoic rocks

A transitional unit between the Allaru Mudstone and Normanton Formation in the Carpentaria Basin is considered to be prospective for manganese mineralisation. The surface occurrence of manganese nodules and the presence of manganese as films and stains on bedding and fracture surfaces in the Myally area are due to a lateritic process. Samples averaged 49% MnO, but no significant manganese mineralisation was intersected in drillholes.

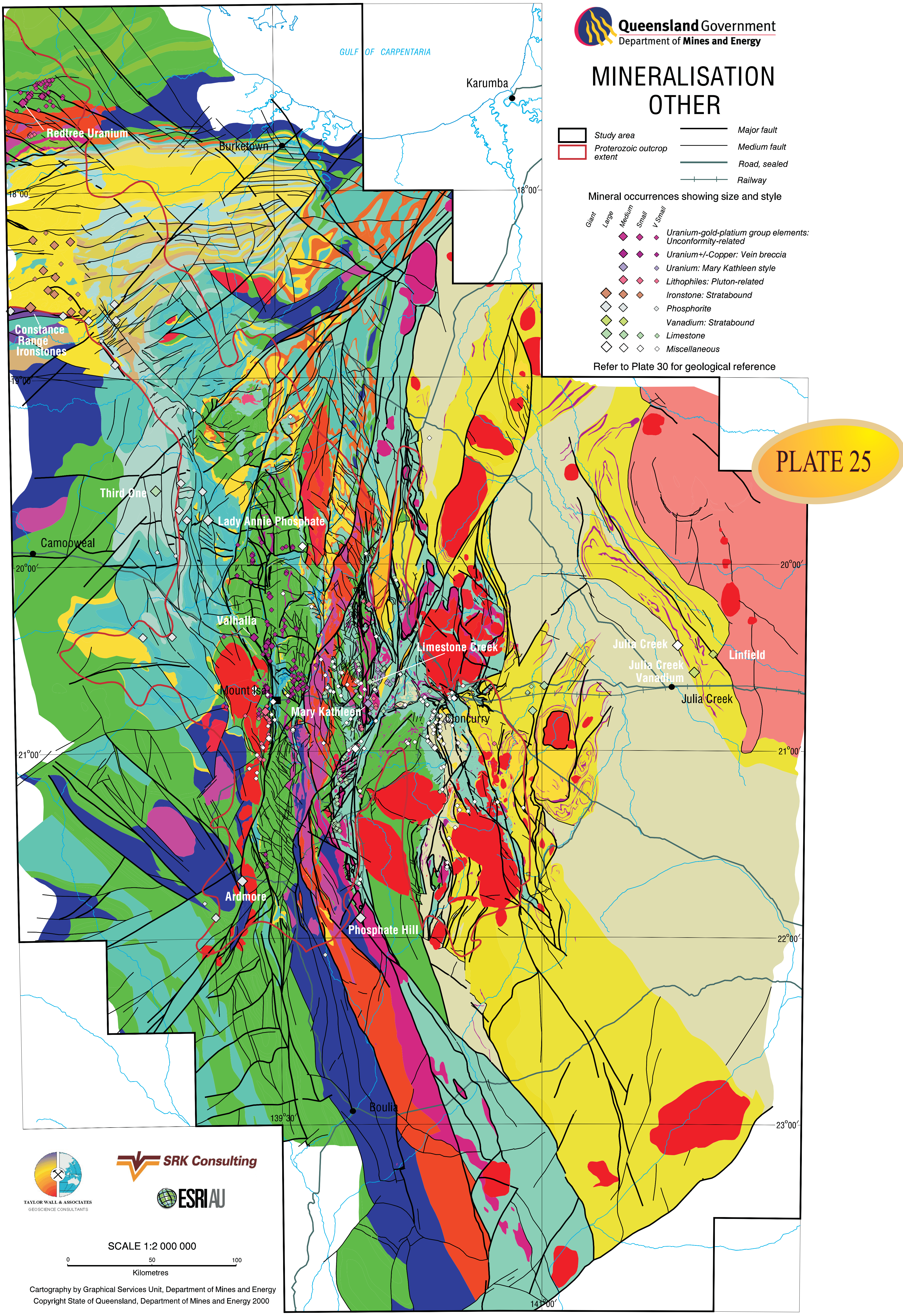
Graphite

Graphitic slate and schist are known from the Corella Formation, Marimo Slate and Kuridala Formation but there are no deposits of economic importance as a source of graphite (Carter & others, 1961).

Granite Building Stone

The Sybella Granite near Mount Isa is a source of high quality granite for tiles, slabs and dimension stone. The granite of interest is a pink to grey, porphyritic, medium to coarse biotite granite that is strongly foliated and has large K-feldspar phenocrysts. The foliation is due to the parallelism of biotite flakes and gives the granite a distinctly gneissic texture.

Australian Granites Ltd produced some granite blocks from quarries south of Mount Isa before going into receivership. Granite from these deposits has recently been used to repave the Queen Street Mall in Brisbane.



Queensland Government
Department of Mines and Energy
MINERALISATION OTHER
Study area
Proterozoic outcrop extent
Major fault
Medium fault
Road, sealed
Railway
Mineral occurrences showing size and style
Giant
Large
Medium
Small
V Small
Uranium-gold-platinum group elements: Unconformity-related
Uranium+/-Copper: Vein breccia
Uranium: Mary Kathleen style
Lithophiles: Pluton-related
Ironstone: Stratabound
Phosphorite
Vanadium: Stratabound
Limestone
Miscellaneous
Refer to Plate 30 for geological reference
PLATE 25
GULF OF CARPENTARIA
Karumba
Burketown
Redtree Uranium
Constance Range Ironstones
Third One
Lady Annie Phosphate
Camooweal
Valhalla
Limestone Creek
Mount Isa
Mary Kathleen
Cloncurry
Julia Creek
Julia Creek Vanadium
Linfield
Ardmore
Phosphate Hill
Boulia
18°00′
19°00′
20°00′
21°00′
22°00′
23°00′
139°30′
141°00′
TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS
SRK Consulting
ESRI AU
SCALE 1:2 000 000
0
50
100
Kilometres
Cartography by Graphical Services Unit, Department of Mines and Energy
Copyright State of Queensland, Department of Mines and Energy 2000

7. EXPLORATION

7.1 EXPLORATION HISTORY

The North-West Queensland Mineral Province has a long exploration and mining history dating back to a prospector's discovery of rich supergene copper near Cloncurry in 1867 and its exploitation as the Great Australia mine from 1868.

Up to the outbreak of the Second World War, mineral discoveries were made by individuals or syndicates in search of outcrops of high-grade copper or lead-silver, or resulted from the chance observations of mineralised rocks by rural workers. The early discoveries of this period, such as the numerous copper deposits of the Cloncurry district and the lead-silver orebodies of the Burketown (Lawn Hill) Mineral Field, became significant mining operations at the time but were not major producers by modern standards.

The region's first find of major, lasting economic importance, the Mount Isa silver-lead-zinc deposit, resulted from a prospector's discovery of prominent gossans in 1923. In 1924, most of the small leases were amalgamated under the control of Mount Isa Mines Ltd and by 1928, a >20Mt resource had been delineated by drilling. The mine was constructed amid a period of high lead prices associated with the nascent automobile industry, but it struggled in its early production years from 1931 due to low metal prices in the industrial depression and also due to metallurgical problems. No profit was made until 1937 and no dividend was paid to the investors until 1947, some 18 years after the start of development!

In the 1930s and the first half of the 1940s, there was little exploration activity in the North-west Queensland region. The only noteworthy initiative was mapping and electromagnetic work on the Dugald River gossan (discovered prior to 1880) by the Aerial Geological and Geophysical Survey of Northern Australia in 1936 to 1939. Drilling failed to intersect economic mineralisation but it was an important step towards the eventual discovery of significant zinc mineralisation in 1951.

After the Second World War, exploration in the region became progressively more scientific, systematic and sophisticated, due to the development of innovative exploration techniques, new concepts on mineralising processes, and the increasing availability of quality data from Commonwealth and State Government regional mapping and geophysical surveys. Amid these advances, the independent prospector became less important and exploration activities began to be controlled by companies. From the end of the war to the early 1960s, there was a modest level of exploration activity dominated by the domestic groups Mount Isa Mines Ltd, Broken Hill Proprietary Ltd, the Zinc Corporation Ltd and Western Mining Corporation Ltd. In the mid 1960s, there was a significant increase in exploration activity due to the entry of major north American groups such as Kennecott, Placer and Anaconda.

The 1945 to 1972 period saw the following developments that greatly enhanced the capabilities of explorers in the region:

- the completion of 1:250 000 scale geological mapping by the Bureau of Mineral Resources and the Geological Survey of Queensland in 1950 to 1954,
- the commencement of 1:100 000 scale mapping programmes by the Bureau of Mineral Resources and the Geological Survey of Queensland in 1969,
- flying of airborne magnetics/ radiometrics surveys over part of the region by the Bureau of Mineral Resources,
- demonstration of the merits of systematic geochemical sampling in the region's first soil sampling programmes by the Bureau of Mineral Resources and Mount Isa Mines Ltd (Hilton area and Mount Novitt prospect) in 1952 and the National Lead Company (Cloncurry area) in 1953–55,
- the commercial development by the CSIRO of the Atomic Absorption Spectrometer, which provided a cheap, fast and accurate means of analysing large batches of samples from regional geochemical surveys,
- the adoption of electromagnetic (late 1950s) and induced polarisation (1960s) techniques,
- new concepts on mineralising processes and deposit styles, and
- an increase in regional mapping programmes around known deposits following prospective stratigraphy or structures.

Of the discoveries in 1945 to 1972 (Table 7.1), Hilton and Hilton North (now George Fisher) can be attributed to the tracing of prospective stratigraphy northwards from Mount Isa, while Lady Loretta resulted from the successful application of soil sampling.

Two other significant discoveries in this period resulted from drilling of known mineralised occurrences. In 1951, the first intersections of zinc-rich intervals were made in holes at the Dugald River gossan, which had previously been investigated as a lead target in 1936 to 1939 and 1948. At the Mount Isa lead-zinc mine, the presence of secondary copper had been known since 1927, and primary copper had been known since 1930, but its world class significance was not demonstrated until 1954 when a hole intersected 202m at 2.2% Cu in what became the 69Mt 1100 copper orebody.

Meanwhile, amid all the technical and conceptual advances of this period, the prospector could still play an influential role. In the late 1960s, a prospector's discovery of lead-rich gossans in an area devoid of old workings culminated in the discovery of the Pegmont deposit in 1971.

Following a slump in metal prices, exploration activity waned in the first half of the 1970s as several local and overseas groups withdrew from base metal exploration. In 1977, the situation was dramatically reversed, when stronger metal prices and high profits by energy-based companies encouraged the entry into the region of several overseas groups including Amoco, Shell, BP and Elf Aquitaine, and an increased involvement by domestic companies.

By 1980, however, this latter resurgence of activity had peaked. During the worldwide boom in gold exploration in the early to mid-1980s, in response to high prices and the development of efficient processing methods for low grade ore, exploration declined in the NWQMP as many companies reduced their base metal exploration budgets in favour of gold.

The only exploration success of the 1972 to 1987 period — Selwyn — resulted from this increasing emphasis on gold exploration. In 1975, Amoco Minerals obtained tenure over the Selwyn ironstones to investigate the copper potential. The exploration was successful initially in identifying the SWAN and Mount Dore copper prospects, but the economic significance of the area was not established until a 1978 rock chip sampling programme outlined areas of gold potential that were successfully drill tested in 1980.

The 1972 to 1987 period may not have been particularly rewarding for the region in terms of discoveries, but there were a number of significant developments that paved the way for the remarkable discovery successes of 1988 to 1994, namely:

- completion of 1:100 000 scale mapping by the Bureau of Mineral Resources and the Geological Survey of Queensland in the 1969 to 1980 period,
- flying of detailed airborne magnetics/radiometrics surveys by major companies,
- the rapid advances in digital imaging technology,
- developments in geophysical instrumentation and digital data processing techniques,
- recognition of the economic significance of copper-gold in Proterozoic iron oxide systems, and
- an increased understanding of the key controls in mineralising systems through detailed studies by company personnel, academia, and Commonwealth/State geological organisations.

The period from 1988 to 1994 saw a significant increase in overall exploration activity, a marked resurgence in the search for base metals, and the best discovery record of any mineralised province in the world. Of the eight major greenfields discoveries in that period (Table 7.1), five are currently in production at a combined annual output of 163 000t copper, 152 000t zinc and 154 000t lead, 700.6t (22.6Moz) silver and 5.1t (165 000oz) gold. Of these, Century is the sixth largest zinc deposit ever discovered, and is currently the world's second largest zinc producer behind Red Dog in Alaska.

Another discovery, the small high-grade Tick Hill gold deposit, had a short but very lucrative production period in 1992 to 1995, yielding a total of 15.8t (511 000oz) of gold at an average grade of 22.5g/t Au. Significant Pb-Zn drill intersections have been reported in the two other discoveries, Walford Creek and Grevillea, but economically mineable resources have yet to be delineated.

In addition, the period also saw an expansion of known resources through drilling at Dugald River, Hilton North (George Fisher) and Gunpowder (now known as Mount Gordon).

After almost half a century of fairly intensive systematic exploration by numerous technically proficient companies, using sophisticated techniques and the latest concepts on geology and mineralisation, the North-west Queensland Mineral Province can be regarded as mature exploration ground. At this advanced stage of a mineralised belt's history, it is generally assumed that there is limited scope for major discoveries, but the following aspects of the discoveries in 1988 to 1994 augur well for future exploration success in the region:

- Four deposits (Eloise, Osborne, Cannington and Ernest Henry) were found under post-Proterozoic cover around the fringes of the outcropping area, by initially targeting magnetic anomalies that later proved to be directly or indirectly associated with economic mineralisation. When one considers the vast tracts of unexplored and underexplored prospective ground at manageable depths in the area under review in this study, the potential is obvious.

- Despite the mature exploration status of the region, discoveries of outcropping to shallow subcropping mineralisation may still be expected. Note that Century and Grevillea both crop out as gossans; Tick Hill had a surface expression of >1ppm Au in soil samples, with maximum assay results of 7.9ppm Au.

- The Century, Tick Hill and Grevillea discoveries resulted from routine geochemical surveys.

- The giant Century deposit was discovered in a mineralised district that had been known for over a hundred years, where good quality geological and geophysical data were available, and that had been investigated by nine exploration companies since the 1940s.

7.2 Current Exploration Tenure

Plate 26 shows the current situation regarding exploration permit tenure and applications in the North-west Queensland Mineral Province. Due to the region's remarkable exploration success rate in the 1988 to 1994 period, and the obvious potential for further discoveries, there is currently a strong demand for ground. It should be noted, however, that the exploration permit relinquishment requirements in Queensland (Chapter 9.4) ensure that ground is freed up on a regular basis. In addition, opportunities exist to obtain interests in prospective ground, as a considerable area is held by parties or companies that may be amenable to farm-in agreements.

7.3 Land Access

Queensland's Mineral Resources Act 1989 provides the framework for accessing land in the State for mineral exploration and development. This Act encourages explorers and miners to responsibly find, assess, develop and use Queensland's mineral resources. At the same time, the Act strongly supports the dual concepts of sustainable development and environmental protection. Exploration may only be allowed in environmentally sensitive areas if an appropriate environmental management plan is developed in consultation with the relevant administering authority and the Department of Mines and Energy.

The three categories of land in Queensland where exploration is not allowed or is only allowed subject to specific constraints are:

- Sterile land — Sterile land includes National Parks, Environmental Parks, Conservation Parks, Fish Habitat Reserves and Commonwealth Government land. Exploration and mining are prohibited on these lands.

- Restricted land — Restricted Areas have been designated to cover land uses such as pipeline routes, electricity transmission lines, damsites, dam catchment areas, fossicking areas, fossil sites, etcetera. There are restrictions on the application for, and grant of, mining tenures in these areas.

- Constrained land — Constrained land includes Aboriginal lands, Historic Mining Sites (including historical mining towns, smelters and battery sites), Wetland Reserves, Departmental and Official Purposes Reserves, and Resource Reserves. There are restrictions on the application for, and grant of, mining tenures in these areas, and specific constraints on allowable exploration methods can be applied.

Plate 26 shows the extent of these three categories of land in the North-west Queensland Mineral Province.

7.4 Native Title

The most significant land access issue affecting mineral exploration in the North-west Queensland Mineral Province in the 1990s has been "native title", which can be defined as the rights and interests that indigenous people claim to the land with which they are connected through traditional laws and customs.

Following the recognition by the High Court of Australia in June 1992 that native title had survived Great Britain's acquisition of sovereignty over Australia (the "Mabo" decision), the Commonwealth Native Title Act was introduced in 1993. Among other provisions, the Act outlined a "right to negotiate" process, whereby miners and State governments are required to negotiate and agree on compensation with native title holders for the grant of new exploration and mining tenures.

At the passage of the 1993 Act, it was assumed that native title existed only over Crown land and did not affect exploration and mining activities over freehold land and pastoral leases. However, in December 1996, the High Court ruled that native title may still exist over pastoral leases (the "Wik" decision). Consequently, applicants for exploration titles over pastoral leases had also to seek access through the "right to negotiate" process. Pastoral leases are the predominant land tenure in the North-west Queensland Mineral Province.

Due to the complex and onerous nature of the "right to negotiate" process and the logistical problems involved, the Commonwealth Government amended the Act in July 1998 (Native Title Amendment Bill) to permit the States to introduce alternative procedures for the "right to negotiate" process, subject to Commonwealth approval.

Accordingly, the Queensland Government passed alternative native title legislation in 1998 and 1999 for inclusion in the Mineral Resources Act 1989. However, this legislation had to be modified following scrutiny by the Senate on August 30, 2000. The modifications were incorporated in the Native Title Resolution Act 2000, which was passed by the Queensland Parliament on September 8, 2000. The State provisions came into effect on September 18, 2000, as Parts 12 to 18 of the Mineral Resources Act 1989.

Under the new provisions, applications for Exploration Permits for activities that are unlikely to have a significant impact on the land ("low impact" Exploration Permits) are exempt from the "right to negotiate" process, but must instead comply with the alternative State procedures of Parts 15 and 16 of the Mineral Resources Act. These procedures still require certain notification and consultation processes with native title parties and reaching of an access agreement before entry. In the case of Exploration Permit applications for both low- and high-impact activities ("high impact" Exploration Permits), the "right to negotiate" process of the Native Title Act 1993 must still be followed.

Although Queensland's new provisions are still constrained in some aspects by the Commonwealth legislation, their advantage is that they are integrated with other provisions of the Mineral Resources Act and hearings in the Queensland Land and Resources Tribunal. They also provide a simpler, less costly and quicker procedure for the granting of exploration permits for "low impact" activities than the "right to negotiate" process.

Definitions of "low-impact" and "high-impact" activities, and explanations of the new native title procedures, which apply to all new and existing exploration and mining tenement applications, can be found in manuals available from the Department of Mines and Energy, and on the website of the Department (www.dme.qld.gov.au).

In summary, the requirements of the new procedures are as follows:

- all tenements — notification of relevant native title parties either before or shortly after lodgement of an application,
- low-impact exploration tenements — consultation with native title parties on the protection of native title rights and interests and the reaching of an access agreement before entry on to the land,
- high-impact exploration tenements — consultation and negotiation with native title parties to enable the grant of the tenement. Native title parties are entitled to object. If agreement for grant cannot be negotiated, the matter is heard by the Land and Resources Tribunal. The Minister may overrule the Tribunal only in limited circumstances.
- Mining Leases — consultation and negotiation with native title parties is required for the grant of the tenement. Native title parties are entitled to object and, if agreement cannot be negotiated, the matter is heard by the Land and Resources Tribunal in conjunction with any other hearing necessary under the Mineral Resources Act. The Minister may overrule the Tribunal in limited circumstances only.

TABLE 7.1: NORTH-WEST QUEENSLAND MINERAL PROVINCE – HISTORY OF MAJOR DISCOVERIES

Deposit	Date	Discovered by	Depth of Cover	Mode of Discovery	Reference
MOUNT ISA Ag-Pb-Zn	1927	James Campbell Miles (prospector)	none - gossanous outcrop	outcrops originally discovered by James Campbell Miles in 1923; drilling of gossans delineated significance of orebodies	Forrestal (1990)
HILTON NORTH (GEORGE FISHER)	1948	Mount Isa Mines Ltd	none - gossanous outcrop	outcrops detected by Mount Isa Mines Ltd geologists in tracing stratigraphy northwards from the Mount Isa mine; drilling of gossans delineated significance of orebodies	Forrestal (1990)
HILTON	1949	Mount Isa Mines Ltd	none - gossanous outcrop	outcrops detected by Mount Isa Mines Ltd geologists in tracing stratigraphy northwards from the Mount Isa mine; drilling of gossans delineated significance of orebodies	Forrestal (1990)
DUGALD RIVER	1951	Zinc Corporation Ltd	none - gossanous outcrop	originally discovered by a prospector prior to 1880; drilling of gossans delineated significance of orebodies	Connor & others (1982); Newberry & others (1993)
MOUNT ISA Cu	1954	Mount Isa Mines Ltd	-	follow-up drilling of low-grade copper intersections from 1941/42 drillholes	Perkins (1990)
LADY LORETTA	1970	Placer Prospecting (Australia) Pty Ltd	none - gossanous outcrop	a regional soil sampling programme was carried out to the east of the Lady Annie copper mine as part of copper exploration adjacent to that deposit; because the stratigraphy was thought to resemble that at Mount Isa, every tenth sample was also analysed for Pb, Zn and Ag; drilling of the best Pb anomaly intersected 7.6m at 21.2% Pb in late 1969; drilling in December 1970 intersected significant stratiform massive Zn-Pb-Ag sulphides	Cox & Curtis (1977)
PEGMONT	1971	Placer Prospecting (Australia) Pty Ltd	none - gossanous outcrop	drilling of ground magnetics and soil geochemical anomalies in an area of gossans discovered by a prospector in the late 1960s	Locsei (1977)
SELWYN	1980	Amoco Minerals Pty Ltd	none - outcropping ironstones	ironstones, delineated in the early 1:250 000 BMR mapping programme, were initially targeted for their copper potential; following a switch to gold exploration in 1978, areas of elevated rock chip gold assay results were outlined, then successfully drill tested in 1980	Kary & others (1989)
ELOISE	1988	BHP Minerals Ltd	50 to 70m	an area of prospective Soldiers Cap stratigraphy under cover, interpreted from the available BMR magnetic data, was flown with aeromagnetics, then followed up with TEM; the discovery drillhole tested a combined magnetics/EM target	Brescianini & others (1992)
OSBORNE	1989	Placer Pacific Ltd	20 to 40m	in 1985, the Billiton-CSR joint venture initiated exploration for ironstone-hosted Cu-Au, similar to Selwyn, 60km to the north-north-west; areas of interest, delineated in airborne magnetics and follow-up ground magnetics and IP, were drill tested with 16 holes, 11 of which intersected quartz-magnetite rocks with subeconomic mineralisation; in 1989, Placer (who had acquired CSR) made the discovery intersection in an area of silica flooding up-dip from the magnetite-rich rocks, in a step-out drilling programme; the discovery owes much to persistence as it was made after 80 reverse circulation (9811m) and 36 diamond core holes (3310m)	Anderson & Logan (1992); Tullemans & Voulgaris (1998)
TICK HILL	1989	Mount Isa Mines Ltd	orebody subcrops under a few cm of soil	in following up a bulk cyanide leach gold drainage anomaly, a high tenor gold soil anomaly was delineated; reverse circulation drilling returned significant gold values	Forrestal & others (1995; 1998)
CENTURY	1990	CRA Exploration Pty Ltd	none - orebody crops out	the Lawn Hill district was initially targeted due to the presence of base metal occurrences, prospective lithologies, and the major Termite Range Fault; in an initial 20km long regional gravity/magnetics traverse line across the Termite Range Fault, soil sampling detected a zinc anomaly over a 1.6km length of Proterozoic and Cambrian rocks at the south-western extremity; in a detailed soil/rock sampling programme, chip sampling of a gossanous outcrop returned significant Pb, Zn and Ag values; following an unsuccessful TEM survey, which failed to detect a conductor, the first drillhole into the geochemical anomaly intersected 27m at 6.3% Zn	Broadbent (1995)
CANNINGTON	1990	BHP Minerals Ltd	10 to 60m	a detailed aeromagnetic survey was flown over a covered area where the existing BMR magnetics data indicated the presence of prospective Soldiers Cap lithologies; in drilling of discrete magnetic anomalies, the third hole (testing a 1000nT bullseye feature) intersected 20m at 12.1% Pb, 0.6% Zn and 870ppm Ag	Bailey & Thomas (1993)
WALFORD CREEK	1990	WMC Resources Ltd	minimum 3 to 10m	Proterozoic stratigraphy adjacent to the Fish River Fault was initially identified as a conceptual target for stratiform sediment-hosted Pb-Zn by WMC in the early 1980s; in 1985, massive pyrite horizons with weak base metals were intersected in drilling of TEM targets detected in a reconnaissance survey; the ground was relinquished in 1986 due to a change in strategy but reacquired in 1989; drilling of TEM targets intersected significant base metals in 1990	Webb & Rohrlach (1992)
ERNEST HENRY	1991	Western Mining Corporation - Hunter Resources Ltd joint venture	25 to 50m	the WMC-Hunter Resources joint venture, exploring for copper-gold in magnetite-rich skarns, initially targeted magnetic anomalies detected in a detailed survey flown over covered ground by a major company in the early 1980s; screening of the anomalies by TEM led to the discovery drillhole, which intersected 7.1m at 4.95% Cu and 0.8g/t Au in the supergene zone and 114m at 1.75% Cu and 0.9g/t Au in the primary zone; it was later shown that the TEM target was due to supergene mineralisation and that the bulk of the primary ore did not produce a TEM anomaly	Webb & Rowston (1995); Ryan (1998)
GREVILLEA	1994	Coolgardie Gold NL - Diversified Mineral Resources NL joint venture	none - gossanous outcrop	follow-up of a regional drainage sampling anomaly resulted in the discovery of a gossan and a vegetation anomaly within siltstone, and the delineation of an associated soil anomaly; the first reverse circulation drillhole intersected 25m at 1.1% Pb, 5.2% Zn and 29g/t Ag	Jenkins & others (1998)

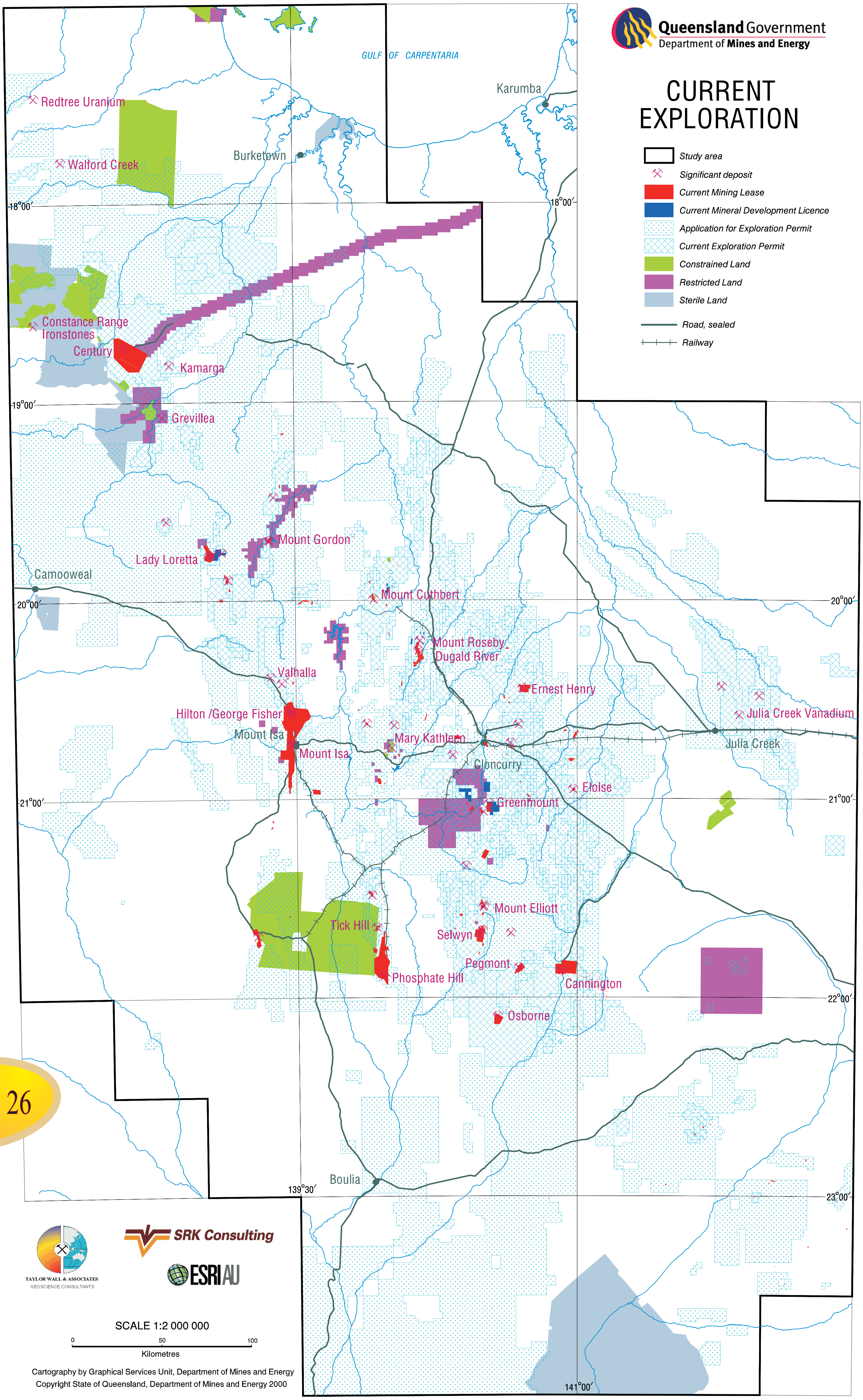

Queensland Government
Department of Mines and Energy
CURRENT EXPLORATION
Study area
Significant deposit
Current Mining Lease
Current Mineral Development Licence
Application for Exploration Permit
Current Exploration Permit
Constrained Land
Restricted Land
Sterile Land
Road, sealed
Railway
GULF OF CARPENTARIA
Karumba
Burketown
Redtree Uranium
Walford Creek
18°00′
Constance Range Ironstones
Century
Kamarga
19°00′
Grevillea
Mount Gordon
Lady Loretta
Camooweal
Mount Cuthbert
20°00′
Mount Roseby
Dugald River
Valhalla
Ernest Henry
Hilton /George Fisher
Mount Isa
Mary Kathleen
Julia Creek Vanadium
Julia Creek
Cloncurry
Eloise
Greenmount
21°00′
Mount Elliott
Tick Hill
Selwyn
Pegmont
Phosphate Hill
Cannington
22°00′
Osborne
Boulia
139°30′
23°00′
141°00′
TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS
SRK Consulting
ESRI AU
SCALE 1:2 000 000
0
50
100
Kilometres
Cartography by Graphical Services Unit, Department of Mines and Energy
Copyright State of Queensland, Department of Mines and Energy 2000

PLATE 26

8. GLOBAL SIGNIFICANCE OF THE NORTH-WEST QUEENSLAND MINERAL PROVINCE

8.1 MINERAL ENDOWMENT

Zinc

The North-west Queensland Mineral Province can be regarded as the premier zinc region in the world based on the following information.

Number and Tenor of World Class Zinc Deposits

World class zinc deposits are defined by Singer (1995) as those in the upper 10% in terms of zinc metal content, containing a minimum of 1.7Mt zinc. Of the 57 deposits outside the CIS countries and China that meet this criterion (Table 8.1), by far the largest concentration (six) occurs within the North-West Queensland Mineral Province , namely, Hilton-George Fisher, Century, Mount Isa, Dugald River, Cannington and Lady Loretta. Of these deposits, four are ranked among the top eighteen in the world in terms of contained zinc in economic reserves, namely, Hilton-George Fisher (3rd), Century (6th), Mount Isa (10th) and Dugald River (18th).

Total Zinc Endowment

The North-west Queensland Mineral Province is the largest known repository of economically mineable zinc in the world. An indication of its global supremacy can be gauged from Table 8.2 and **Figure 8.1**, which compare the total contained zinc in economic reserves of the six largest deposits in the North-west Queensland Mineral Province (Hilton/George Fisher, Century, Mount Isa, Dugald River, Cannington and Lady Loretta) with various combinations of total zinc endowment for the largest zinc provinces world wide. The pre-eminence of the North-west Queensland Mineral Province is illustrated by the fact that the total zinc content of these six deposits alone is:

- 2.7 times higher than the total of the Abitibi Subprovince (Noranda, Matagami, Chibougamau areas, etcetera) of Quebec/Ontario in Canada, which has the largest zinc content of all the volcanogenic massive sulphide districts in the world,
- 3.3 times higher than the total zinc content of the 19 largest known carbonate-hosted zinc deposits in the Irish Central Plain,
- 3.1 times higher than the total contained zinc in the numerous deposits of the Tri-State District, which has the largest zinc content of all the North American Mississippi Valley districts,
- 1.9 times higher than the total zinc content of the 11 largest sediment-hosted deposits of the Selwyn Basin in Yukon/British Columbia, Canada, and

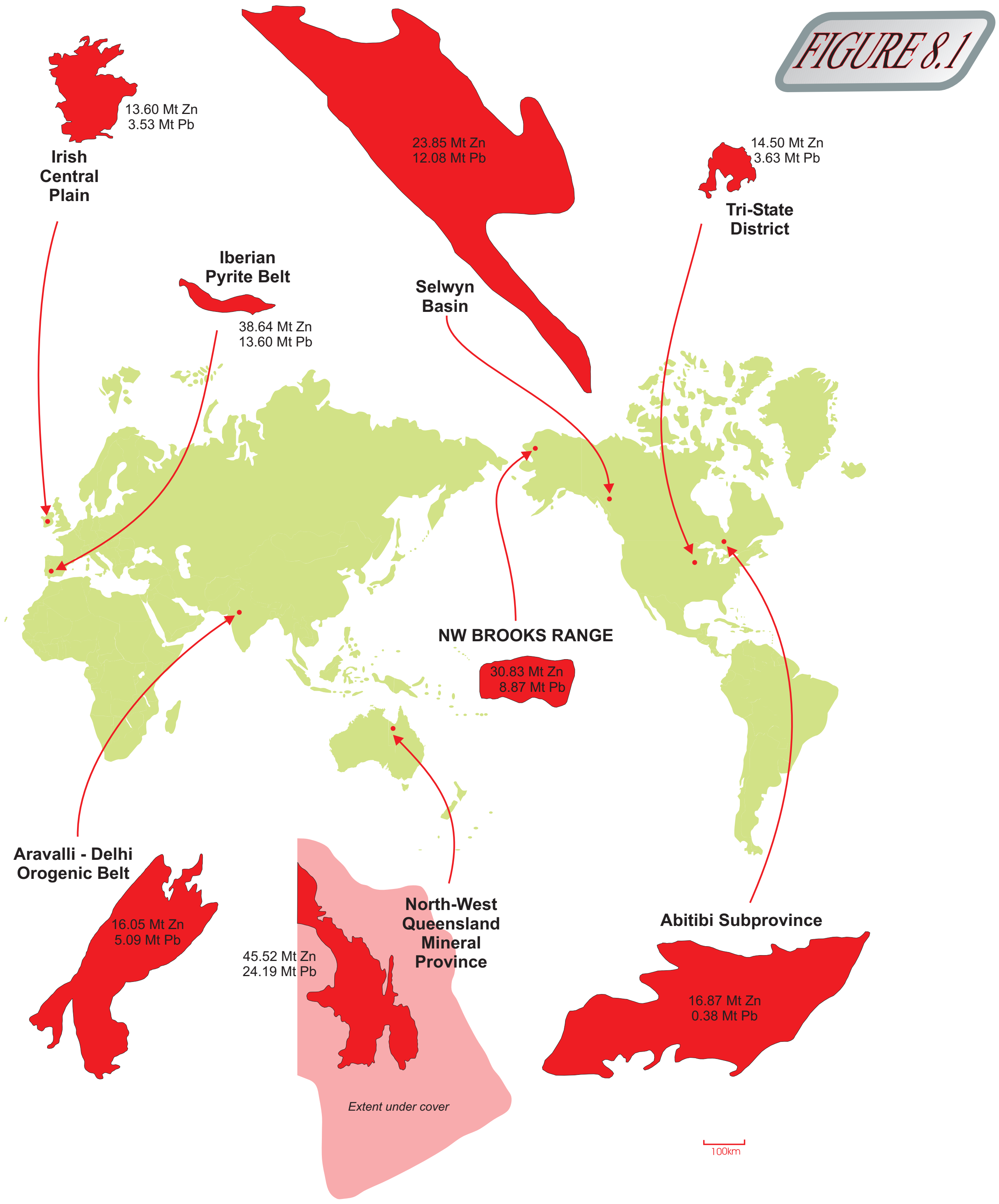


Figure 8.1: Comparison of size and Zn-Pb content of the world's major zinc-lead provinces

- 1.2 times higher than the total of 85 deposits in the Iberian Pyrite Belt, which is regarded as the largest concentration of massive sulphide mineralisation in the world.

Lead

Of the 31 deposits outside the CIS countries and China (Table 8.3) that meet the Singer (1995) definition of world class lead deposits (> 1Mt Pb), four are in the North-west Queensland Mineral Province. These four rank among the 18 largest lead deposits in the world – Hilton/George Fisher (3rd), Mount Isa (5th), Cannington (7th) and Century (18th).

Silver

The bulk of the world's silver production has come from high-grade vein deposits in Bolivia, Mexico and Peru, from high temperature carbonate-hosted lead-zinc deposits in Mexico and Peru, and as a by-product of lead-zinc mining. In the latter category, the four largest known deposits (production + current reserves) are Broken Hill (1016Moz silver) in New South Wales, followed by three deposits in the North-west Queensland Mineral Province — Cannington (757Moz), Mount Isa (643Moz) and Hilton/George Fisher (517Moz).

An indication of the significance of these deposits in a world context can be gauged from Table 8.4, which lists the estimated silver content (production + reserves) of the world's largest silver districts/deposits.

Copper

In terms of total copper mineral endowment, the North-west Queensland Mineral Province is not in the same league as the major porphyry and sediment-hosted copper belts of the world. Nevertheless, the two largest deposits in the region, Mount Isa (255Mt at 3.3% Cu) and Ernest Henry (127Mt at 1.1% Cu and 0.55g/t Au) represent attractive exploration targets by world standards by virtue of their high in-ground value per tonne.

The Mount Isa deposit, best known as a world class zinc body, is also of world class stature in copper according to the Singer (1995) definition that world class deposits contain >2Mt copper.

8.2 MINERAL PRODUCTION

Zinc

The North-west Queensland Mineral Province is a leading source of the world's zinc. Total mine production in the year to end June 2000 (Table 8.5) amounted to some 296 000t Zn, which is equivalent to 5% of the total western world output in calendar year 1999, or 3.8% of the global total over the same period.

With an output of 106 734t Zn in the nine month period from the inception of production in September 1999 to end June 2000, the Century mine was the region's largest producer in the 1999/2000 year. At its current production rate of some 250,000tpa Zn, Century is the second largest individual zinc producer in the world behind Red Dog in Alaska (~ 530 000tpa Zn). When it attains its full capacity of 500 000tpa Zn by the end of 2001, Century will provide around 7.4% of the western world's mine zinc production.

At the district scale, the North-west Queensland Mineral Province will become the foremost world zinc producer by 2002 when both Century and the new George Fisher mine (~170 000tpa Zn) are in full production. At that time, the North-west Queensland Mineral Province will yield around 10.9% of the projected western world zinc output.

Lead

The North-west Queensland Mineral Province contains the two largest lead producers in the world — Cannington (~155 000tpa) and Mount Isa/Hilton (~137 000tpa). Together, their production in the year to end June 2000 was equivalent to almost 13% of the western world lead output in calendar 1999, or 9.7% of the global total over the same period.

Silver

In terms of annual production Cannington (~22.5Moz per annum) is currently the world's largest silver producer, yielding an amount equivalent to 4.7% of total western world silver production in calendar 1999. Mount Isa/Hilton (~10.6Moz per annum) is currently ranked fifth among individual mine silver producers after Fresnillo in Mexico (~21Moz/yr), Eskay Creek in British Columbia (~11.7Moz/yr) and McCoy/Cove in Nevada (11Moz/yr).

Copper

With an output of 335 000t in the 1999/2000 year, the North-west Queensland Mineral Province provided almost half of Australia's total mine production of copper. In a world context, the North-west Queensland Mineral Province output is small compared with the top producers — Chile (4.38Mt in calendar 1999) and USA (1.63Mt) — but is nevertheless significant when compared with the likes of Peru (536 000t), Mexico (381 000t), and Zambia (340 000t), three major copper-producing countries.

8.3 DISCOVERY RECORD

Table 8.6 lists significant zinc and copper discoveries world wide (outside the CIS countries and China) over the past 20 years. In that period, the North-west Queensland Mineral Province can claim to have the best greenfields zinc discovery rate of any mineralised province in the world in terms of the number and size of the discoveries (Century, Cannington, Walford Creek, Grevillea). Century is the second largest zinc discovery of the past two decades behind Red Dog and, although Cannington is primarily a lead-silver deposit, its zinc content is such that it is eighth largest in the ranking of zinc discoveries since 1980 (Table 8.7).

In terms of total greenfields zinc metal discovered since 1980, the North-west Queensland Mineral Province is the second ranked region in the world behind the Brooks Range of Alaska, where the various components of the Red Dog deposit now amount to 26.7Mt and the Anarraaq discovery in 1999 added a further 2.16Mt.

In addition to the new discoveries, there have also been significant additions to the total zinc resource endowment of the North-west Queensland Mineral Province over the past decade through further drilling of the Dugald River, Lady Loretta and Hilton/George Fisher deposits, all of which were discovered prior to 1980.

Regarding copper, there have been no discoveries in the North-west Queensland Mineral Province to match the size of those in the porphyry belts of Chile and Indonesia, but the region nevertheless boasts a good discovery record for medium-sized copper-gold deposits. Since 1980, three such deposits have been found and put into production — Selwyn (7.4Mt at 1.9% Cu and 3.8g/t Au), Eloise (3.1Mt at 5.5% Cu and 1.4g/t Au) and Ernest Henry (127Mt at 1.1% Cu and 0.55g/t Au).

As for gold, there are no known major deposits of world class stature in the region, but the 1989 discovery of the small, high-grade Tick Hill deposit proved to be a lucrative find for Mount Isa Mines Ltd. In the 1992 to 1995 period, the deposit yielded a total of 511 000oz Au from 706 000t of ore for an average grade of 22.5g/t Au.

TABLE 8.1: RANKING OF WORLD CLASS ZINC DEPOSITS BY ZINC CONTENT

DEPOSIT	LOCATION	STATUS	Mt Zn
BROKEN HILL	New South Wales, Australia	o.m.	35.53
RED DOG	Alaska, USA	o.m.	26.7
HILTON/GEORGE FISHER	**North-west Queensland**	**o.m.**	**15.35**
McARTHUR RIVER	Northern Territory, Australia	o.m.	14.62
BRUNSWICK No. 12	New Brunswick, Canada	o.m.	11.63
CENTURY	**North-west Queensland**	**o.m.**	**11.42**
GAMSBERG	South Africa	a.p.	10.65
SULLIVAN	British Columbia, Canada	o.m.	9.77
REOCIN	Spain	o.m.	9.57
MOUNT ISA	**North-west Queensland**	**o.m.**	**8.75**
RAMPURA AGUCHA	India	o.m.	8.66
KIDD CREEK	Ontario, Canada	o.m.	8.40
KIPUSHI	Democratic Republic of the Congo	o.m.	7.74
CERRO de PASCO	Peru	o.m.	7.36
NAVAN	Republic of Ireland	o.m.	6.98
ANGOURAN	Iran	a.p.	5.88
HOWARDS PASS	Yukon, Canada	a.p.	5.86
DUGALD RIVER	**North-west Queensland**	**a.p.**	**5.74**
SAN GREGORIO	Peru	a.p.	5.13
ZINKGRUVAN	Sweden	o.m.	4.99
MEHDIABAD	Iran	a.p.	4.29
RAMMELSBERG	Germany	f.m.	4.46
FRANKLIN	New Jersey, USA	f.m.	4.08
ROSEBERY	Tasmania, Australia	o.m.	4.04
MEGGEN	Germany	f.m.	4.00
SANTA EULALIA	Mexico	o.m.	3.65
ELURA	New South Wales, Australia	o.m.	3.64
SANTA BARBARA	Mexico	o.m.	3.44
NICOLET	Wisconsin, USA	a.p.	3.40

DEPOSIT	LOCATION	STATUS	Mt Zn
NEVES CORVO	Portugal	o.m.	3.32
FARO	Yukon, Canada	f.m.	3.28
SAN VICENTE	Peru	o.m.	3.12
KABWE	Zambia	f.m.	3.10
CIRQUE	British Columbia, Canada	a.p.	3.08
POLARIS	Nanavut, Canada	o.m.	3.08
SKORPION	Namibia	a.p.	2.72
FLIN FLON	Manitoba, Canada	o.m.	2.58
LISHEEN	Republic of Ireland	o.m.	2.41
BUCHANS	Newfoundland, Canada	f.m.	2.35
HELLYER	Tasmania, Australia	f.m.	2.33
LADY LORETTA	**North-west Queensland**	**a.p.**	**2.32**
BALMAT	New York, USA	o.m.	2.25
ANARRAAQ	Alaska, USA	a.p.	2.16
FEITAS/MOINHO	Portugal.	a.p.	2.15
HEATH STEELE	New Brunswick, Canada	f.m.	2.13
ARCTIC	Alaska, USA	a.p.	2.00
VAZANTE	Brazil	o.m.	1.99
LIK-SU	Alaska, USA	a.p.	1.96
CANNINGTON	**North-west Queensland**	**o.m.**	**1.93**
IZOK LAKE	North West Territories, Canada	a.p.	1.88
MASA	Brazil	o.m.	1.88
IRANKUH	Iran	o.m.	1.86
EL AGUILAR	Argentina	o.m.	1.86
SCUDDLES	Western Australia, Australia	o.m.	1.80
WOODLAWN	New South Wales, Australia	f.m.	1.78
FALUN	Sweden	o.m.	1.75
TAXCO	Mexico	o.m.	1.70

- o.m. operating mine; f.m. former mine; a.p. advanced project
- Compiled from numerous sources; references are available from Taylor Wall and Associates
- Deposits in the CIS countries and China are not included
- The zinc contents listed are based on published resource and reserve estimates of a variety of categories, comprising Indicated and Measured Resources, Probable and Proved Reserves and Previous Production. Where known, Inferred Resources have not been included.

TABLE 8.2: COMPARISON OF OVERALL LEAD AND ZINC CONTENTS IN MAJOR MINERALISED PROVINCES WORLD WIDE

PROVINCE	COMPOSITION OF TOTAL	Mt Pb	Mt Zn	Source of Data
NORTH-WEST QUEENSLAND MINERAL PROVINCE Australia	The six largest known deposits	24.19	45.52	See table
BROOKS RANGE Alaska	Red Dog, Anarraaq and Lik-Su	8.87	30.83	References to each deposit*
SELWYN BASIN Canada	The eleven largest known deposits	12.08	23.85	References to the individual deposits*
ABITIBI Canada	All known economic resources in the district	0.38	16.87	Barrie & others (1993)
TRI-STATE DISTRICT USA	All known economic resources in the district	3.63	14.50	Kyle (1994)
ARAVALLI-DELHI BELT North-west India	The ten largest known deposits	5.09	16.05	Deb & others (1989)
IBERIAN PYRITE BELT Spain and Portugal	85 deposits, the majority of which are subeconomic	13.60	38.64	Leistel & others (1998)
IRISH CENTRAL PLAIN Republic of Ireland	19 deposits, 14 of which are subeconomic	3.53	13.60	Johnston (1999)

* References used can be supplied by Taylor Wall and Associates on request

TABLE 8.3: RANKING OF WORLD CLASS LEAD DEPOSITS BY LEAD CONTENT

DEPOSIT	LOCATION	STATUS	Mt Pb
BROKEN HILL	New South Wales, Australia	o.m.	27.07
SULLIVAN	British Columbia, Canada	o.m.	10.02
HILTON/GEORGE FISHER	**North-west Queensland, Australia**	**o.m.**	**8.23**
RED DOG	Alaska, USA	o.m.	7.60
MOUNT ISA	**North-west Queensland, Australia**	**o.m.**	**7.50**
McARTHUR RIVER	Northern Territory, Australia	o.m.	6.64
CANNINGTON	**North-west Queensland, Australia**	**o.m.**	**5.08**
BRUNSWICK No. 12	New Brunswick, Canada	o.m.	4.82
SANTA EULALIA	Mexico	o.m.	4.40
TSUMEB	Namibia	f.m.	3.00
CERRO de PASCO	Peru	o.m.	2.80
HOWARDS PASS	Yukon, Canada	a.p.	2.65
ELURA	New South Wales, Australia	o.m.	2.27
RAMMELSBERG	Germany	f.m.	2.12
FARO	British Columbia, Canada	f.m.	1.96
NAVAN	Republic of Ireland	o.m.	1.82
SANTA BARBARA	Mexico	o.m.	1.81
CENTURY	**North-west Queensland, Australia**	**o.m.**	**1.67**
EL AGUILAR	Argentina	o.m.	1.65
ZINKGRUVAN	Sweden	o.m.	1.54
SAN GREGORIO	Peru	a.p.	1.53
KABWE	Zambia	f.m.	1.32
REOCIN	Spain	o.m.	1.30
HELLYER	Tasmania, Australia	f.m.	1.22
ROSEBERY	Tasmania, Australia	o.m.	1.22
BUCHANS	Newfoundland, Canada	f.m.	1.22
RAMPURA AGUCHA	India	o.m.	1.21
PRAIRIE CREEK	North West Territories, Canada	a.p.	1.20
MEHDIABAD	Iran	a.p.	1.10
ANGOURAN	Iran	a.p.	1.05
JASON	Yukon, Canada	a.p.	1.00

- o.m. operating mine; f.m. former mine; a.p. advanced project
- Compiled from numerous sources, references for which are available from Taylor Wall and Associates
- Deposits in the CIS countries and China are not included
- The lead contents listed are based on published resource and reserve estimates of a variety of categories, comprising Indicated and Measured Resources, Probable and Proved Reserves and Previous Production. Where known, Inferred Resources have not been included.

TABLE 8.4: THE WORLD'S LARGEST SILVER DISTRICTS/DEPOSITS

District/Deposit	Location	Production + Reserves Moz Ag
CERRO RICO DE POTOSI	Bolivia	~2000
PACHUCA DISTRICT	Mexico	1500
GUANAJUATO DISTRICT	Mexico	1050
BROKEN HILL	New South Wales, Australia	1016
CANNINGTON	North-west Queensland Mineral Province, Australia	757
MOUNT ISA	North-west Queensland Mineral Province, Australia	643
PASCUA/LAMA	Chile/Argentina	558
HILTON/GEORGE FISHER	North-west Queensland Mineral Province, Australia	517
SANTA EULALIA	Mexico	511
SAN CRISTOBAL	Bolivia	480
RED DOG	Alaska	457
GUANACEVI	Mexico	450
FRESNILLO	Mexico	450

Note: References for the above data can be obtained from Taylor Wall & Associates on request

TABLE 8.5: NORTH-WEST QUEENSLAND MINERAL PROVINCE, YEAR 1999-2000 PRODUCTION

		ORE TREATED						METAL CONTENT OF PRODUCT					
DEPOSIT Owner(s) Start of Production	**ORE MINED (tonnes)**	**tonnes**	**% Cu**	**% Pb**	**% Zn**	**g/t Au**	**g/t Ag**	**Copper**	**Lead**	**Zinc**	**Silver**	**Gold**	**COMMENTS**
CANNINGTON BHP Ltd 1997									154349t in Pb concentrates	45112t in Zn concentrates	22.44Moz in Pb concentrates		
CENTURY Pasminco Ltd 1999		1414872		3.5	11.1		86.2			106734t in Zn concentrates			Production commenced in September 1999
ELOISE Amalg Resources NL 1996	508231		4.29			1.19		21190t in Cu concentrates			176127oz in Cu concentrates	12405oz in Cu concentrates	
ERNEST HENRY MIM Holdings Ltd 51% Pasminco Ltd 49% 1997	9820992	9720750	1.08			0.55		94794t in Cu concentrates				114939oz in Cu concentrates	
GEORGE FISHER MIM Holdings Ltd |1999	227745												Metal content of product is included in the Mount Isa total
HILTON MIM Holdings Ltd 1987	947485												Metal content of product is included in the Mount Isa total
MOUNT CUTHBERT Matrix Metals Ltd 1996		205039	1.90					2844t stripped copper					Mount Cuthbert was purchased by Matrix Metals in early 2000; production in 1999-2000 was by Murchison United NL
MOUNT GORDON Western Metals Ltd 1989		476164	8.33					34813t copper cathode					production dates back to 1927; 1989 was the start of the modern SX-EW operation by Adelaide Brighton Ltd
MOUNT ISA MIM Holdings Ltd Pb-Ag 1931 Zn 1935 Cu 1939	1872575 lead-zinc ore	5016174 copper ore 3007225 lead-zinc ore	3.9	5.8	6.6		155	133937t anode copper	137190t crude lead	144029t in Zn concentrates	10.65Moz in crude lead 767555oz in anode		the lead-zinc ore treated and metal content of product data include production from Hilton and George Fisher
OSBORNE Placer Dome Incorporated 1994								47232t in Cu concentrates				37905oz in Cu concentrates	
							TOTAL	**334810t**	**291539t**	**295875t**	**34Moz**	**165249oz**	

Source of data: Company Quarterly and Annual Reports, plus Department of Mines and Energy statistics

TABLE 8.6: BASE METAL DISCOVERIES 1980 TO 2000

YEAR DISCOVERED/DEPOSITS		ORE (Mt)	% Cu	% Pb	% Zn	g/t Ag	g/t Au
1980							
MIDWAY (Silvertip)	British Columbia, Canada	1.1		7.7	9.5	378	0.85
RAMPURA AGUCHA	India	63.7		1.9	13.6	45	
SELWYN	**North-west Queensland Mineral Province**	7.4	1.9				3.8
RED DOG	Alaska, USA	173		4.4	15.5	82	
1981							
NIFTY	Western Australia, Australia	28	3.36				
ANSIL	Quebec, Canada	1.6	7.2		0.9	26	1.6
ZALDIVAR	Chile	246	1.02				
EL TESORO	Chile	153	0.96				
ESCONDIDA	Chile	2118	1.31				
BISMARK	Mexico	8.5		0.6	8.4	55	
LEPANTO F.S.E.	Philippines	650	0.65				1.33
BOU GRINE	Tunisia	5		2.6	11.7		
ADMIRAL BAY	Western Australia, Australia	120		2.3	6.4	32	
		+20		16.9	0.4	57	
1982							
PERKOA	Burkina Faso	7			17.6		
ISCAY CRUZ	Peru	3.3		2	19	52	
WINSTON LAKE	Ontario, Canada	3.0	1.0		15.6	31	1.0
1983							
HELLYER	Tasmania, Australia	16.9	0.4	7.2	13.8	167	2.5
1984							
CADJEBUT	Western Australia, Australia	4.3		3.3	11.3		
HAJAR	Morocco	12	0.7	3.0	10.5	70	
1985							
AGUAS TENIDAS EAST	Spain	12.7	1.7	1.9	6.2	60	
SHEEP CREEK	U.S.A.	8.5	3.2				
ISLE DIEU	Quebec, Canada	2.1	1.03		17.8		0.45
NORITA EAST	Quebec, Canada	4	1.8		3.8		
1986							
12 MILE BORE	Western Australia, Australia	2.4		2.7	10.1	38	
GALMOY	Republic of Ireland	6.9		1.3	12.8		
VALVERDE	Spain	11	0.5		5.0		
1987							
LA CANDELARIA	Chile	366	1.29				0.3
DUDDAR	Pakistan	14.3		3.2	8.6		
DUCK POND	Newfoundland, Canada	5.7	3.37	1.12	6.5	66	0.9
1988							
ESKAY CREEK	British Columbia, Canada	1.1	0.77		5.6	2900	65
GRASBERG	Indonesia	2738	1.16				1.1
ELOISE	**North-west Queensland Mineral Province**	3.1	5.5			16	1.4
1989							
LOUVICOURT	British Columbia, Canada	24	3.9		2.0	31	1
GREVET	Quebec, Canada	18.5	0.41	0.15	7.22	31	
CHIMBORAZO	Chile	236	0.6				
OSBORNE	**North-west Queensland Mineral Province**	11.2	3.51				1.5
DIDIPIO	Philippines	17.2	0.66				2.37
MIGOLLAS	Spain	57.6	0.88	1.12	2.23		
1990							
MANSA MINA	Chile	325	0.96				
SAN ANTONIO	Dominican Republic	**no**	**resource**	**reported**	**to date**		
LISHEEN	Ireland	18.9		2.2	12.7	26	
CENTURY	**North-west Queensland Mineral Province**	98.5		1.7	11.6	43	
CANNINGTON	**North-west Queensland Mineral Province**	43.8		11.6	4.4	538	
WALFORD CREEK	**North-west Queensland Mineral Province**	**no**	**resource**	**reported**	**to date**		
MOUNT ROSEBY	**North-west Queensland Mineral Province**	62.5	0.75				
CERATEPPE	Turkey	5.6	4.3				
LYNNE	U.S.A.	6.1	0.64	1.65	8.7	84	0.8
1991							
DON MARIO (Upper Zone)	Bolivia	6	1.5				1.5
UJINA	Chile	1266	0.78				
BATU HIJAU	Indonesia	914	0.52				0.4
ERNEST HENRY	**North-west Queensland Mineral Province**	127	1.1				0.55
MILPILLAS	Mexico	230	0.85				
1992							
DAMIANA	Chile	300	0.3				
TAMPAKAN	Philippines	900	0.75				0.30
1993							
KUDZ ZE KAYAH	Yukon, Canada	11.3	0.9	1.5	5.9	133	1.3
PRAIRIE CREEK	NWT, Canada	11.9		10.1	12.5	161	
CITRONEN FJORD	Greenland	7		1.0	9.0		
PUTHEP	Thailand	116	0.4				
BELLALLARD	Quebec, Canada	3.2	1.5		13.8		
1994							
AREX	Brazil	**no**	**resource**	**reported**	**to date**		
LOMAS BAYAS	Chile	131	0.53				
GREVILLEA	**North-west Queensland Mineral Province**	**no**	**resource**	**reported**	**to date**		
SAN GREGORIO	Peru	70		2.19	7.33	14	
RELINCHO	Chile	150	0.7				0.3
LAS CRUCES	Spain	15	5.8				
1995							
WOLVERINE	Yukon, Canada	6.2	1.3	1.5	12.7	371	1.8

YEAR DISCOVERED/DEPOSITS		ORE (Mt)	% Cu	% Pb	% Zn	g/t Ag	g/t Au
FRANCISCO I MADERO	Mexico	33		0.5	4.5	31	
ALEMAO	Brazil	176	1.5				0.8
1996							
TRITTON	New South Wales, Australia	9.2	2.6				
SAN CRISTOBAL	Bolivia	240		0.58	1.67	62	
VALLEY	Brazil	11.6		2.25	6.29	65	0.25
FYRE LAKE	Yukon, Canada	15.4	1.2				0.46
SPENCE	Chile	400	1.0				
GABY	Chile	400	0.54				
ACCHA	Peru	9			9.0		
1997							
SOSSEGO	Brazil	219	1.14				0.34
SAN NICOLAS	Mexico	75	1.4		2.1	29	0.5
BONGARA	Peru	no	resource	reported	to date		
DIMAKAWAL	Philippines	no	resource	reported	to date		
SEPON (Khanong)	Laos	41.4	2.4				
GABY	Chile	no	resource	reported	to date		
1998							
SOPOKOMIL	Indonesia	no	resource	reported	to date		
STORLIDEN	Sweden	1.8	3.5		10.3	24	0.28
1999							
LOS CHANCAS	Peru	no	resource	reported	to date		
ANARRAAQ	Alaska, USA	12		5	18	90	

- References for the above data are available from Taylor Wall and Associates
- The year of discovery is defined as the date of the first drill intersection of economic tenor mineralisation

TABLE 8.7: THE LARGEST ZINC DISCOVERIES SINCE 1980

Ranking	Deposit	Total Contained Zinc (Mt)
1	Red Dog: Alaska, USA	26.70
2	Century: North-west Queensland Mineral Province, Australia	11.42
3	Rampura Agucha: India	8.66
4	San Gregorio: Peru	5.13
5	Skorpion: Namibia	2.72
6	Lisheen: Republic of Ireland	2.41
7	Hellyer: Tasmania, Australia	2.33
8	Cannington: North-west Queensland Mineral Province, Australia	1.93

Note: The references used can be supplied by Taylor Wall and Associates on request

9. REGULATIONS GOVERNING EXPLORATION AND MINING IN QUEENSLAND

9.1 GENERAL ASPECTS

- In Australia all minerals belong to the Crown.
- Under the Australian federal system the Commonwealth and State Governments are responsible for different aspects of the minerals regulatory system. The Commonwealth Government is responsible for overall economic policy, tax, interest rates, foreign investment and corporate law. The six States and the Northern Territory own and allocate mineral property rights for exploration and mining, regulate operations and collect royalties on minerals produced.

9.2 FOREIGN INVESTMENT

- Foreign companies are allowed 100% ownership of mineral exploration properties. Under foreign investment regulations, they are not required to seek approval for acquisition of exploration title nor for farming-in to an existing title.
- Mining developments with a total investment of $A10 million or more in which foreign companies are involved require approval from the Foreign Investment Board. Investment in the range $A10M to $A50M is normally approved without detailed examination. Proposals of $A50M or more are normally approved unless considered to be against the national interest.

9.3 MINERAL REGULATIONS IN QUEENSLAND

The Queensland Mining Act (Mineral Resources Act 1989) is administered by the Minister for Mines and Energy through the Department of Mines and Energy. Contact details for the latter are as follows:

Department of Mines and Energy
GPO Box 194
BRISBANE QLD 4001
61 Mary Street
BRISBANE QLD 4000
Telephone: +61 (0)7 3237 1435
Facsimile: +61 (0)7 3224 8380
http://www.dme.qld.gov.au

For administrative purposes, Queensland is subdivided into three regions and nine mining districts (Figure 9.1). Each mining district is managed by a Mining Registrar. Under the Mineral Resources Act 1989, the Land and Resources Tribunal can rule on disputes regarding exploration and mining tenements. The Tribunal operates generally under the same procedure as the Supreme Court of Queensland. Appeals on any decision of the Tribunal can be lodged with the District Court of Queensland.

The North-west Queensland Mineral Province lies mainly within the Mount Isa District. Contact details for the district office, which is also the Northern Region Office, are:

Mount Isa District Office
(also Northern Regional Office)
PO Box 334
MOUNT ISA QLD 4825
13 Isa Street
MOUNT ISA QLD 4825
Telephone: +61 (0)7 4747 2104
Facsimile: +61 (0)7 4743 7165

The Mineral Resources Act (1989) is simplified in the **"Mineral Resources Act Handbook (Parts 1-6)"** published by the Department of Mines and Energy in 1995, and summarised in very concise form in the Department of Mines and Energy publication of April 1 2000 **"Exploring and Developing Minerals, Coal and Petroleum in Queensland, Australia – A Guide for Investors"**, which is available as a free download over the internet. The current listing of the various fees regarding exploration and mining tenure in Queensland is available on the DME website or from any DME District Office.

9.4 FORMS OF MINERAL TITLE IN QUEENSLAND

There are three forms of mineral title in Queensland for large-scale exploration and mining activities — the Exploration Permit, the Mineral Development Licence and the Mining Lease, as follows:

Exploration Permit

The Exploration Permit (EP) allows large-scale exploration activities and is granted for all minerals other than coal (EPM), for coal itself (EPC), or for petroleum (EPP) exploration. As stated in the section on Native Title, Exploration Permits are conditioned to allow either low-impact activities only, or both low- and high-impact activities. Different Native Title Procedures apply in each case.

When an EP is granted over ground not affected by native title, title holders are assured access to land and need only to notify landowners to obtain entry. If the EP is granted over ground subject to native title, entry is not possible until an access agreement is reached with the registered native title party for the land in question. In each case, once title is granted and entry negotiated, title holders are assured security of tenure and the right to mine provided they meet their obligations under the Mineral Resources Act. The key regulations governing Exploration Permits can be summarised as follows:

- EPs are delineated according to a system of blocks and sub-blocks based on the Block Identification Map, Series B, available from the Department of Mines and Energy. A block consists of 25 sub-blocks, each of which comprises one minute of latitude by one minute of longitude (an area of approximately 3km^2).
- The maximum size limit of an EP for metallic minerals is 100 sub-blocks (an area of approximately 300km^2) unless the Minister approves otherwise (under exceptional circumstances).
- An EP can be granted for an initial term of five years, but can be renewed provided expenditure and reporting requirements are met, annual ground rental is paid and there are no infringements under the Mineral Resources Act. At the end of five years, the EP can only be extended under special circumstances on the approval of the Minister.
- After two years of tenure, the EP area must be reduced by 50%, unless the Minister otherwise specifies or allows. At the end of each subsequent one year period, the remaining area must again be reduced by 50%.
- Annual reports are required, detailing exploration progress and results, expenditure, and the proposed programme and budget for the following one year period.
- The annual expenditure requirement is not prescribed in the regulations, but is established according to the nature and scope of the proposed programme.
- Annual ground rental, for rentals due after June 30, 2000, is $A98.50 per sub-block.
- An EP, or interest in an EP, may be transferred to another entity at any time on the approval of the Minister, provided that the proposed transfer includes all the ground held under the EP.

Mineral Development Licence

The Mineral Development Licence (MDL) is an intermediate form of tenure between the Exploration Permit and Mining Lease. It allows companies to undertake further evaluation and feasibility studies of resources identified under an Exploration Permit and, in cases where such resources are subeconomic, guarantees security of tenure until the market, technology or economic conditions become more favourable. Environmental Management Plans are required for any major activity.

MDLs are granted for periods of up to five years, but may be extended under special circumstances. The annual rental fee per hectare in Australian dollars is $2.75 in

Year 1, \$5.65 (Year 2), \$8.50 (Year 3), \$14.35 (Year 4) and \$17.25 (after Year 4).

Mining Lease

The Mining Lease (ML) is necessary to allow mining to proceed. Title will only be granted once mining plans and environmental management strategies are approved, a formal objection process is heard, agreement to the grant is negotiated with native title parties, and compensation to land holders is settled. There is no restriction on the size and shape of an ML, provided this is justified in the application, and no limit on its duration, provided it is not for a term longer than the period for which compensation has been agreed to or stipulated. Annual rental is \$A36.30 per hectare.

9.5 THE EXPLORATION PERMIT APPLICATION PROCEDURE IN QUEENSLAND

The application procedure for an Exploration Permit (EP) requires the lodgement of an Application Form at the local Mining District office or at the Brisbane District office. In addition, the relevant native title parties must be notified of the application either before or shortly after the lodgement. Unlike some other jurisdictions elsewhere in the world, no physical staking of property limits is necessary.

In the Application Form, applicants must state whether the tenement is to be conditioned for high- or low-impact activities, and provide details of the proposed work programme and expenditure for each year applied for, plus a summary of the company's technical and financial capabilities. Provided this information is acceptable and there is compliance with Native Title Procedures, the title is granted on a first come-first served basis. In rare cases where applications are lodged simultaneously for the same ground by different companies on the same day, priority is determined on the merits of the applications by a panel of assessment officers according to Departmental policy.

Queensland differs from the rest of Australia in that there is no notification of the EP application in the local Government Gazette or press, and thus no provision for public comment or objection at the application stage.

Before the EP is granted, it is necessary to pay the first full year rental and also to lodge a security deposit, which is determined by the Minister on the basis of the application. The security may be in the form of cash, a bond, guarantee or other financial arrangement from a bank or other financial institution. The deposit is refundable six months after the expiry or termination of an EP, provided the financial obligations of the EP have been met and any environmental damage rectified.

9.6 ENVIRONMENTAL REGULATIONS

Under the Environmental Protection Act 1998, companies involved in exploration and mining activities in Queensland have clearly defined environmental responsibilities, which ensure that environmental management and rehabilitation of mined areas are treated as an integral part of mine planning and operations. The body responsible for overseeing environmental compliance is the Environmental Protection Agency.

Explorers and small miners who agree to act in accordance with the relevant code of environmental compliance will be issued with an environmental authority. Where these conditions cannot be met, an Environmental Management Plan (EMP) must be developed.

An application for a Mining Lease must be accompanied by an **Environmental Management Overview Strategy** (EMOS), a strategic planning document that outlines long-term strategies and some short-term operation details for protecting the environment and managing environmental impacts. It also addresses progressive and final rehabilitation of the land.

The degree of environmental assessment for mining leases has been simplified into three levels according to the potential environmental impacts of the mining project. The process is as follows:

- **Level 2**

  Very small mining operations that can comply with a Code of Environmental Compliance – Mining Leases. For these low-impact mining operations a simple administrative process is used for the issue of the Environmental Authority, relying on compliance with the Code.

- **Level 1(a)**

  Mining Lease applications that are likely to have some significant environmental impacts. Companies are required to liaise with relevant Government agencies before developing an EMOS.

- **Level 1(b)**

  Mining Lease applications that are generally for large projects that have potentially high or uncertain impacts on the environment or have been declared a project of State significance. To assess environmental management issues for these applications, an **Environmental Impact Statement** (EIS) is required.

Guidelines are issued for companies to follow when preparing an EIS. Copies of the completed EIS must be made available to land owners, local government and the public, who are entitled to make submissions before a decision is made to grant the Environmental Authority and the Mining Lease.

A **Plan of Operations** which is based on the EMOS and which sets out the time frame for rehabilitation and other commitments, must also be submitted to the Environmental Protection Agency for all Mining Leases before mining begins.

9.7 COMPARISON OF MINING/EXPLORATION REGULATIONS IN QUEENSLAND WITH OTHER JURISDICTIONS WORLD WIDE

Table 9.1 (on the CD-ROM) presents a comparison of the main regulations governing exploration and mining titles in Queensland with those in other parts of the world in which there is currently a significant level of exploration activity. With the exception of Ghana and Papua New Guinea, all these jurisdictions allow 100% foreign ownership of mining properties.

As the various regulatory schemes listed are too diverse and complex to permit a meaningful objective quantification of their relative merits, no attempt has been made to rank these jurisdictions in terms of their overall impact on the exploration and mining process. Instead, the detailed information is presented to enable decision-makers to make their own overall assessments and conclusions.

It should be noted, however, that in the following aspects the Queensland regulations are more favourable than certain other jurisdictions worldwide:

- Regulations governing the size of an Exploration Permit (up to 300km^2), and no limitations on the amount of adjacent titles which can be held, are appropriate for modern regional-scale exploration practice. In contrast, the tenure system in certain jurisdictions (for example, Nevada, Alaska, Yukon, Philippines and Peru) is based on small units of ground, which are much more difficult to administrate and manage.

- In contrast to the tenure application system in North America and Mexico, physical claim staking of exploration permits is not a requirement in Queensland.

- The maximum initial duration of an Exploration Permit (5 years) is an appropriate balance between allowing enough time for companies to adequately assess the mineral potential, and ensuring that ground is freed up on a regular basis for other explorers. In several jurisdictions (for example, Yukon, Ontario, Nevada, Mexico and Peru) ground can be tied up in perpetuity provided the holders meet annual expenditure/rental commitments; in others (for example, Ireland and Ghana) tenure can be prolonged if acceptable programmes are proposed.

• The relinquishment requirements also ensure the continual turnover of ground in Queensland. In contrast, there is no such relinquishment mechanism in Ireland, Mexico, Peru, Namibia, Nevada, Ontario and Yukon.

• The annual ground rental for an Exploration Permit in Queensland (equivalent to ~$US17/km^2) lies in the middle of the range, being much higher than in the likes of Ghana, Indonesia, Namibia and Papua New Guinea, but significantly lower than in Chile, Peru, Bolivia, Nevada and Alaska.

• The annual exploration expenditure requirement is fair and realistic as it is set according to the programme proposed by the company, and is not based on stipulated expenditure per unit of area, as in some jurisdictions.

FIGURE 9.1

10. MINERAL INDUSTRY TAXATION

10.1 SUMMARY OF TAXATION IN QUEENSLAND

Mining companies operating in Queensland are subject to Commonwealth and State taxes, the main elements of which are summarised below.

Commonwealth Taxes

Corporate Income Tax

- 34% of taxable income (that is, revenue minus allowable deductions) for the year 2000/01; 30% thereafter

Allowable Deductions for Calculating Taxable Income

The following costs are deductible — post-production exploration expenses, operating costs, capital expenses, depreciation, amortization, loan interest, royalty, import duties, excise/sales tax on equipment and services, withholding tax on interest, local development costs, property tax, fees based on land area, stamp taxes, payroll taxes.

- Pre- and post-production exploration costs are deductible in the year incurred,
- capital expenditure on the Environmental Impact Statement is deductible over ten years, or the life of the project, whichever is lesser,
- feasibility studies are deductible in the year incurred,
- capital costs for mine development are deductible over ten years, or over the life of the mine if less than that period, and
- expenditure on mine transport facilities is deductible over ten years.

Withholding Tax

- On loan interest paid to foreign lenders: 10% on the gross amount of interest paid, deductible, and
- on dividends remitted abroad: 15% for remittance to a country with which Australia has a tax treaty, otherwise 30%, not deductible. However, if the dividend is fully franked, no withholding tax is payable.

Import Duty

- 5% for most plant and equipment imported into Australia, but higher rates apply to some goods, and exemptions are possible if the items are not available in Australia.

Fringe Benefit Tax

A rate of 48.5% is payable on the value of certain benefits provided to employees (for example, motor vehicles for private use, subsidised or free housing and travel). Mining companies can take advantage of specific concessions in the taxation of benefits provided in remote areas (40km from a population centre of 14,000, or 100km from a centre of 130,000 or more), and in some of the methods used to calculate benefits, such as work-related travel.

Goods and Services Tax

A type of value-added tax, the Goods and Services Tax (GST), is payable on most supplies and services at a rate of 10%. Under the GST arrangements, companies can claim tax credits for all their business-related inputs. In addition, several items are GST-free. Those of most interest to the mining sector are:

- exports of goods and services, and
- taxes and water charges levied by all levels of government.

Tax Incentives

- Losses can be carried forward until absorbed, with no time limit,
- a development allowance of 10% of eligible capital expenditure incurred on plant is allowable as a deduction,
- research and development activities are 125% deductible in the year the expenses are incurred, and
- there is a 100% rebate of the customs or excise paid on diesel consumed in mining activities.

Queensland Government Taxes

Queensland is the lowest taxed state in Australia. The main State taxes are as set out below.

Royalties

Companies can elect to pay a royalty for copper, lead, zinc, gold and silver, fixed for five years, at a rate of 2.7% of the value of payable metal, or a variable rate (1.5 to 4.5% based on the average quarterly metal prices, and as advised by the Department of Mines and Energy). The rate applies to the revenue base less a statutory exemption of $A30 000 per year. For copper, lead and zinc a reduced royalty (50%) applies to the first $A4 million per annum of combined payable metal revenue, but no such reductions apply in the case of gold and silver. Processing discounts of 20% for copper, 25% for lead, and 35% for zinc apply when production is processed in the State to 95% contained metal.

Payroll Tax

Currently the maximum rate is 5% of gross wages less any allowable deductions.

Land Tax

Companies owning freehold land in Queensland may be liable for land tax. The maximum rate is 1.8% on land owned in excess of $A1.5 million.

10.2 COMPARISON OF THE TAXATION REGIME IN QUEENSLAND WITH OTHER JURISDICTIONS WORLDWIDE

As taxation regulations in the major mineralised belts worldwide are complex, voluminous and show considerable variation, a comprehensive summary and comparison is beyond the scope of this publication. Instead, only a select number of the more important regulations are presented (Table 10.1 on the CD-ROM), to give an indication of how Queensland's tax regime compares in gross aspects with certain jurisdictions (for example, Chile, Peru and Sweden) that are highly regarded by the mining investment community.

Over the past decade, a number of workers have attempted to quantify and rank the various mineral taxation regimes in terms of their relative financial impact on mining operations. By far the most comprehensive, detailed and authoritative of these studies has been by Otto & others (2000), which succinctly summarizes the myriad of mining industry taxes in 23 countries worldwide, including Australia, then analyses and ranks the impact of these taxes on two hypothetical copper and gold deposits. The Australian taxation regulations used in the study are those of Western Australia, which do not differ significantly from those of Queensland, and can thus be used as an indication of how the latter's mineral taxation regime compares with other major mineralised belts of the world.

The results (**Figures 10.1** and **10.2**) show that, based on the internal rate of return for the model copper and gold mines, the Western Australia/Queensland taxation regimes can be regarded as among the most favourable in the world for investment in mining projects.

FIGURE 10.1

Figure 10.1: Model copper mine after tax rates of return

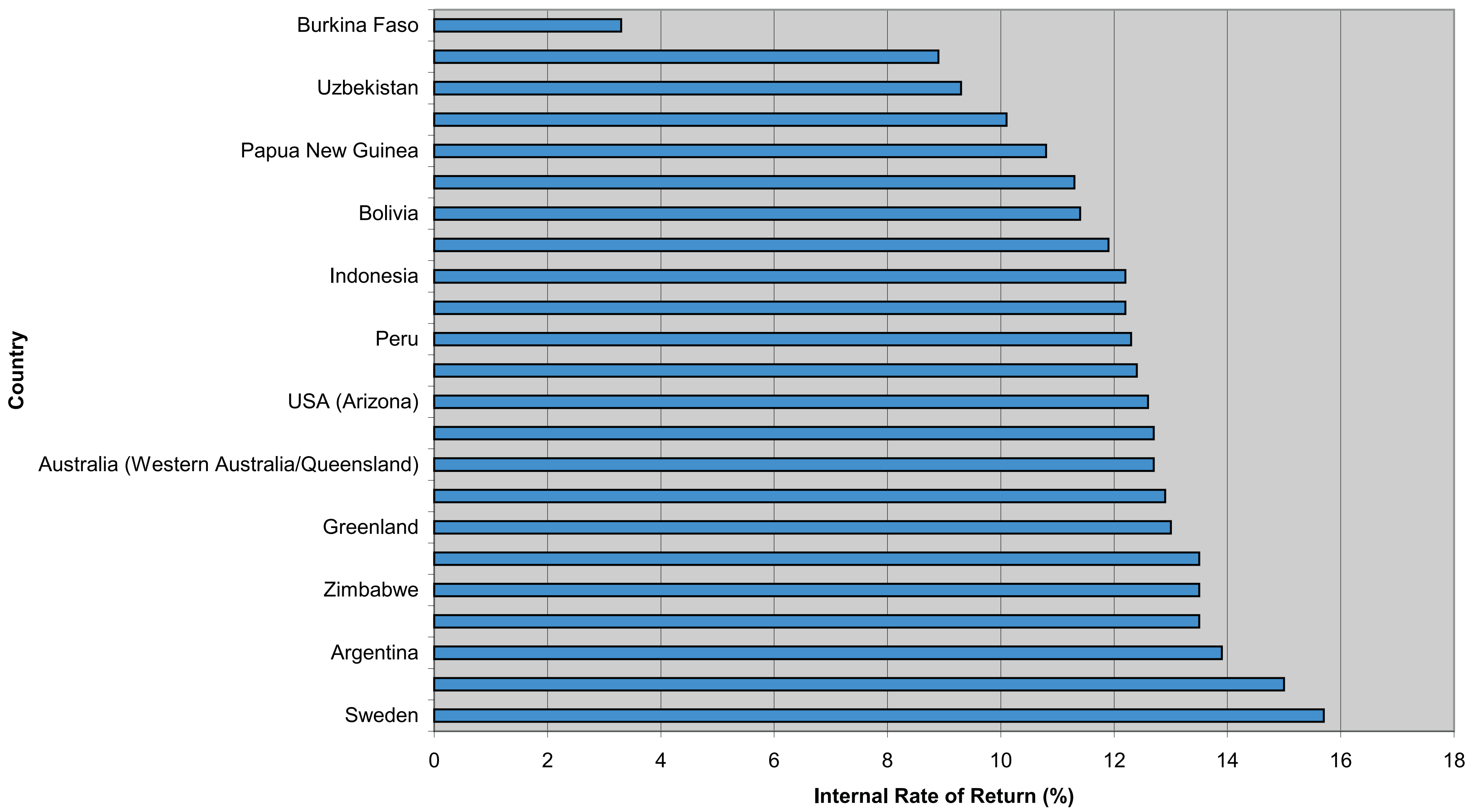
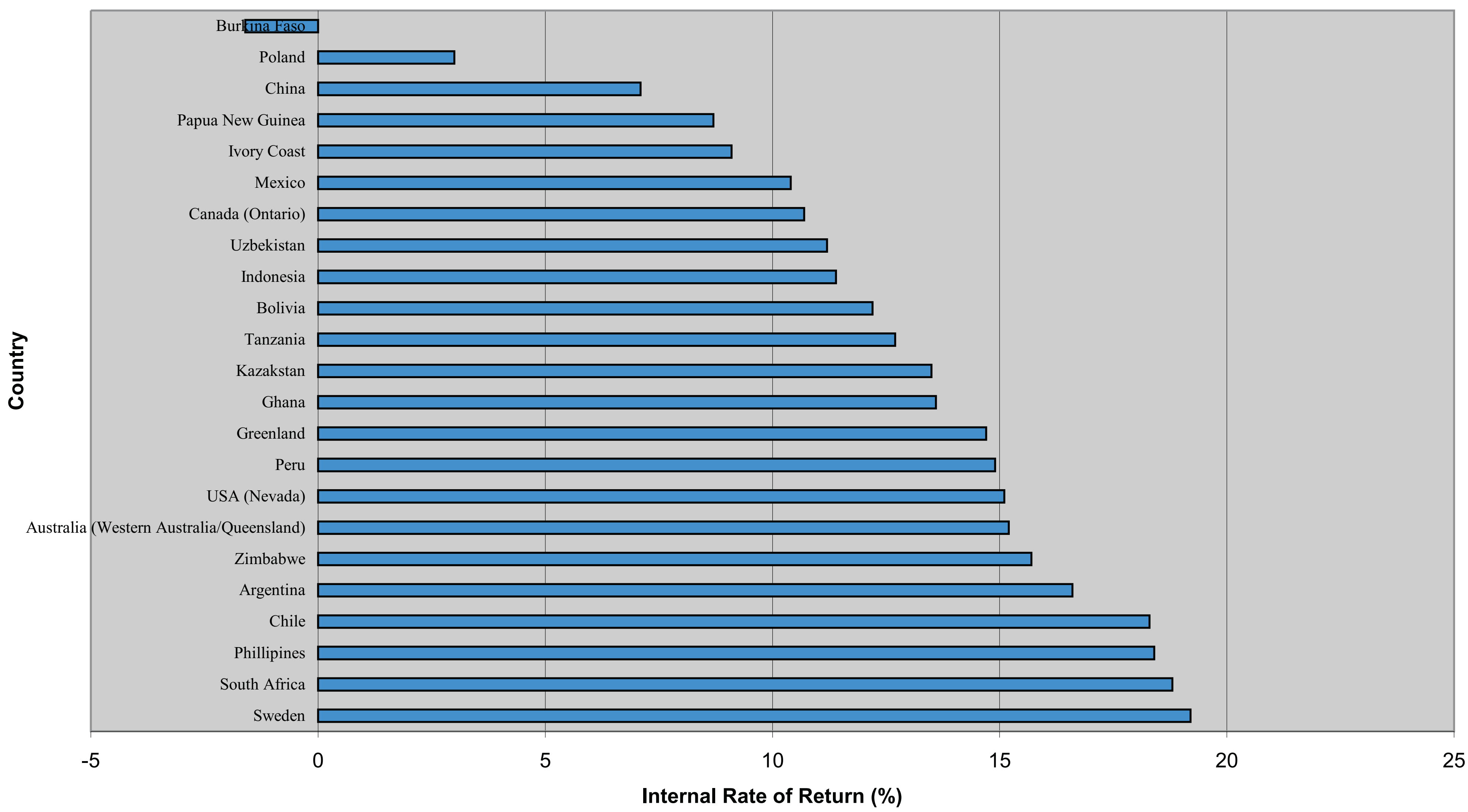


FIGURE 10.2

Figure 10.2: Model gold mine after tax rates of return



11. DISCOVERY POTENTIAL

11.1 GENERAL COMMENTS

The North-west Queensland Mineral Province is world-class and is richly endowed with an attractive spread of commodities and deposit types (**Chapter 6**). At times of historically low global discovery rates the region has continued to produce new world-class base metal deposits. Most of the recently discovered resources are under post-mineralisation cover, or geologically blind and were discovered by a combination of sophisticated geological, geophysical and geochemical techniques (**Chapter 7**).

The following sections of this report present:

- information on and maps of the depth of post-mineralisation cover over about two-thirds of the North-west Queensland Mineral Province, including some highly prospective ground, and
- commodity-specific target zones for selected styles of mineralising systems that appear to offer the greatest exploration potential in the North-west Queensland Mineral Province. Target zones were outlined on the basis of target models (**Chapter 6**) and geological interpretations developed in this Study (**Chapter 5**) and ranked according to target criteria and depth of cover.

These sections further highlight the mineral discovery potential of the North-west Queensland Mineral Province and provide explorers with keys to unlock this potential.

11.2 POST-MINERALISATION COVER

Cover depths

The mineral discovery history (**Chapter 7**) and also the geological interpretations of the North-west Queensland Mineral Province indicate that much of the potential of the region is in areas overlain by post-mineralisation, transported cover. This applies particularly to the Proterozoic, which is partly covered by Palaeozoic, Mesozoic and younger material. Exploration strategies require knowledge of the depth of cover for the ranking and prioritisation of targets as does planning and execution of efficient exploration.

Estimated cover depths have been determined for two important Phanerozoic horizons, using petroleum exploration well, stratigraphic drillhole and water bore data from DME's QPED database and water bore data from the Department of Natural Resources database. The depth of cover to the top of the Toolebuc Formation (Plate 27) was calculated because:

- the top of the Toolebuc Formation is generally identifiable in the available drill logs,
- the Toolebuc Formation is an important Mesozoic unit with known potential as a source of oil shale, vanadium and limestone, and
- at a coarse level, the depth to the top of the Toolebuc Formation mirrors the topography of the Proterozoic basement.

The depth of cover to the top of the Georgina Basin sequence (Plate 28) was calculated because:

- this horizon is generally well constrained in drill logs, and
- the Georgina Basin rocks form an important cover sequence with known potential as a source of phosphorite, limestone, base metals, groundwater and hydrocarbons.

Estimated depths of cover to Proterozoic basement in the North-west Queensland Mineral Province are presented in **Plate 29** and also **Maps 3, 5, 6, 7** as contours. **Plate 29** and the digital product also contain located point data, used to constrain these estimates. These data included information from:

- mineral exploration drillhole data from the Terra Search Pty Ltd database (**Chapter 4.5**),
- petroleum exploration well, stratigraphic drillhole and water bore data from DME's QPED database (**Chapter 4.5**),
- water bore data from the Department of Natural Resources database, for which drill logs were adequate for the interpretation of lithological information, and
- modelled depths to basement magnetic anomalies for some areas, particularly in the south and east of the study region where adequate aeromagnetic data is available.

These model depths include those from AGSO's study of the Boulia and Springvale 1:250 000 sheets (Brodie, 1999). Other areas were modelled by Encom Technology, as part of this study, utilising two techniques applied to magnetic survey data sets:

- AUTOMAG, a quick depth estimation technique, was performed on the line data and was tuned to the in-line first vertical derivative of total magnetic intensity. This procedure reduced the regional anomaly effect and provides efficient depth estimates for various magnetic sources including dyke, intrusive body, fault and edge.
- For the areas where located line data was not supplied, a modelling technique was applied to the TMI grids. Firstly, magnetic profile traverses were designed through selected major magnetic anomalies of interest. Secondly, the profile data were extracted from the TMI grids. An inversion method was then applied to those profile data by using Encom developed ModelVision software.

  Both methods provide detailed information of magnetic bodies, such as depth, width, dip, susceptibility and body location. Model depths to magnetic basement are generally in good agreement with constraints provided by drilling.

Cover depths over the Proterozoic are now well constrained over much of the North-west Queensland Mineral Province. However, adequate drillhole data or suitable magnetics are not available in the westernmost and south-eastern areas, and hence cover depths were not estimated. In these areas, depths to the Proterozoic are apparently large enough to limit exploration interest in Proterozoic targets.

Maps 3, 5, 6, 7 show that there are large areas of Proterozoic rocks under less than 500m of younger cover, that exhibit potential for most key target styles and are amenable to exploration by modern techniques.

Regolith

Regolith in the North-west Queensland Mineral Province comprises:

- generally thin Quaternary superficial deposits of transported material, and also
- products related to several Tertiary surfaces.

These have been the subject of detailed and systematic studies in AMIRA Project 417, the results of which will soon be publicly available. Interested parties should contact AMIRA or the CRC for Landscape Evolution and Mineral Exploration.

COVER DEPTH TOOLEBUC FORMATION

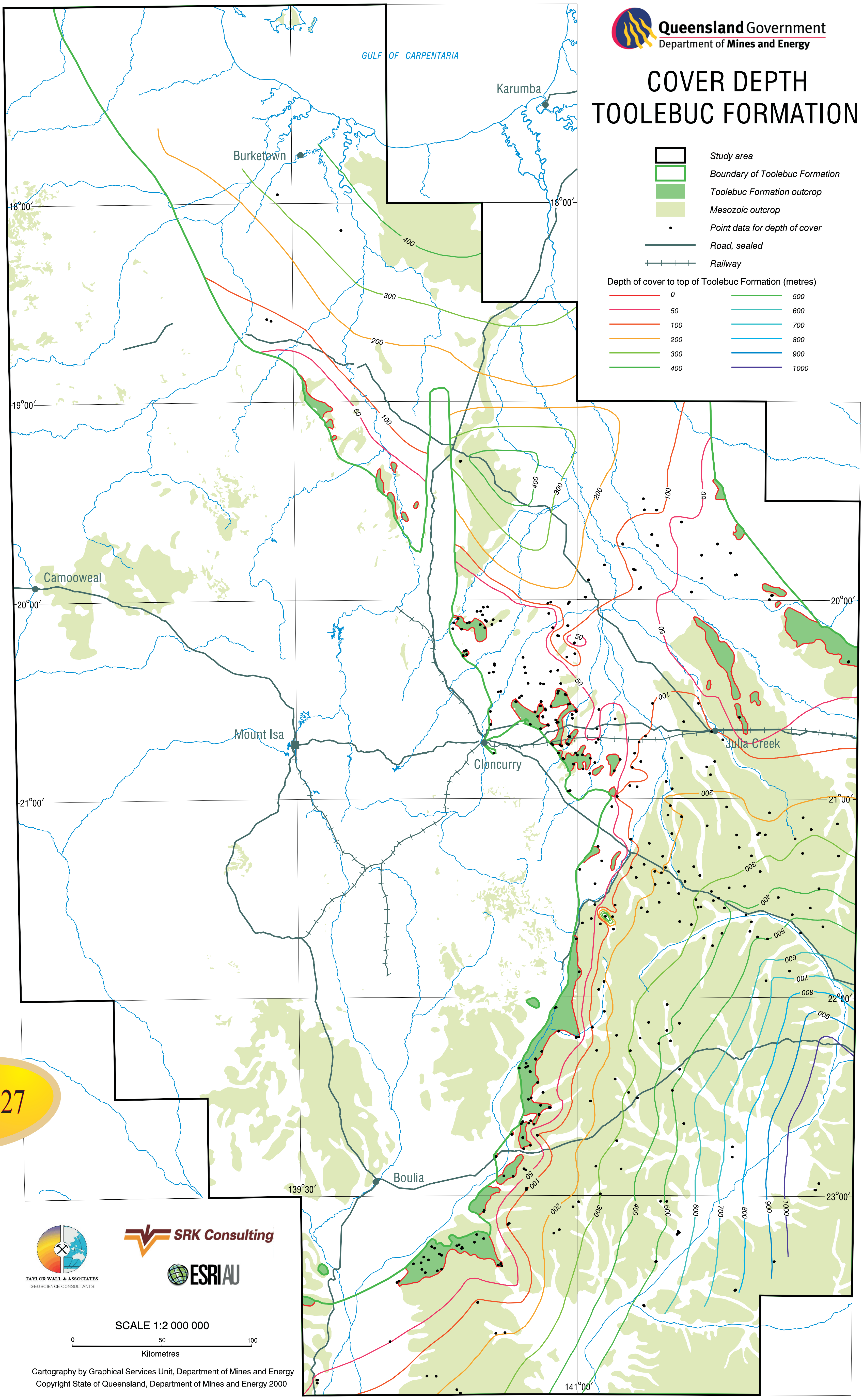


PLATE 27

SRK Consulting

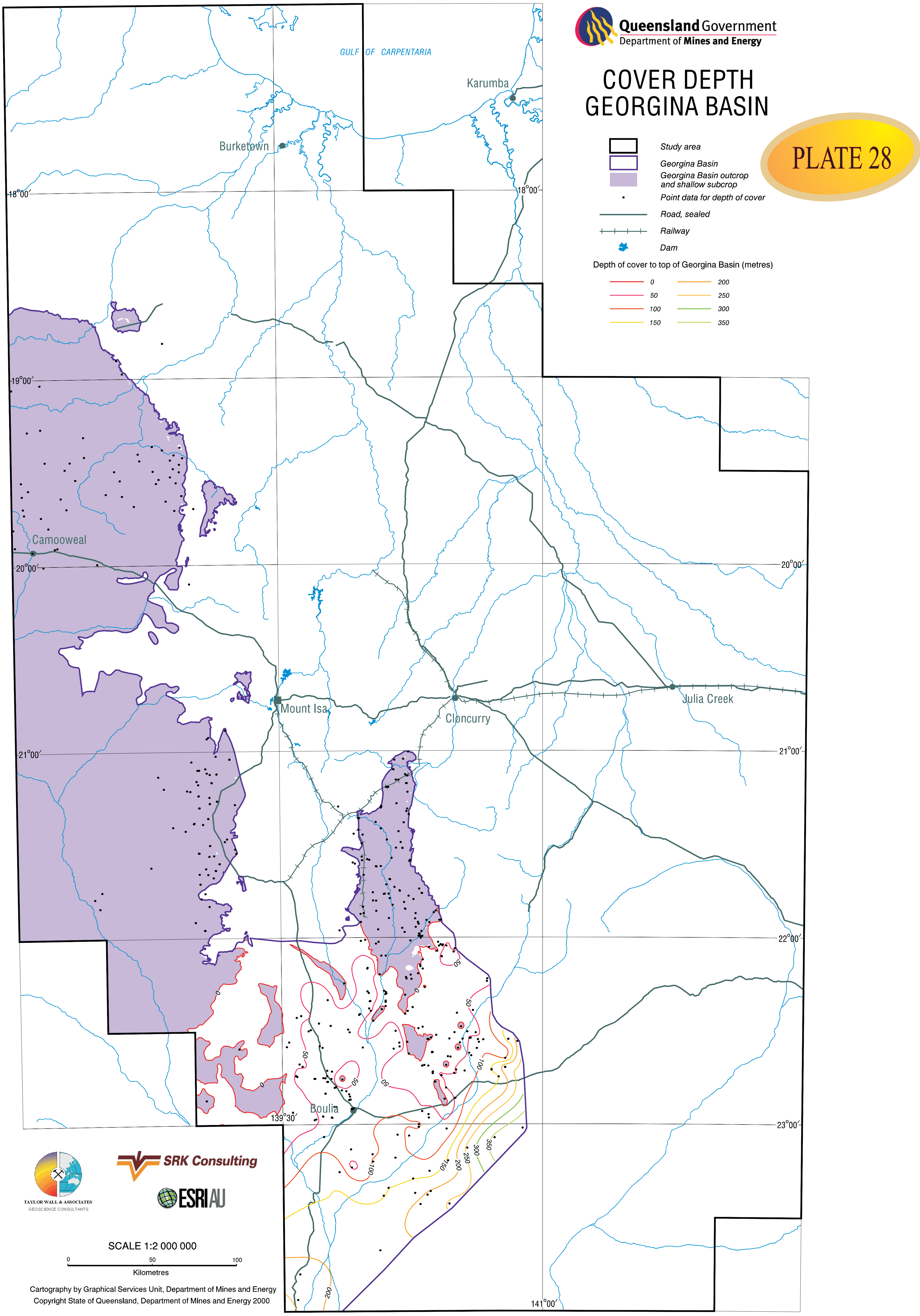
ESRI AU

TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS

SCALE 1:2 000 000

0 50 100
Kilometres

Cartography by Graphical Services Unit, Department of Mines and Energy


Queensland Government
Department of Mines and Energy
COVER DEPTH
GEORGINA BASIN
PLATE 28
Study area
Georgina Basin
Georgina Basin outcrop and shallow subcrop
Point data for depth of cover
Road, sealed
Railway
Dam
Depth of cover to top of Georgina Basin (metres)
0
50
100
150
200
250
300
350
GULF OF CARPENTARIA
Karumba
Burketown
Camooweal
Mount Isa
Cloncurry
Julia Creek
Boulia
18°00′
19°00′
20°00′
21°00′
22°00′
23°00′
139°30′
141°00′
TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS
SRK Consulting
ESRI AU
SCALE 1:2 000 000
0
50
100
Kilometres
Cartography by Graphical Services Unit, Department of Mines and Energy
Copyright State of Queensland, Department of Mines and Energy 2000

COVER DEPTH PROTEROZOIC BASEMENT

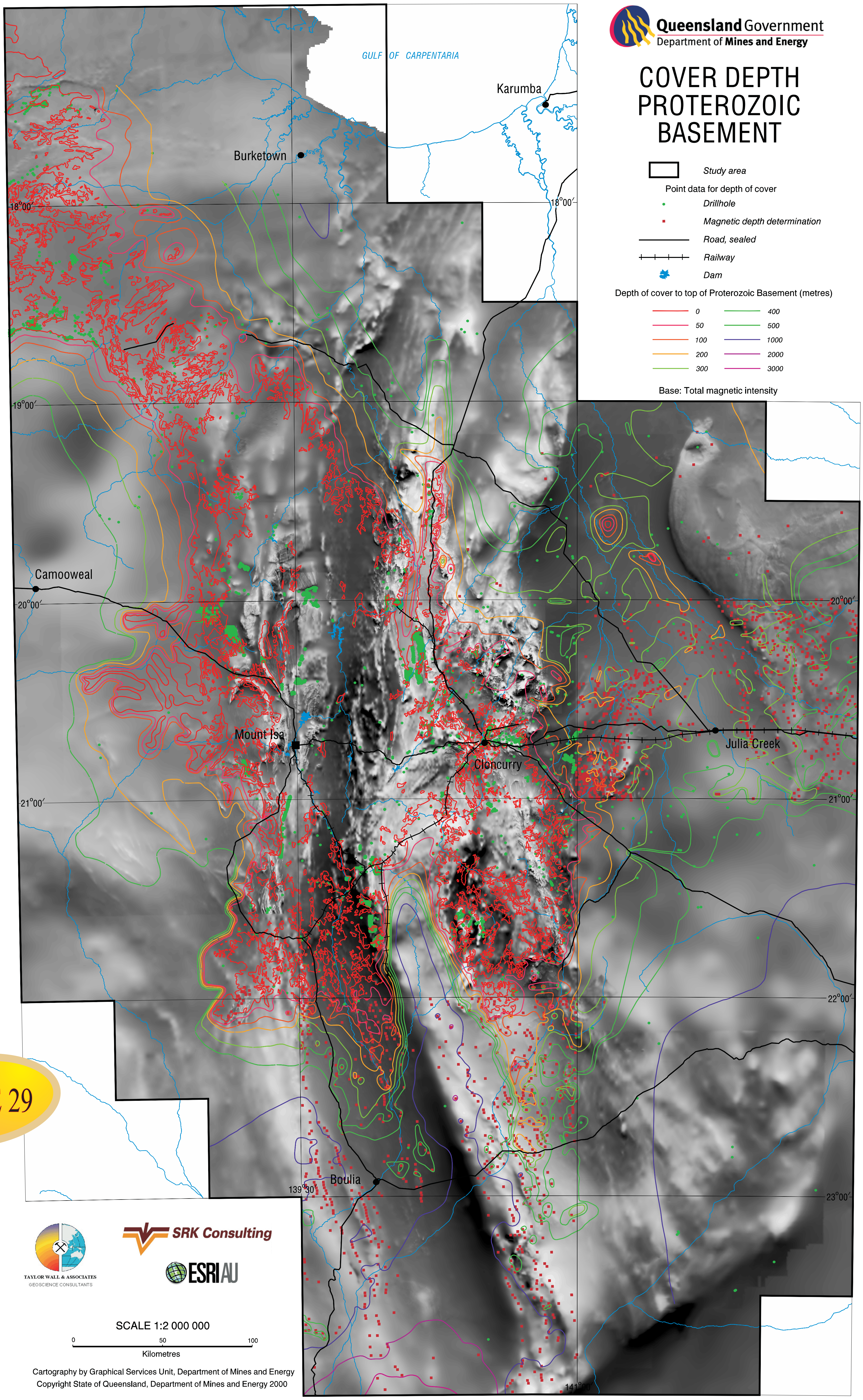


PLATE 29

Queensland Government
Department of Mines and Energy

TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS

SRK Consulting

ESRI AU

11.3 PRIORITY TARGET AREAS

The North-west Queensland Mineral Province remains highly prospective for a broad range of mineral commodities including:

- zinc-lead-silver,
- copper,
- copper-gold, and
- gold.

Target areas for several key styles of deposits of these commodities have been defined in this Study by:

- application of the models for mineralising systems outlined in **Chapter 6**,
- space- and time-favourable geological settings (**Chapter 5.2, 5.3**), and
- geological map, geophysically-based delineation of potentially ore-forming plumbing systems (Chapter 5.5; **Table 5.1**; **Maps 2 and 4**).

Identified commodity- and style-specific exploration targets are characterised in terms of their:

- regional structural setting,
- local structural setting,
- lithostratigraphic environment,
- alteration/mineralisation indicators, and
- cover thickness.

For each target zone each of these characteristics is rated in relation to model-based target criteria and estimated cover thickness, as:

'A' highly favourable,

'B' moderately favourable ***or*** not known, or

'C' less favourable.

An overall target rating is then assigned in the light of the target criteria scores, as follows:

'1' high priority,

'2' medium priority, or

'3' lower priority.

Target information is given in **Maps 5, 6, 7** against a backdrop of the key geological features that controlled their localisation and also in Tables 11.1 to 11.7 on the North-west Queensland Mineral Province CD-ROM. In view of the 1:250 000 scale of geological interpretation, target zones are typically tenement-scale areas.

However, the mineral deposit models (**Chapter 6.2**) and aspects of the exploration and targeting criteria are applicable at deposit scale and can be used to design follow-up programs to define and assess drill targets.

These target zones may also exhibit the essential ingredients for styles of mineralisation not discussed here. The list of targets is far from exclusive. Data, information and interpretations supplied in this report will assist explorationists in identifying other targets.

The Queensland Department of Mines and Energy open file system of exploration reports and other databases (**Chapter 4**) contain a wealth of data useful for the recognition, evaluation and refinement of exploration targets. Evaluation of these data has been outside the scope of this study.

ACKNOWLEDGEMENTS

The North-west Queensland Mineral Province Study team wishes to thank the following organisations and individuals for their assistance in various aspects of the project.

- MIM Exploration Pty Ltd for providing their aeromagnetic-radiometric data,
- The Australian Geological Survey Organisation for providing their regional and detailed aeromagnetic and gravity data, stratigraphic names data, OZCHRON data, depth to magnetic basement data, and 1:100 000 geological map data,
- Terra Search Pty Ltd for making available their geochemical and exploration data sets,
- Geoimage Pty Ltd for carrying out the image stitch of the aeromagnetic data. The Landsat MSS image backdrop in the hard copy report and on the CD-ROM was derived from the Geoimage Landsat MSS Mosaic
  Copyright Geoimage Pty Ltd
  ACN 010 840 294 / ABN 96 624 199 108 (1994).

  See also Appendix, Software Licences Agreements, Software Licencing Agreement for Geoimage's MSS Derived Product, on the CDRom,
- Justin Vaughan of ESRI Australia for CD-ROM and Web Site development,
- Airesearch Mapping Pty Ltd for large format scanning services,
- Encom Technology for carrying out depth to magnetic basement determinations and image enhancement of selected areas to assist the geological interpretation,
- The Department of Natural Resources, Queensland, for providing their water bore data,
- The Queensland Department of State Development for permission to include Plate 2 (Queensland Infrastructure), and
- AUSLIG for providing their 9 second digital terrain model data.

The following, for providing information on mining regulations for inclusion in Table 9.1:

- Piers Gardiner, Exploration and Mining Division, Department of the Marine and Natural Resources, Dublin, Republic of Ireland,
- Steve Vaughan, Aird and Berlis, Toronto, Canada,
- Kerr Anderson, Minera Almagrera (Navan Resources), Huelva, Spain,
- Malcolm Robb, Mineral Resources Directorate, Indian and Northern Affairs, Yellowknife, NT, Canada,
- Rick Brown, Minera Calipuy, Lima, Peru,
- Ian Mathison, North Ltd, Jakarta, Indonesia,
- Allister Taylor, Department of Mines and Energy, Government of Newfoundland and Labrador, St John's, Newfoundland, Canada,
- Dugi Wilson, Mt Isa Mines Namibia, Windhoek, Namibia,
- Lori Walton, Yukon Department of Economic Development, Whitehorse, Yukon, Canada,
- John Gammon, Ontario Ministry of Northern Development and Mines, Sudbury, Ontario, Canada,
- Chris Patterson, Alaska Department of Natural Resources, Anchorage, Alaska,
- Professor James Otto, Institute for Global Resources Policy and Management, Colorado School of Mines, Golden, Colorado, for permission to use data incorporated in Table 10.1, and also for the use of Figures 10.1 and 10.2, and
- Lesley Wyborn (AGSO), Deb Scott and the NABRE team are thanked by Mike Etheridge for providing data, and fruitful discussions.

Regarding the interpretation of the Western Succession and Time-Space Framework, Mark Hinman acknowledges:

- Extensive and fruitful discussions with Peter Southgate and Deb Scott (NABRE, AGSO; sequence stratigraphy and regional tectonics),
- Mart Idnurm (ex-AGSO; palaeomagmatism),
- Andrew Allan (ex-North Limited; time-space analysis and tectonostratigraphy),
- Rod Page (ex-AGSO; latest geochronology), and
- Lesley Wyborn (AGSO; magmatism & geochronology).

These have allowed small steps to be made towards some tectonostratigraphic 'truth'.

Additional discussions with Richard Blewett, John Bain, Dave Blake, Alaister Stewart (AGSO) and Kelvin Hussey (NTGS) enabled the preliminary presentation of complex and incompletely understood relationships between Mount Isa-southern McArthur with the Tennant Creek-Davenport and Georgetown-Coen Provinces.

The current Time-Space chart draws heavily on previous time-space analysis undertaken by Mark Hinman for North Limited (in 1998) and Pasminco Mining (in 1999). Pasminco has kindly allowed a Time-Space chart prepared by Mark Hinman in 1999 to serve as a basis of the current chart.

The following Department of Mines and Energy staff for their contributions to the study:

- Richie Huber for geophysical and other image processing,
- John Tuttle for compilation and entry of metadata,
- Mal Jones for providing information on the characteristics of regolith in the study area,
- Warwick Willmott for information on the current status of native title legislation in Queensland,
- Leslie Blight, Tom Moore, Noel Gatehouse, Colin Roberts, Bob Rapkins and Bob Blight of the Graphical Services Unit for production of the figures, plates and all maps except Map 1,
- Jim Beeston and Sharon Beeston for production editing and desktop publishing,
- Annalisa Philp for converting the text to html and assembling the elements for the digital report, and
- The Marketing and Communications Unit for the cover design and report packaging concept.

REFERENCES

The following list of references includes those cited in the text, plus other uncited publications that have proved useful in the geological interpretation.

ABBOTT, S.T. & SWEET, I.P., 2000: Tectonic control on third-order sequences in a siliciclastic ramp-style basin: an example from the Roper Superbasin (Mesoproterozoic) northern Australia. *Australian Journal of Earth Sciences*, **47**, 637–657.

ADSHEAD, N.D., VOULGARIS, P. & MUSCIO, V.N., 1998: Osborne copper-gold deposit. *In* Berkman, D.A., & Mackenzie, D.H. (Editors): Geology of Australian and Papua New Guinean Mineral Deposits. *The Australasian Institute of Mining and Metallurgy, Monograph* **22**, 793–800.

ADSHEAD-BELL, N. S., 1998: Evolution of the Starra and Selwyn high strain zones, Eastern Fold Belt, Mount Isa Inlier: implications for Au – Cu mineralisation. *Economic Geology*, **93**, 1450–1462.

AILLERES, L. & VAUGHAN, S. (Editors), 1999: Mount Isa tectonic synthesis, a compilation of research in the Mount Isa Terrane. *Australian Crustal Research Centre, Technical Publication* **75**.

ALLEN, R.L., LUNDSTROM, I., RIPA, M., SIMEONOV, A. & CHRISTOFFERSON, H., 1996: Facies analysis of a 1.9 Ga, continental margin, back-arc, felsic Caldera province with diverse Zn-Pb-Ag-(Cu-Au) Sulfide and Fe oxide deposits, Bergslagen Region, Sweden. *Economic Geology*, **91**, 979–1008.

ANAND, R.R., FRASER, S.J., JONES, M.R., LI SHU, MUNDAY, T.J., PHANG, C., ROBERTSON, I.D.M., SCOTT, K.M., VASCONCELOS, P., WILDMAN, J.E. & WILFORD, J., 1997: Geochemical exploration in regolith-dominated terrain, north Queensland. CRC LEME-AMIRA P417 Final Report. CRC LEME Restricted Report 63R / E&M Report 447R, Cooperative Research Centre for Landscape Evolution & Mineral Exploration.

ANDERSON, C.G. & LOGAN, K.J., 1992: The history and current status of geophysical exploration at the Osborne Cu & Au deposit, Mt Isa. *Exploration Geophysics*, **23**, 1–8.

ANDREW, A. S., HEINRICH, C. A., WILKINS, R. W. T. & PATTERSON, D. J., 1989: Sulphur isotope systematics of copper ore formation at Mount Isa, Australia. *Economic Geology*, **84**, 1614–1626.

ANDREWS, S.J., 1998: Stratigraphy and depositional setting of the upper McNamara Group, Lawn Hill region, northwest Queensland. *Economic Geology*, **93**, 132–1152.

BAILEY, A. & THOMAS, M.J., 1993: The Cannington deposit – its discovery, geology and evaluation. *Proceedings of Carpentaria and Mount Isa Regional Development Forum, North-west Queensland Branch of the Australasian Institute of Mining and Metallurgy*, August 1993, Mount Isa, 59–67.

BAIN, J.H.C. & DRAPER, J.J., (Editors), 1997: North Queensland Geology. *Australian Geological Survey Organisation, Bulletin* **240**, and Queensland Department of Mines & Energy, *Queensland Geology* **9**.

BAIN, J.H.C., HEINRICH, C.A. & HENDERSON, G.A.M., 1992: Stratigraphy, structure, and metasomatism of the Haslingden Group, East Moondarra area, Mount Isa: a deformed and mineralised Proterozoic multistage rift-sag sequence. *In* Stewart, A.J. & Blake, D.H. (Editors): Detailed studies of the Mount Isa Inlier. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **243**, 125–136.

BAKER, T., 1998: Alteration, mineralization and fluid evolution at the Eloise Cu-Au deposit, Cloncurry District, northwest Queensland, Australia, *Economic Geology*, **93**, 1213–1236.

BAKER, T. & LAING, W.P., 1998: Eloise Cu-Au deposit, east Mt Isa Block: structural environment and structural controls on ore. *Australian Journal of Earth Sciences*, **45**, 429–444.

BAKER, T., ROTHERHAM, J., RICHMOND, J., MARK, G. & WILLIAMS, P. (Editors), 1996: MIC'96 Extended Conference Abstracts. New developments in metallogenic research: the McArthur, Mt Isa, Cloncurry Minerals Province. *Economic Geology Research Unit, Contribution* **55**.

BARRACLOUGH, D., 1981: A-P 2468M, Undilla, annual report, period June 1980 - June 1981. Report held by the Queensland Department of Mines and Energy, as CR 9397.

BARRIE, C.T., CATHLES, L.M. & ERENDI, A., 1998: Finite element and fluid flow computer simulations of a deep ultramafic sill model for the giant Kidd Creek volcanic-associated massive sulfide deposit, Ahitibi subprovince, Canada. *Economic Geology Monograph* **10**.

BARRIE, C.T., LUDDEN, J.N. & GREEN, T.H., 1993: Geochemistry of volcanic rocks associated with Cu-Zn and Ni-Cu deposits in the Abitibi Subprovince. *Economic Geology*, **88**, 1341–1358.

BARTON, M. D., 1996: Evaporitic source model for igneous-related Fe oxide (REE–Cu–U) mineralisation. *Geology*, **24**, 259–262.

BEARDSMORE, T.J., NEWBERRY, S.P. & LAING, W.P., 1988: The Maronan Supergroup, an inferred early volcanosedimentary rift sequence in the Mount Isa Inlier, and its implications for ensialic rifting in the Middle Proterozoic of northwest Queensland. *Precambrian Research*, **40/41**, 487–507.

BEESON, R., 1990: Broken Hill – type deposits – an overview of their occurrence and geological setting. *Institute of Mining and Metallurgy, Transactions*, **99**, B163-175.

BELL, T. H., PERKINS, W. G. & SWAGER, C. P., 1988: Structural controls on development and localisation of syntectonic copper mineralisation at Mount Isa, Queensland. *Economic Geology*, **83**, 69-85.

BETTS, P. G., 1997: An example of Middle Proterozoic intracontinental extension. PhD thesis, Monash University, Melbourne.

BETTS, P.G., 1997: Aeromagnetic constraints on the basin architecture and evolution of the north Mount Isa Terrane. *Australian Crustal Research Centre, Publication* **61**.

BETTS, P.G., 1999: Palaeoproterozoic mid-basin inversion in the northern Mt Isa terrane, Queensland. *Australian Journal of Earth Sciences*, **46**, 735–748.

BETTS, P.G., AILLÈRES, L., O'DEA, M. & MACCREADY, T., 1997: Polyphase thrust-related deformation of the Mitakoodi Culmination: Evidence along the eastern limb of the Duck Creek Anticline. *In* Aillères, L. & Betts, P.G. (Editors): Structural Elements of the Eastern Successions — A field guide illustrating the structural geology of the eastern Mount Isa Terrane, *Australian Crustal Research Centre, Technical Publication* **63**, 17–36.

BETTS, P.G., LISTER, G.S. & POUND, K.S., 1999: Architecture of a Palaeoproterozoic rift system: evidence from the Fiery Creek Dome region, Mt Isa terrane. *Australian Journal of Earth Sciences*, **46**, 533–554.

BLAKE, D.H., 1987: Geology of the Mount Isa Inlier and environs, Queensland and Northern Territory. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **225**.

BLAKE, D.H., 1992a: Stratigraphy, folding, and faulting within the Quilalar Fault System, Mount Isa Inlier. *In* Stewart, A.J. & Blake, D.H. (Editors): Detailed studies of the Mount Isa Inlier. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **243**, 161–180.

BLAKE, D.H., 1992b: The compressional Lake Mary Kathleen Fold and Thrust Zone, Mount Isa Inlier. *In* Stewart, A.J. & Blake, D.H. (Editors): Detailed studies of the Mount Isa Inlier. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **243**, 181–190.

BLAKE, D.H., BULTITUDE, R.J. & DONCHAK, P.J.T., 1982: *Dajarra, Queensland, 1:100 000 Geological Map Commentary*. Bureau of Mineral Resources, Geology and Geophysics, Australia, Canberra.

BLAKE, D.H., ETHERIDGE, M.A., PAGE, R.W., STEWART, A.J., WILLIAMS, P.R. & WYBORN, L.A.I., 1990: Mount Isa Inlier — regional geology and mineralisation. *In* Hughes, F.E., (Editor): Geology of the Mineral Deposits of Australia and Papua New Guinea. *Australasian Institute of Mining and Metallurgy, Monograph Series*, **14**, 915–925.

BLAKE, D.H., JAQUES, A.L. & DONCHAK, P.J.T., 1983: *Selwyn Region, Queensland, 1:100 000 Geological Map Commentary*. Bureau of Mineral Resources, Geology and Geophysics, Australia, Canberra.

BLAKE, D.H., STEWART, A.J., SWEET, I.P. & HONE, I.G., 1987: Geology of the Proterozoic Davenport province, central Australia. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **226**.

BODON, S. B., 1998: Paragenetic relationships and their implications for the genesis of the Cannington Ag-Pb-Zn deposit, Mount Isa Inlier, Queensland, Australia. *Economic Geology*, **93**, 1463–1488.

BRADSHAW, B.E., LINDSAY, J.F., KRASSAY, A.A. & WELLS, A.T., 2000: Attenuated basin-margin sequence stratigraphy of the Palaeoproterozoic Calvert and Isa Superbasins: the Fickling Group, southern Murphy Inlier, Queensland. *Australian Journal of Earth Sciences*, **47**, 599–624.

BRADSHAW, B.E. & SCOTT, D.L. (Editors), 1999: Integrated basin analysis of the Isa Superbasin using seismic, well-log and geopotential data: an evaluation of the economic potential of the northern Lawn Hill Platform, preliminary edition data release. *Australian Geological Survey Organisation, Record* **1999/19**.

BRESCIANINI, R.F., ASTEN, M.W. & MCLEAN, N., 1992: Geophysical characteristics of the Eloise Cu-Au deposit, north-west Queensland. *Exploration Geophysics*, **23**, 33–42.

BROADBENT, G.C., 1995: The Century discovery, northwest Queensland — is exploration ever complete? *Proceedings, Pacific Rim Congress '95*, the Australasian Institute of Mining and Metallurgy, 81–86.

BROADBENT, G.C., MYERS, R.E. & WRIGHT, J.V., 1996: Geology and origin of shale-hosted Zn-Pb-Ag mineralisation at the Century mine, northwest Queensland. *In* Baker, T., Rotherham, J., Richmond, J., Mark, G. & Williams, P., (Editors): MIC '96, extended conference abstracts, new developments in metallogenic research: the McArthur, Mt Isa, Cloncurry minerals province. *Economic Geology Research Unit, Contribution* **55**, 24–28.

BROADBENT, G.C., MYERS, R.E. & WRIGHT, J.V., 1998: Geology and origin of shale-hosted Zn-Pb-Ag mineralisation at the Century deposit, northwest Queensland. *Economic Geology*, **93**, 1264–1290.

BROADBENT, G.C. & WALTHO, A.E., 1998: Century zinc-lead-silver deposit. *In* Berkman, D.A., & Mackenzie, D.H. (Editors): Geology of Australian and Papua New Guinean Mineral Deposits. *The Australasian Institute of Mining and Metallurgy, Monograph* **22**, 729–736.

BRODIE, R.C., 1999: Boulia and Springvale, Qld, airborne geophysical survey, 1997, operations report. *Australian Geological Survey Organisation, Record* **1999/28**.

BROOKS, J.H. & SHIPWAY, C.H., 1960: Mica Creek pegmatites, Mount Isa, North-Western

Queensland. *Queensland Government Mining Journal*, **61**, 511-522.

BULTITUDE, R., 1982: *Ardmore, Queensland, 1:100 000 Geological Map Commentary*. Bureau of Mineral Resources, Geology and Geophysics, Australia, Canberra.

BULTITUDE, R.J., BLAKE, D.H., MOCK, C.M. & DONCHAK, P.J.T., 1982: *Duchess Region, Queensland, 1:100 000 Geological Map Commentary*. Bureau of Mineral Resources, Geology and Geophysics, Australia, Canberra.

BURNHAM, C.W. & OHMOTO, H., 1980: Late-stage processes of felsic magmatism. *In* Ishihara, S. & Takenouchi, S. (Editors): Granitic magmatism and related mineralisation, Tokyo. *The Society of Mining Geologists of Japan*, 1–12.

CARPENTARIA EXPLORATION COMPANY PTY LTD, 1971: A-P 664M Carrier, NW Queensland, annual report. Report held by the Queensland Department of Mines and Energy as CR 3865.

CARTER, E.K., BROOKS, J.H. & WALKER, K.R., 1961: The Precambrian mineral belt of northwestern Queensland. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **51**.

CARTWRIGHT, I., 1998: Regional-scale hydrothermal fluid flow and origins of Pb-Zn-Ag mineralisation at Broken Hill, Australia. Constraints from oxygen isotope geochemistry. *Geological Society of Australia, Abstracts*, 49, 70.

CATHLES, L.M., ERENDI, A.H.J. & BARRIE, T., 1997: How long can a hydrothermal system be sustained by a single intrusive event? In A special issue on the timing and duration of hydrothermal events. *Economic Geology*, **92**, 766–771.

CHAPMAN, L.H. & WILLIAMS, P. J., 1998: Evolution of pyroxene-pyroxenoid-garnet alteration at the Cannington Ag-Pb-Zn deposit, Cloncurry district, Queensland, Australia. *Economic Geology*, **93**, 1390–1405.

CONNOR, A.G., JOHNSON, I.R. & MUIR, M.D., 1982: The Dugald River zinc-lead deposit, north-west Queensland. *Proceedings of the Australasian Institute of Mining and Metallurgy*, **283**, 1–19.

CONNORS, K.A. & PAGE, R.W., 1995: Relationships between magmatism, metamorphism and deformation in the western Mount Isa Inlier, Australia. *Precambrian Research*, **71**, 131–153.

CONNORS, K.A., PROFFETT, J.M., LISTER, G.S., SCOTT, R.J., OLIVER, N.H.S. & YOUNG, D.J., 1992: Geology of the Mount Novit Ranges, southwest of Mount Isa mine. *In* Stewart, A.J. & Blake, D.H. (Editors): Detailed studies of the Mount Isa Inlier. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **243**, 137–160.

COX, R. & CURTIS, R., 1977: The discovery of the Lady Loretta zinc-lead-silver deposit, north-west Queensland; a geochemical exploration case history. *Journal of Geochemical Exploration*, **8**, 189–202.

DASH, P., 2000: Queensland minerals industry overview. *Queensland Government Mining Journal*, **101**(1179), 6–15.

DAVIDSON, G. J. & DIXON, G. H., 1992: Two sulphur isotope provinces deduced from ores in the Mount Isa Eastern Succession, Australia. *Mineralium Deposita*, **27**, 30–41.

DAY, R.W., 1983: Geology and potential development of Queensland oil shales. *Queensland Government Mining Journal*, **84**, 463–470.

DEB, M., THORPE, R.I., CUMMING, G.L. & WAGNER, P.A., 1989: Age, source and stratigraphic implications of Pb isotope data for conformable sediment-hosted, base metal deposits in the Proterozoic Aravalli-Delhi Orogenic Belt, northwestern India. *Precambrian Research*, **43**, 1–22.

DE KEYSER, F. & COOK, P.J., 1972: Geology of the Middle Cambrian phosphorites and associated sediments of northwest Queensland. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **138**.

DEPARTMENT OF STATE DEVELOPMENT, 2000: Strategic Infrastructure for Queensland's Growth. Directions Paper, September 2000. Draft report prepared for discussion, Department of State Development, Brisbane.

DERRICK, G.M., 1980: *Marraba, Queensland, 1:100 000 Geological Map Commentary*. Bureau of Mineral Resources, Geology and Geophysics, Australia, Canberra.

DERRICK, G.M., 1982: A Proterozoic rift zone at Mount Isa, Queensland, and implications for mineralization. *BMR Journal of Australian Geology and Geophysics*, **7**, 81–92.

DERRICK, G.M. & WILSON, I.H., 1982: Geology of the Alsace 1:100, 000 Sheet area (6858), Queensland. Bureau of Mineral Resources, Geology and Geophysics, Australia, Record 1982/6.

DERRICK, G.M., WILSON, I.H., HILL, R.M, GLICKSON, A.Y. & MITCHELL, J.E., 1977: Geology of the Mary Kathleen 1:100 000 Sheet area, northwest Queensland. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **193**.

DERRICK, G.M., WILSON, I.H. & SWEET, I.P., 1980: The Quilalar and Surprise Creek Formations — new Proterozoic units from the Mount Isa Inlier: their regional sedimentology and application to regional correlation. *BMR Journal of Australian Geology and Geophysics*, **5**, 215–223.

DOMAGALA, J., SOUTHGATE, P.N., McCONACHIE, B.A. & PIDGEON, B.A., 2000: Evolution of the Palaeoproterozoic Prize, Gun and lower Loretta Supersequences of the Surprise Creek Formation and Mt Isa Group. *Australian Journal of Earth Sciences*, **47**, 485–508.

DONCHAK, P.J.T, BLAKE, D.H., JAQUES, A.L. & NOON, T.A., 1983: *Kuridala Region, Queensland, 1:100 000 Geological Map Commentary*. Bureau of Mineral Resources, Geology and Geophysics, Australia, Canberra.

DONNELLAN, N., HUSSEY, K.J. & MORRISON, R.S., 1995: *Flynn 5759, Tennant Creek 5758. 1:100 000 Geological Map Series, Explanatory Notes*, Northern Territory Geological Survey.

DONNELLAN, N., MORRISON, R.S. & HUSSEY, K.J., 1997: Tennant Creek Province: stratigraphic and structural framework. *Australian Geological Survey Organisation, Record* **1997/44**.

DRAPER, J.J., 1996: Queensland Mineral Commodity Report - phosphate. *Queensland Government Mining Journal*, **97** (February), 14–25.

DRUMMOND, B.J., GOLEBY, B.R., GONCHAROV, A.G., WYBORN, L.A.I., COLLINS, C.D.N. & MACREADY, T., 1998: Crustal-scale structures in the Proterozoic Mount Isa Inlier of north Australia: their seismic response and influence on mineralization. *Tectonophysics*, **288**, 43–56.

DUNNET, D., 1976: Some aspects of the Panantarctic cratonic margin in Australia. *Philosophic Transactions of the Royal Society of London*, **A280**, 641–654.

DUNNET, D., 1976: Mt Isa - reconstruction of a faulted ore body. *Philosophic Transactions of the Royal Society of London*, **A283**, 333–344.

EGGERS, A.J., 1998: Exploration and assessment of the Valhalla uranium deposit in northwest Queensland. *Australian Uranium Summit*, 11-12 February 1998, Hyatt Hotel, Adelaide. AIC Conferences, Sydney, Paper 20.

ETHERIDGE, M.A. & WALL, V.J., 1994: Tectonic and structural evolution of the Australian Proterozoic. 12th Australian Geological Convention, Perth, September 1994, *Geological Society of Australia, Abstracts*, **37**, 102–103.

EVANS, R.C., 1980: A-P 996M, Annual Report 1979. Westmoreland Project 431, AMP associated leases (5 Vols). Report held by the Queensland Department of Mines and Energy as CR 7672.

FIMISTON MINING NL, 1999: Annual Report 1999. Fimiston Mining NL, West Perth.

FORRESTAL, P. J., 1990: Mount Isa and Hilton silver-lead-zinc deposits. *In* Hughes, F. E. (Editor): Geology of the Mineral Deposits of Australia and Papua New Guinea. *The Australasian Institute of Mining and Metallurgy, Melbourne, Monograph* **14**, 927–934.

FORRESTAL, P.J., PEARSON, P.J., COUGHLIN, T. & SCHUBERT, C.J., 1998: Tick Hill gold deposit. *In* Berkman, D.A. & Mackenzie, D.H., (Editors): Geology of Australian and Papua New Guinean Mineral Deposits. *The Australasian Institute of Mining and Metallurgy, Monograph* **22**, 699–706.

FORRESTAL, P.J., PERKINS, W.G., MCINTOSH, D.C. & BUCKLAND, K.R., 1995: Discovery and evaluation of the Tick Hill gold mine, north west Queensland. *Proceedings of New Generation Gold Mines Conference*, 27-28 November 1995, Perth. Australian Mineral Foundation, Adelaide, 13.1-13.10.

FORTOWSKI, D.B. & MCCRACKEN, S.J.A., 1998: Mount Elliott copper-gold deposit. *In* Berkman, D.A. & Mackenzie, D.H. (Editors): Geology of Australian and Papua New Guinean Mineral Deposits. *The Australasian Institute of Mining and Metallurgy, Monograph* **22**, 775–782.

GLIKSON, A.Y., DERRICK, G.M., WILSON, I.H. & HILL, R.M., 1976: Tectonic evolution and crustal setting of the middle Proterozoic Leichhardt River fault trough, Mount Isa region, northwestern Queensland. *BMR Journal of Australian Geology and Geophysics*, **1**, 115–129.

GREEN P.M., HAWKINS, P.J., CARMICHAEL, D.C., BRAIN, T.J., SMITH, R.J., QUARANTOTTO, P, GENN, D.L.P., HOFFMANN, K.L., McKELLAR, J.L., JOHN, B.H. & SHIELD, C.J., 1992: An assessment of the hydrocarbon potential of the northern Eromanga Basin, Queensland. *Queensland Government Mining Journal*, **93**, 25–41.

GRIMES, K.G., 1980: The Tertiary geology of north Queensland. *In* Henderson, R.A. & Stephenson, P.J., (Editors): *The Geology and Geophysics of Northeastern Australia*. Geological Society of Australia Inc, Queensland Division, Brisbane.

GOW, P. A., WALL, V. J., OLIVER, N. H. S. & VALENTA, R. K., 1994: Proterozoic iron oxide (Cu-U-Au-REE) deposits: further evidence of hydrothermal origins. *Geology*, **22**, 633–636.

HANCOCK, M.C. & PURVIS, A.H., 1990: Lady Loretta silver-lead-zinc deposit. *In* Hughes, F. E. (Editor): Geology of the Mineral Deposits of Australia and Papua New Guinea. *The Australasian Institute of Mining and Metallurgy, Melbourne, Monograph* **14**, 943–948.

HARMS, J.E., 1965: Iron ore deposits of Constance Range. *In* McAndrew, J. (Editor): Geology of Australian Ore Deposits. Eighth Commonwealth Mining and Metallurgical Congress, Australia and New Zealand, 1965. *The Australasian Institute of Mining and Metallurgy, Melbourne*, 264–269.

HAWKINS, B.W., 1975: Mary Kathleen uranium deposit. *In* Knight, C.L. (Editor): *Economic Geology of Australia and Papua New Guinea, 1. Metals*. The Australasian Institute of Mining and Metallurgy, Melbourne, 398-402.

HAYNES, D.W., CROSS, K.C., BILLS, R.T. & REED, M.H., 1995: Olympic Dam ore genesis: a fluid mixing model. *Economic Geology*, **90**, 281–307.

HEINRICH, C.A., ANDREW, A.S., WILKINS, R.W.T. & PATTERSON, D.J., 1989: A fluid inclusion and stable isotope study of syn-metamorphic copper ore formation at Mount Isa, Australia. *Economic Geology*, **84**, 529–550.

HEINRICH, C.A., AUDETAT, A., ULRICH, T. & GUNTHER, D., 1998: Liquid – vapour partitioning of trace-elements in boiling hydrothermal systems: Laser-Ablation ICPMS data from natural fluid inclusions. 8th International V.M. Goldschmidt Conference. *European Journal of Mineralogy* **62A**, 593–594.

HEINRICH, C.A., BAIN, J.H.C., FAROY, J.J. & WARING, C.L., 1993: Bromine/chloride geochemistry geochemistry of hydrothermal brines associated with Proterozoic metasediment-hosted copper mineralisation at Mount Isa, northern Australia. *Geochimica et Cosmochimica Acta*, **57**, 2991–3000.

HEINRICH, C.A., BAIN, J.H.C., MERNAGH, T.P., WYBORN, L.A.I., ANDREW, A.S. & WARING, C.L., 1995: Fluid and mass transfer during metabasalt alteration and copper mineralisation at Mount Isa, Australia. *Economic Geology*, **90**, 705–730.

HILL, E.J., LOOSVELD, R.J.H. & PAGE, R.W., 1992: Structure and geochronology of the Tommy Creek Block, Mount Isa Inlier. *In* Stewart, A.J. & Blake, D.H. (Editors): Detailed studies of the Mount Isa Inlier. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **243**, 329–348.

HILL, R.M., WILSON, I.H. & DERRICK, G.M., 1975: Geology of the Mount Isa 1:100 000 Sheet area, northwest Queensland. Bureau of Mineral Resources, Geology and Geophysics, Australia, Record 1975/175.

HINMAN, M.C., 1995: The structure and kinematics of the HYC-Cooley Zone at McArthur River. *Australian Geological Survey Organisation, Record* **1995/5**.

HINMAN, M.C., 1996: Constraints, timing and processes of stratiform base metal mineralisation at the HYC Ag-Pb-Zn deposit, McArthur River. *In* Baker, T., Rotherham, J., Richmond, J., Mark, G., & Williams, P., (Editors): MIC '96, extended conference abstracts, new developments in metallogenic research: the McArthur, Mt Isa, Cloncurry minerals province. *Economic Geology Research Unit, Contribution* **55**, 56–59.

HINMAN, M.C., 1998: Speculation on syn-diagenetic processes of sulphate reduction at the HYC Ag-Pb-Zn deposit, Northern Territory. ASG '98, Townsville, *Geological Society of Australia, Abstracts*, **49**, 212.

HINMAN, M.C., WALL, V.J. & HEINRICH, C., 1994: The interplay between sedimentation, deformation and mineralisation at the McArthur Pb-Zn (-Cu) deposit. 12th Australian Geological Convention, Perth, September 1994, *Geological Society of Australia, Abstracts*, **37**, 176–177.

HITZMAN, M. W., ORESKES, N. & EINAUDI, M. T., 1992: Geological characteristics and tectonic setting of Proterozoic iron oxide (Cu-U-Au-REE) deposits. *Precambrian Research*, **58**, 241–287.

HOBBS, B., WALSHE, J., ORD, A., ZHANG, Y. & ZHAO, C., 2000: Geodynamic Modelling of the Broken Hill Mineralising System. *Geological Society of Australia, Abstracts*, **59**, 230.

HOLCOMBE, R.J., PEARSON, P.J. & OLIVER, N.H.S., 1991: Geometry of a Middle Proterozoic extensional decollement in northeastern Australia. *Tectonophysics*, **191**, 255–274.

HOLCOMBE, R.J., PEARSON, P.J. & OLIVER, N.H.S., 1992: Structure of the Mary Kathleen Fold Belt. *In* Stewart, A.J. & Blake, D.H. (Editors): Detailed studies of the Mount Isa Inlier. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **243**, 257–288.

HUSSAIN, B., 1983: Geology and mineralisation of Mary Kathleen uranium deposit, north-west Queensland. In Laing, W.P. (Editor): Abstracts, Ph.D. and M.Sc. Theses in geology, 1971-1982. James Cook University of North Queensland. *Economic Geology Research Unit, Contribution* **1**, 40.

HUTTON, L.J. & WILSON, I.H., 1984: *Mount Oxide Region, Queensland, 1:100 000 Geological Map Commentary*. Bureau of Mineral Resources, Geology and Geophysics, Australia, Canberra.

HUTTON, L.J. & WILSON, I.H., 1985: *Mammoth Mines Region, Queensland, 1:100 000 Geological Map Commentary*. Bureau of Mineral Resources, Geology and Geophysics, Australia, Canberra.

IDNURM, M., 2000: Towards a high resolution late Palaeoproterozoic — earliest Mesoproterozoic apparent polar wander path for northern Australia. *Australian Journal of Earth Sciences*, **47**, 405–430.

IDNURM, M. & GIDDINGS, J.W., 1988: Australian Precambrian polar wander, a review. *Precambrian Research*, **40/41**, 61–88.

IDNURM, M., GIDDINGS, J.W. & PLUMB, K.A., 1993: Palaeomagnetism of the northeastern McArthur Basin: poles, overprints and reversals. *Exploration Geophysics*, **24**, 227–230.

JACKSON, M.J., SCOTT, D.L. & RAWLINGS, D.J., 2000: Stratigraphic framework for the Leichhardt and Calvert Superbasins: review and correlations of the pre-1700 Ma successions between Mt Isa and McArthur River. *Australian Journal of Earth Sciences*, **47**, 381–404.

JACKSON, M.J. & SOUTHGATE, P.N., 2000: Evolution of three unconformity-bounded sandy carbonate successions in the McArthur River region of northern Australia: the Lawn, Wide and Doom Supersequences in a proximal part of the Isa Superbasin. *Australian Journal of Earth Sciences*, **47**, 625–636.

JENKINS, D.R., LAURIE, J.P. & BEAMS, S.D., 1998: Grevillea zinc-lead-silver deposit. In Berkman, D.A. & Mackenzie, D.H. (Editors): Geology of Australian and Papua New Guinean Mineral Deposits. *The Australasian Institute of Mining and Metallurgy, Monograph* **22**, 753–758.

JOHNSTON, J.D., 1999: Regional fluid flow and the genesis of Irish Carboniferous base metal deposits. *Mineralium Deposita*, **34**, 571–598.

KARY, G., DESOE, C., DINUZZO, P. & WYCHE, J., 1989: The Selwyn Gold-copper Mine. In North Queensland Gold `89 Conference, Townsville, Queensland, April 1989. *The Australasian Institute of Mining and Metallurgy, Publication* **Series No. 3/89**, 181–203.

KORSCH, R.J., GOLEBY, B.R., LEVEN, J.H. & DRUMMOND, B.J., 1998: Crustal architecture of central Australia based on deep seismic reflection profiling. *Tectonophysics*, **288**, 57–69.

KRASSAY, A.A., BRADSHAW, B.E., DOMAGALA, J. & JACKSON, M.J., 2000: Siliciclastic shoreline to growth-faulted, turbiditic sub-basins: the Proterozoic River Supersequence of the upper McNamara Group on the Lawn Hill Platform, northern Australia. *Australian Journal of Earth Sciences*, **47**, 533–562.

KRASSAY, A.A., BRADSHAW, B.E., DOMAGALA, J., McCONACHIE, B.A., LINDSAY, J.F., JACKSON, M.J., SOUTHGATE, P.N., BARNETT, K. & ZEILINGER, I., 1999: Measured sections and sequence stratigraphic interpretations: upper McNamara and Fickling Groups, preliminary edition data release. *Australian Geological Survey Organisation, Record* **1999/15**.

KRASSAY, A.A., DOMAGALA, J., BRADSHAW, B.E. & SOUTHGATE, P.N., 2000: Lowstand ramps, fans and deep-water Palaeoproterozoic and Mesoproterozoic facies of the Lawn Hill Platform: the Term, Lawn, Wide and Doom Supersequences of the Isa Superbasin, northern Australia. *Australian Journal of Earth Sciences*, **47**, 563–598.

KYLE, J.R., 1994: Short Course on Sediment-Hosted Mineral Deposits. Earth Resources Foundation, The University of Sydney, May 18-19 1994.

LAING, W.P., 1998: Structural-metasomatic environment of the east Mt Isa Block base-metal-gold province. *Australian Journal of Earth Sciences*, **45**, 413–428.

LARGE, R.R., BULL, S.W., COOKE, D.R. & McGOLDRICK, P.J., 1998: A genetic model for the HYC deposit, Australia: Based on regional sedimentology, geochemistry and sulphide-sediment relationships. *Economic Geology*, **93**, 1345–1368.

LARGE, R. & MCGOLDRICK, P.M., 1998: Lithogeochemical halos and geochemical vectors to stratiform sediment hosted Zn-Pb-Ag deposits, 1. Lady Loretta Deposit, Queensland. *Journal of Geochemical Exploration*, **63**, 37–56.

LEISTEL, J.M., MARCOUX, E., THIEBLEMONT, D., QUESADA, C., SANCHEZ, A., ALMODOVAR, G.R., PASCUAL, E. & SAEZ, R., 1998: The volcanic-hosted massive sulphide deposits of the Iberian Pyrite Belt. Review and preface to the thematic issue. *Mineralium Deposita*, **33**, 2–30.

LISTER, G.S., O'DEA, M.G. & SOMAIA, I., 1999: A tale of two synclines: rifting, inversion and transpressional popouts at Lake Julius, northwestern Mt Isa terrane, Queensland. *Australian Journal of Earth Sciences*, **46**, 233–250.

LOCSEI, J., 1977: Pegmont: a stratiform lead-zinc deposit in the Precambrian of northwest Queensland. *Proceedings of the Australasian Institute of Mining and Metallurgy*, **262**, 25–28.

LOOSVELD, R.J.H., 1989a: The intra-cratonic evolution of the central eastern Mount Isa Inlier, Northwest Queensland, Australia. *Precambrian Research*, **44**, 243–276.

LOOSVELD, R.J.H., 1989b: The synchronism of crustal thickening and high T/low P metamorphism in the Mount Isa Inlier, Australia. 1. An example, the central Soldiers Cap belt. *Tectonophysics*, **158**, 173–190.

LOOSVELD, R.J.H., 1992: Structural geology of the central Soldiers Cap Belt, Mount Isa Inlier, Australia. *In* Stewart, A.J. & Blake, D.H. (Editors): Detailed studies of the Mount Isa Inlier. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **243**, 349–360.

LOOSVELD, R.J.H. & SCHREURS, G., 1987: Discovery of thrust klippen, northwest of Mary Kathleen, Mt Isa Inlier, Australia. *Australian Journal of Earth Sciences*, **34**, 387–402.

LOUTIT, T.S., WYBORN, L.A., HINMAN, M.C. & IDNURM, M., 1994: Palaeomagnetic, tectonic, magmatic and mineralization events in the Proterozoic of northern Australia. *Australasian Institute of Mining and Metallurgy Annual Conference, Darwin, August 1994*, 123-128.

MARLOW, N.G., 1975: Final report, "Wagunda" project, A-P 1405M, Police Creek district, NW Queensland. Report held by the Queensland Department of Mines and Energy as CR 5479.

McCONACHIE, B.A., DUNSTER, J.N., WELLMAN, P., DENARO, T.J., PAIN, C.F., HABERMEHL, M.A. & DRAPER, J.J., 1997: Carpentaria Lowlands and Gulf of Carpentaria Regions In Bain, J.H.C. & Draper, J.J., (Editors): North Queensland Geology. *Australian Geological Survey Organisation, Bulletin* **240**, and Queensland Department of Mines & Energy, *Queensland Geology* **9**.

MacCREADY, T., 1998: Geologic interpretation of the Mount Isa deep seismic transect. PhD thesis, Monash University, Melbourne.

McGOLDRICK, P. & LARGE, R., 1998: Proterozoic stratiform sediment-hosted Zn-Pb-Ag deposits. *AGSO Journal of Australian Geology and Geophysics*, **17**, 189–196.

NEWBERY, S., CARSWELL, J.T., ALLNUTT, S.L. & MUTTON, A.J., 1993: The Dugald River zinc-lead-silver deposit; an example of a tectonised Proterozoic stratabound sulphide deposit. *Proceedings, World Zinc '93 International Symposium*, October 1993, Hobart. The Australasian Institute of Mining and Metallurgy, 7-21.

NIJMAN, W., MIJNLIEFF, H.F. & SCHALKWIJK, G., 1992a: The Hero Fan delta (Lower Mount Isa Group) and its structural control: deformation in the Hero/Western Fault Zone and Paroo Range compared, Proterozoic, Mount Isa Inlier, Queensland, Australia. *In* Stewart, A.J. & Blake, D.H. (Editors): Detailed studies of the Mount Isa Inlier. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **243**, 75–110.

NIJMAN, W., Van LOCHEM, J.H., SPLIETHOFF, H. & FEIJTH, J., 1992b: Deformation model and sedimentation patterns of the Proterozoic of the Paroo Range, Mount Isa Inlier, Queensland, Australia. *In* Stewart, A.J. & Blake, D.H. (Editors): Detailed studies of the Mount Isa Inlier. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **243**, 29–74.

O'DEA, M.G. & LISTER, G.S., 1995: The role of ductility contrast and basement architecture in the structural evolution of the Crystal Creek block, Mount Isa Inlier, NW Queensland, Australia. *Journal of Structural Geology*, **17**, 949–960.

O'DEA, M.G., LISTER, G.S., BETTS, P.G. & POUND, K.S., 1997: A shortened intraplate rift system in the Proterozoic Mount Isa terrane, NW Queensland, Australia. *Tectonics*, **16**, 425–441.

O'DEA, M.G., LISTER, G.S., MacREADY, T., BETTS, P.G., OLIVER, N.H.S., POUND, K.S., HUANG, W. & VALENTA, R.K., 1997: Geodynamic evolution of the Proterozoic Mount Isa terrain. *In* Burg, J.-P. & Ford, M. (Editors): Orogeny Through Time. *Geological Society Special Publication* **121**, 99–122.

OLIVER, N.H.S., PEARSON, P.J., HOLCOMBE, R.J. & ORD, A., 1999: Mary Kathleen metamorphic-hydrothermal uranium — rare earth element deposit: ore genesis and numerical model of coupled deformation and fluid flow. *Australian Journal of Earth Sciences*, **46**, 467–484.

OLIVER, N.H.S., VALENTA, R.K. & WALL, V.J., 1990: The effects of heterogeneous stress and strain on metamorphic fluid flow, Mary Kathleen, Australia, and a model for large-scale fluid circulation. *Journal of Metamorphic Geology*, **8**, 311–331.

OLIVER, N.H.S., WALL, V.J. & PEARSON, P.J., 1986: The Mary Kathleen uranium-REE deposit; a product of regional metamorphism. *Geological Society of Australia, Abstracts*, **15**, 149–150.

OLIVER, N.H.S., WALL, V.J., PEARSON, P.J. & HOLCOMBE, R.J., 1990: Unravelling more obscurities in the genesis of the Mary Kathleen U-REE orebody. *Abstracts, Mount Isa Inlier Geology Conference*, Monash University, Melbourne.

ORD, A., HOBBS, B., WALSHE, J., ZHANG, Y., BROWN, M. & ZHAO, C., 2000: Geodynamic modelling of the Century zinc mineralising system: three scenarios. *Geological Society of Australia, Abstracts*, **59**, 371.

OTTO, J., BATARESEH, M.L. & CONDES, J., 2000: *Global Mining Taxation, Comparative Study* (Second Edition). Institute for Global Resources, Policy and Management, Colorado School of Mines, Golden, Colorado.

OZIMIC, S., 1981: Stratigraphic drilling in the Cretaceous Toolebuc Formation in the southern and eastern Eromanga Basin, 1980 – a contribution to BMR/CSIRO NERDDC Project 78/2616. Bureau of Mineral Resources, Geology and Geophysics, Australia, Record 1981/12.

PAGE, R.W., JACKSON, M.J. & KRASSAY, A.A., 2000: Contrasting sequence stratigraphy in north Australian basins: U-Pb zircon geochronology between Mt Isa and McArthur River. *Australian Journal of Earth Sciences*, **47**, 431–460.

PAGE, R.W. & LAING, W.P., 1992: Felsic metavolcanic rocks related to the Broken Hill Pb-Zn-Ag orebody, Australia: geology, depositional age and timing of metamorphism. *Economic Geology*, **87**, 2138–2168.

PAGE, R.W. & SUN, S.-S., 1998: Aspects of geochronology and crustal evolution in the Eastern Fold Belt, Mt Isa Inlier. *Australian Journal of Earth Sciences*, **45**, 343–361.

PAGE, R.W. & SWEET, I.P., 1998: Geochronology of basin phases in the western Mt Isa Inlier, and correlation with the McArthur Basin. *Australian Journal of Earth Sciences*, **45**, 219–232.

PARR, J.M. & PLIMER, I.R., 1993: Models for Broken Hill-type lead-zinc-silver deposits. *In* Kirkham, R.V., Sinclair, W.E., Thorpe, R.I. & Duke, J.M. (Editors.): Mineral Deposit Modelling. *Geological Association of Canada Special Paper* **40**, 253–288.

PASSCHIER, C.W., 1986: Evidence for early extensional tectonics in the Proterozoic Mount Isa Inlier, Australia. *Geology*, **14**, 1008–1011.

PASSCHIER, C.W., 1992: Geology of the Myubee area, Mount Isa Inlier, Queensland. *In* Stewart, A.J. & Blake, D.H. (Editors): Detailed studies of the Mount Isa Inlier. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **243**, 199–208.

PASSCHIER, C.W. & WILLIAMS, P.R., 1989: Proterozoic extensional deformation in the Mount Isa Inlier, Queensland, Australia. *Geological Magazine*, **126**, 43–53.

PEARSON, P.J., HOLCOMBE, R. J. & PAGE, R., 1992: Synkinematic emplacement of the middle Proterozoic Wonga Batholith into a mid-crustal extensional shear zone, Mount Isa Inlier, Queensland, Australia. *Australian Geological Survey Organisation, Bulletin* **243**, 289–328.

PERKINS, C., HEINRICH, C.A. & WYBORN, L.A.I., 1999: 40Ar/39Ar geochronology of copper mineralization and regional alteration, Mount Isa, Australia. *Economic Geology*, **94**, 23–36.

PERKINS, C. & WYBORN, L.A.I., 1998: Age of Cu-Au mineralisation, Cloncurry district, eastern Mt Isa Inlier, Queensland, as determined by 40Ar/39Ar dating. *Australian Journal of Earth Sciences*, **45**, 233–246.

PERKINS, W.G., 1984: Mount Isa silica dolomite and copper orebodies: the result of a syntectonic hydrothermal alteration system. *Economic Geology*, **79**, 601–637.

PERKINS, W.G., 1990: Mount Isa Copper Orebodies. *In* Hughes, F. E. (Editor): Geology of the Mineral Deposits of Australia and Papua New Guinea. *The Australasian Institute of Mining and Metallurgy, Melbourne, Monograph* **14**, 935–941.

PERKINS, W.G., 1997: Mount Isa lead-zinc orebodies: Replacement lodes in a zoned syndeformational copper-lead-zinc system? *Ore Geology Reviews*, **12**, 61–110.

PERKINS, W.G. & BELL, T.H., 1998: Stratiform replacement lead-zinc deposits: A comparison between Mount Isa, Hilton and McArthur River. *Economic Geology*, **93**, 1190–1212.

PERKINS, W.G., HEINRICH, C.A. & WYBORN, L.A.I., 1996: 40Ar/39Ar geochronology of copper mineralisation and regional alteration Mount Isa, Australia. *Economic Geology*, **94**, 23–36.

PERRING, C.S., POLLARD, P.J., DONG, G., NUNN, A.J. & BLAKE, K.L., 2000: The Lightning Creek Sill Complex, northwest Queensland: a source of fluids for Fe oxide-Cu-Au mineralisation and sodic-calcic alteration. *Economic Geology*, **95**, 1067–1089.

PIDGEON, B.A., 1997: The sedimentology and sequence stratigraphy of the Surprise Creek Formation and Warrina Park Quartzite, lower Mount Isa Group, Mt Isa Basin. B.Sc. (Honours) thesis, Queensland University of Technology, Brisbane.

POTMA, W.A., 1995: The structures of the east limb of the Mitakoodi Culmination, eastern Mount Isa Inlier. *Geological Society of Australia, Abstracts*, **41**, 350.

RAWLINGS, D.J., 1999: Stratigraphic resolution of a multiple intracratonic basin system: the McArthur Basin, northern Australia. *Australian Journal of Earth Sciences*, **46**, 703–723.

REINHARDT, J., 1992: The Corella Formation of the Rosebud Syncline (central Mount Isa Inlier): deposition, deformation, and metamorphism. *In* Stewart, A.J. & Blake, D.H. (Editors): Detailed studies of the Mount Isa Inlier. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **243**, 229–256.

RHEINBERGER, G.M., HALLENSTEIN, C. & STEGMAN, C.L., 1998: Westmoreland uranium deposits. *In* Berkman, D.A. & Mackenzie, D.H. (Editors): Geology of Australian and Papua New Guinean Mineral Deposits. *The Australasian Institute of Mining and Metallurgy, Monograph* **22**, 807–814.

RICHARDSON, S.M. & MOY, A.D., 1998: Gunpowder copper deposits. *In* Berkman, D.A. & Mackenzie, D.H. (Editors): Geology of Australian and Papua New Guinean Mineral Deposits. *The Australasian Institute of Mining and Metallurgy, Monograph* **22**, 743–752.

ROTHERHAM, J.F., BLAKE, K.L., CARTWRIGHT, I. & WILLIAMS, P.J., 1998: Stable isotope evidence for the origin of the Mesoproterozoic Starra Au-Cu deposit, Cloncurry district, northwest Queensland. *Economic Geology*, **93**, 1435–1449.

RYAN, A.J., 1998: Ernest Henry copper-gold deposit. *In* Berkman, D.A. & Mackenzie, D.H. (Editors): Geology of Australian and Papua New Guinean Mineral Deposits. *The Australasian Institute of Mining and Metallurgy, Monograph* **22**, 759–768.

RYBURN, R.J., WILSON, I.H., GRIMES, K.G. & HILL, R.M, 1988: *Cloncurry, Queensland, 1:100 000 Geological Map Commentary*. Bureau of Mineral Resources, Geology and Geophysics, Australia, Canberra.

SCOTT, D.L., BRADSHAW, B.E. & TARLOWSKI, C.Z., 1998: The tectonostratigraphic history of the Proterozoic northern Lawn Hill Platform, Australia: an integrated intracontinental basin analysis. *Tectonophysics*, **300**, 329–358.

SCOTT, D.L., RAWLINGS, D.J., PAGE, R.W., TARLOWSKI, C.Z., IDNURM, M., JACKSON, M.J. & SOUTHGATE, P.N., 2000: Basement framework and geodynamic evolution of the Palaeoproterozoic superbasins of north-central Australia: an integrated review of geochemical, geochronological and geophysical data. *Australian Journal of Earth Sciences*, **47**, 341–380.

SHAW, R.D., 1991: The tectonic development of the Amadeus Basin, central Australia. *In* Korsch, R.J., & Kennard, J.M., (Editors): Geological and geophysical studies in the Amadeus Basin, central Australia. *Bureau of Mineral Resources Geology and Geophysics, Bulletin* **236**, 429–462.

SHERGOLD, J.H. & DRUCE, E.C., 1980: Upper Proterozoic and Lower Palaeozoic rocks of the Georgina Basin *In* Henderson, R.A. & Stephenson, P.J., (Editors): *The Geology and Geophysics of Northeastern Australia*. Geological Society of Australia Inc, Queensland Division, Brisbane.

SINGER, D.A., 1995: World class base and precious metal deposits — a quantitative analysis. *Economic Geology*, **90**, 88–104.

SLATYER, R.O., 1964: Climate of the Leichhardt – Gilbert area. *CSIRO Land Research Series*, **11**, 90–104.

SLATYER, R.O. & CHRISTIAN, C.S., 1954: Climate of the Barkly Region. In Survey of the Barkly Region, Northern Territory and Queensland, 1947-48. *CSIRO Land Use Research Series*, **3**, 17-23.

SMART J. & SENIOR, B.R., 1980: Jurassic – Cretaceous basins of northeastern Australia. *In* Henderson, R.A. & Stephenson, P.J., (Editors): *The Geology and Geophysics of Northeastern Australia*. Geological Society of Australia Inc, Queensland Division, Brisbane.

SOLOMON, M., GROVES, D.I. & JAQUES, A.L., 1994: The Geology and Origin of Australia's Mineral Deposits. *Oxford Monographs on Geology and Geophysics* **No. 24**, Clarendon Press, Oxford.

SOUTHGATE, P.N., 1988: A model for the development of phosphatic and calcareous lithofacies in the Middle Cambrian Thorntonia Limestone, northeast Georgina Basin, Australia. *Australian Journal of Earth Sciences*, **35**, 111–130.

SOUTHGATE, P.N., BRADSHAW, B.E., DOMAGALA, J., JACKSON, M.J., IDNURM, M., KRASSAY, A.A., PAGE, R.W., SAMI, T.T., SCOTT, D.L., LINDSAY, J.F., MCCONACHIE, B.A. & TARLOWSKI, C., 2000: A chronostratigraphic basin framework for Palaeo- and Mesoproterozoic rocks (1730-1575 Ma) in northern Australia and implications for base metal mineralisation. *Australian Journal of Earth Sciences*, **47**, 461–484.

SOUTHGATE, P.N., SAMI, T.T., JACKSON, M.J., DOMAGALA, J., KRASSAY, A.A., LINDSAY, J.F., McCONACHIE, B.A., PAGE, R.W., PIDGEON, B., BARNETT, K., ROKVIC, U. & ZEILINGER, I., 1999: Measured sections and sequence stratigraphic interpretations: lower McNamara, Mt Isa and Fickling Groups, preliminary edition data release. *Australian Geological Survey Organisation, Record* **1999/10**.

SOUTHGATE, P.N., SCOTT, D.L., SAMI, T.T., DOMAGALA, J., JACKSON, M.J., JAMES, N.P. & KYSER, T.K., 2000: Basin shape and sediment architecture in the Gun Supersequence: a strike-slip model for Pb-Zn-Ag ore genesis at Mt Isa. *Australian Journal of Earth Sciences*, **47**, 509–532.

SOUTHGATE, P.N. & SHERGOLD, J.H., 1991: Application of sequence stratigraphic concepts to Middle Cambrian phosphogenesis, Georgina Basin, Australia. *BMR Journal of Australian Geology and Geophysics*, **12**, 119–144.

STEVENS, B.P.J., BROWN, R.E., STROUD, W.J. & WILLIS, I.L., 1988: The Willyama Supergroup in the Broken Hill and Eurowie Blocks, N.S.W. *Precambrian Research*, **40-41**, 297-327.

STEWART, A., 1987: Fault reactivation and superimposed folding in a Proterozoic sandstone-volcanic sequence, Davenport Province, central Australia. *Journal of Structural Geology*, **9**, 441–455.

STEWART, A.J., 1989: Extensional faulting as the explanation for the Deighton 'Klippe' and the Mount Albert Group outliers, Mount Isa Inlier, northwestern Queensland. *Australian Journal of Earth Sciences*, **36**, 405–421.

STEWART, A.J., 1992a: Geology of the Horse's Head structure, north of Mount Isa, and its bearing on the 'roof thrust + imbricate stack' hypothesis, Mount Isa Inlier, Queensland. *In* Stewart, A.J. & Blake, D.H. (Editors): Detailed studies of the Mount Isa Inlier. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **243**, 111–124.

STEWART, A.J., 1992b: Stratigraphy, extension, and contraction in the Ballara-Mount Frosty area, Mount Isa Inlier, Queensland. *In* Stewart, A.J. & Blake, D.H. (Editors): Detailed studies of the Mount Isa Inlier. Bureau of Mineral Resources, *Geology and Geophysics, Australia, Bulletin* **243**, 209–228.

STEWART, A.J. & BLAKE, D.H. (Editors), 1992: Detailed studies of the Mount Isa Inlier. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **243**.

STEWART, G.A., 1954: Geomorphology of the Barkly region. *In* Survey of the Barkly Region, 1947-48. *CSIRO Land Research Series*, **3**, 42–58.

SUN, S.-S., CARR, G.R. & PAGE, R.W., 1996: A continued effort to improve lead-isotope model ages. *AGSO Research Newsletter*, **24**, 19–20.

SUN, S.-S., PAGE, R., & CARR, G., 1994: Lead-isotope-based stratigraphic correlations and ages of Proterozoic sediment-hosted Pb-Zn deposits in the Mount Isa Inlier. *AGSO Research Newsletter*, **20**, 1–2.

SWEET, I.P. & HUTTON, L.J., 1980: Geology of the Lawn Hill/Riversleigh region, Queensland. Bureau of Mineral Resources, Geology and Geophysics, Australia, Record 1980/43.

SWEET, I.P. & HUTTON, L.J., 1982: *Lawn Hill Region, Queensland, 1:100 000 Geological Map Commentary*. Bureau of Mineral Resources, Geology and Geophysics, Australia, Canberra.

SWEET, I.P., MOCK, C.M. & MITCHELL, J.E., 1981: *Seigal, Northern Territory, and Hedleys Creek, Queensland, 1:100 000 Geological Map Commentary*. Bureau of Mineral Resources, Geology and Geophysics, Australia, Canberra.

TARLOWSKI, C.Z. & SCOTT, D.L., 1999: Geophysical investigation of north central Australia, images, algorithms and crustal models. *Australian Geological Survey Organisation Record* **1999/27**.

TORREALDAY, H.I., HITZMAN, M.W., STEIN, H.J., MARKLEY, R.J., ARMSTRONG, R. & BROUGHTON, D., 2000: Re-Os and U-Pb dating of the vein-hosted mineralisation at the Kansanshi copper deposit, Northern Zambia. *Economic Geology*, **95**, 1165–1170.

TULLEMANS, F.J. & VOULGARIS, P., 1998: The role of geology and exploration within the mining cycle at the Osborne Mine, NW Queensland. *Proceedings of AusIMM '98, The Mining Cycle*, 19-23 April 1998. Annual Conference, Mount Isa, Queensland. The Australasian Institute of Mining and Metallurgy, Melbourne, 159-169.

TWIDALE, C.R., 1964: Geomorphology of the Leichhardt-Gilbert area. *CSIRO Land Research Series*, **11**, 115–124.

VALENTA, R. K., 1994a: Systematic discordant copper mineralisation at the Hilton mine, Mount Isa. *Economic Geology*, **89**, 1031–1052.

VALENTA, R., 1994b: Deformation of host rocks and stratiform mineralisation in the Hilton area, Mt Isa. *Australian Journal of Earth Sciences*, **41**, 429–443.

VALENTA, R.K. & WALL, V.J., 1995: Controls on gold mineralisation at The Granites, Tanami Desert, Northern Territory. 13th Australian Geological Convention, Canberra. *Geological Society of Australia, Abstracts*, **41**, 451.

VAN DIJK, P.M., 1991: Regional syndeformational copper mineralisation in the Western Mount Isa Block, Australia. *Economic Geology*, **86**, 278–301.

WALL, V.J., (in press): Pluton-Related (Thermal Aureole) Gold. Northwest Mining Association. Taylor, Wall & Associates, Brisbane.

WALL, V.J., 1999: Mount Isa style copper systems. Unpublished contribution to Brisbane Exploration Discussion Group (BEDG), The Mount Isa Inlier. Taylor Wall & Associates, Brisbane.

WALL, V.J. & GOW, P.M., 1995: Some copper-gold ore-forming systems: iron (ic) connections in Giant Ore Deposits II. *In* Clark, A.H. (Editor): *Proceedings of the Second Giant Ore Deposits Workshop*. Queens University, Kingston, Ontario, 557–582.

WALL, V.J. & HEINRICH, C.A., 1990: Breccia pipes at Redbank, Southern McArthur Basin: copper mineralisation by fluid mixing. *Abstracts, Mount Isa Inlier Geology Conference*. Monash University, Melbourne.

WALL, V.J. & TAYLOR, J.R., 1990: Granite emplacement and temporally related gold mineralisation. *Geological Society of Australia, Abstract Series*, **25**, 264–265.

WALL, V.J, & VALENTA, R.K., 1990: Ironstone-related gold-copper mineralisation: Tennant Creek and elsewhere. *Pacific Rim Congress 90*. Australasian Institute of Mining and Metallurgy, Melbourne, 855–864.

WALLIS, D.S., 1998: Mount Isa Minerals Province – A New Mining Cycle. *Proceedings of AusIMM '98, The Mining Cycle*, 19-23 April 1998. Annual Conference, Mount Isa, Queensland. The Australasian Institute of Mining and Metallurgy, Carlton, Victoria, 3–13.

WALTER, M.R., VEEVERS, J.J., CALVER, C.R. & GREY, K., 1995: Neoproterozoic stratigraphy of the Centralian Superbasin, Australia. *Precambrian Research,* **73**, 173–195.

WALTERS, S. & BAILEY, A., 1998: Geology and mineralisation of the Cannington Ag-Pb-Zn deposit, an example of Broken Hill-type mineralisation in the Eastern Succession, Mount Isa Inlier, Australia. *Economic Geology*, **93**, 1307–1329.

WARING, C.L., HEINRICH, C.A. & WALL, V.J., 1998: Proterozoic metamorphic copper deposits. *AGSO Journal of Australian Geology and Geophysics*, **17**, 239–246.

WARING, C.L., ANDREW, A.S. & EWERS, G.R., 1998: Use of O, C, and S, stable isotopes in regional mineral exploration. *AGSO Journal of Australian Geology and Geophysics*, **17**, 301–313.

WEBB, M. & ROHRLACH, B.D., 1992: The Walford Creek Prospect — an exploration overview. *Exploration Geophysics*, **23**, 407–412.

WEBB, M. & ROWSTON, P., 1995: The geophysics of the Ernest Henry Cu-Au deposit (N.W.) Queensland. *Exploration Geophysics*, **26**, 51–59.

WEBSTER, A.E., 1996: A detailed description of the Broken Hill deposit — lessons from the ore fabrics. *In* Pongrantz, J. & Davidson, G (Editors): New developments in Broken Hill type deposits. *CODES Special Publication* **1**, 95–104.

WILLIAMS, P.J., 1998: Metalliferous economic geology of the Mount Isa Eastern Succession, northwest Queensland. *Australian Journal of Earth Sciences*, **45**, 329–341.

WILLIAMS, P.J., CHAPMAN, L.H., RICHMOND, J., BAKER, T., HEINEMANN, M. & PENDERGAST, W.J., 1996: Significance of late orogenic metasomatism in the Broken Hill-type deposits of the Cloncurry district, NW Queensland. *In* Prongratz, J. & Davidson, G. J. (Editors): New developments in Broken Hill-type deposits. *CODES Special Publications* **1**, 119–132.

WILLIAMS, P.R. & BLAKE, D.H., 1992: Black Mountain — a strike slip pull-apart structure in the Quilalar Fault System, Mount Isa Inlier. *In* Stewart, A.J. & Blake, D.H. (Editors): Detailed studies of the Mount Isa Inlier. *Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin* **243**, 191–198.

WILLIAMS, P.R. & BLAKE, K.L., 1993: Alteration in the Cloncurry District. Roles of recognition and interpretations in exploration for Cu-Au and Pb-Zn-Ag deposits. *Economic Geology Research Unit, Contribution* **49**.

WILSON, I.H, DERRICK, G.M., HILL, R.M., DUFF, B.A., NOON, T.A. & ELLIS, D.J., 1977: Geology of the Prospector 1:100 000 Sheet area (6857), Queensland. Bureau of Mineral Resources, Geology and Geophysics, Australia, Record 1977/4.

WILSON, I.H. & GRIMES, K.G., 1984: *Myally, Queensland, 1:100 000 Geological Map Commentary*. Bureau of Mineral Resources, Geology and Geophysics, Australia, Canberra.

WILSON, I.H. & GRIMES, K.G., 1986: *Coolullah, Queensland, 1:100 000 Geological Map Commentary*. Bureau of Mineral Resources, Geology and Geophysics, Australia, Canberra.

WILSON, I.H., HILL, R.M., NOON, T.A., DUFF, B.A. & DERRICK, G.M., 1979a: Geology of the Kennedy Gap 1:100 000 Sheet area (6757), Queensland. Bureau of Mineral Resources, Geology and Geophysics, Australia, Record 1979/24.

WILSON, I.H., NOON, T.A., HILL, R.M. & DUFF, B.A., 1979b: Geology of the Quamby 1:100 000 Sheet area (6957), Queensland. Bureau of Mineral Resources, Geology and Geophysics, Australia, Record 1979/56.

WRIGHT, J.V., HAYDON, R.C. & MCCONACHY, G.W., 1987: Sedimentary model for the giant Broken Hill Pb-Zn deposit, Australia. *Geology*, **15**, 598–602.

WYBORN, L. A. I., 1992: The Williams and Naraku batholiths, Mount Isa Inlier: an analogue of the Olympic Dam granites? *Bureau of Mineral Resources Research Newsletter*, **16**, 13–16.

WYBORN, L., 1998: Younger ca 1500 Ma granites of the Williams and Naraku Batholiths, Cloncurry district, eastern Mount Isa Inlier: geochemistry, origin, metallogenic significance and exploration indicators. *Australian Journal of Earth Sciences*, **45**, 397–411.

WYBORN, L.A.I., HENSLEY, C. & BUDD, A.R., 1997: *The Metallogenic Potential of Australian Proterozoic Granites, Mount Isa Inlier*. Australian Geological Survey Organisation, Canberra.

Queensland Government
Department of Mines and Energy

PLATE 30

NORTH-WEST QUEENSLAND MINERAL PROVINCE
GEOLOGICAL REFERENCE

DEPOSITIONAL EVENTS

- Neoproterozoic to Devonian
- Quamby
- Croydon
- South Nicholson
- Doom Supersequence
- Cover Sequence 3
  - Wide Supersequence
  - Lawn Supersequence
  - Term Supersequence
  - River Supersequence
  - Loretta Supersequence
  - Gun Supersequence
  - Prize Supersequence
- Soldiers Cap
  - Soldiers Cap 4
  - Soldiers Cap 3
  - Soldiers Cap 2
  - Soldiers Cap 1
- Big Supersequence
- Tawallah
- Cover Sequence 2 Sag Phase
- Cover Sequence 2 Volcanic Phase
- Cover Sequence 1.5
- Cover Sequence 1
- Pre-Barramundi Orogeny

IGNEOUS EVENTS

- Unspecified Igneous
- Williams
- Maramungee
- Sybella
- Weberra
- Wonga
- Argylla
- Toby-Ewan
- Kalkadoon

DEFORMATION EVENTS / FAULTS

- *Unknown deformation*
- *Palaeozoic (post-Cambrian) deformation*
- *Cambrian deformation*
- *Isan deformation - unknown age*
- *Isan D3 deformation*
- *Isan D2 deformation*
- *Isan D1 deformation (post South Nicholson)*
- *Isan D1 deformation*
- *1620 Ma compression*
- *1640 Ma extension*
- *1650 Ma deformation*
- *1675 Ma extension*
- *1710 Ma compression*
- *Wonga extension*
- *Pre-Wonga extension*
- *Cover sequence 2 volcanic phase extension*
- *Barramundi Orogeny deformation*
- *Barramundi basin formation*
- *Archaean deformation*

- *Normal fault*
- *Blind fault*
- *Thrust fault*
- *Transfer fault*
- *Sinistral strike slip fault*
- *Dextral strike slip fault*
- *Sinistral oblique slip reverse fault*
- *Dextral oblique slip reverse fault*
- *Sinistral oblique slip normal fault*
- *Dextral oblique slip normal fault*
- *Detachment fault*
- *Anticline*
- *Syncline*
- *Overturned anticline*
- *Overturned syncline*
- *Geological boundary*
- *Dyke*
- *Concealed granite*
- *Trend line*

TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS

SRK Consulting

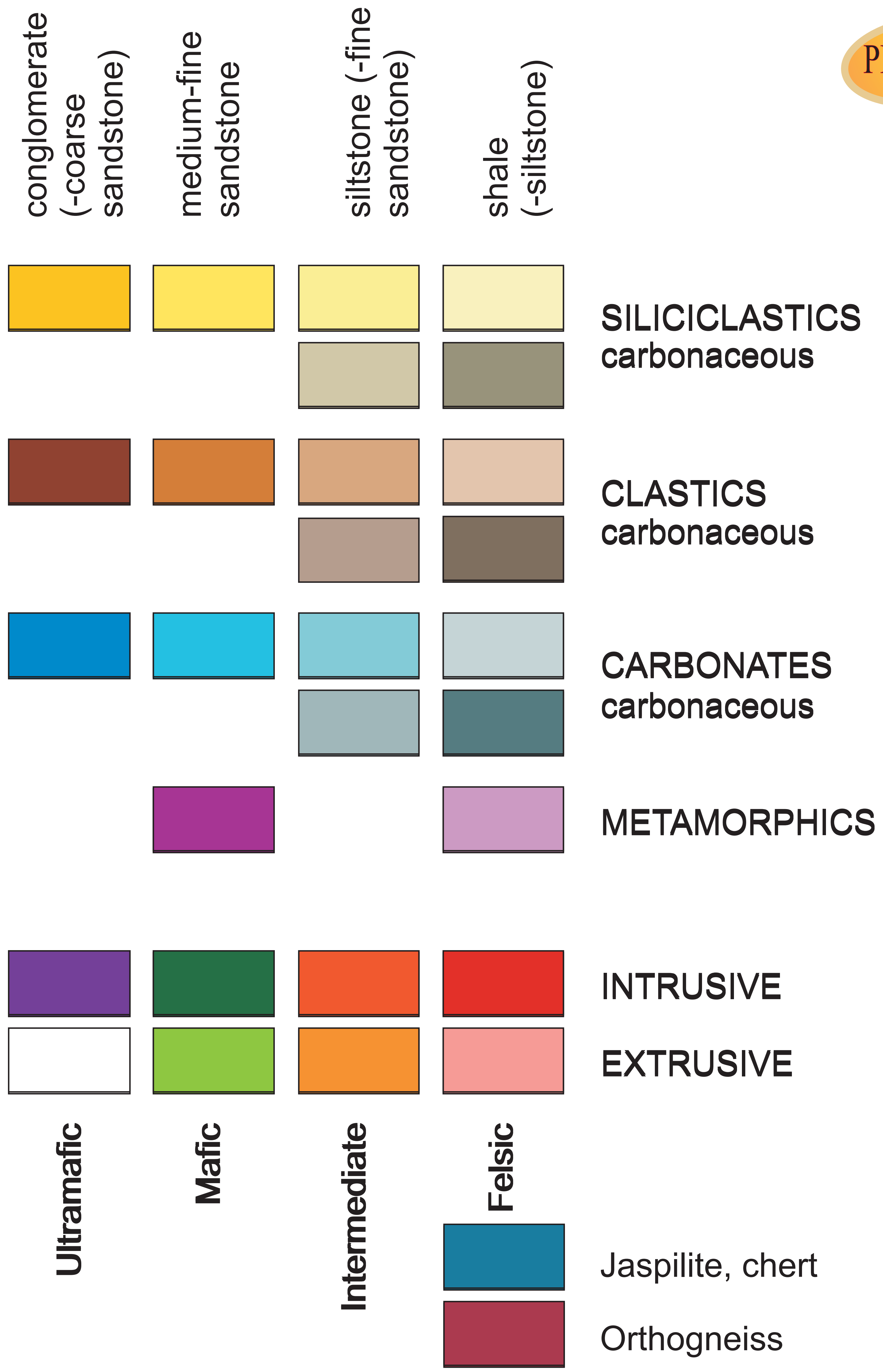
ESRI AU

Cartography by Graphical Services Unit, Department of Mines and Energy

Queensland Government
Department of Mines and Energy

LITHOLOGY KEY

PLATE 31



TAYLOR WALL & ASSOCIATES
GEOSCIENCE CONSULTANTS

SRK Consulting

ESRI AU

TABLE 11.1: ISA-CENTURY STYLE ZN-PB-AG TARGETS

Identifier	Location (AMG)	Styles	Regional structural setting	Local structural setting	Lithostratigraphic setting	Alteration/Mineralisation indicators	Cover thickness	Overall rating	Comments
	E N	Target Style and Mineralising Events	Key structural elements, geometries and kinematic histories relevant to target style, ie target zone in regional structural context.	Key structural elements, geometries and kinematic histories relevant to target style – at scale of target zone or prospect	Unit(s), lithologies, ages Any key features with respect to target styles)	Mineral occurrences of styles related to target Geochemical anomalism Any significant local lithological and alteration features)	Depth to Proterozoic basement Estimate of target depths, if possible		Any relevant comments, opinions, qualifiers from target generator Historical exploration data, if available
ZIC1	E: 343610 N: 7585510	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640, 1650Ma	Cover Sequence 2 accommodation (transfer) zone, NE-trending. Transtensional segment of 1640Ma accommodation structure Rating: A	Possible basin related to transtensional jog Rating: A	Gun Supersequence, Moondarra Siltstone Rating: B	Not known Rating: B	<50m Rating: A	2	
ZIC2	E: 331370 N: 75 77350	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640, 1650Ma	Cover Sequence 2 accommodation (transfer zone), NE-trending. Weak transtensional segment of 1640Ma accommodation structure Rating: B	Not known Rating: B	Isa Superbasin possible Gun Supersequence and above Rating: B	Not known Rating: B	<100m Rating: B	2	
ZIC3	E: 342450 N: 7552000	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640, 1650Ma	ENE-Wonga-age normal faults at intersection with 1640Ma accommodation structure Rating: B	Not known Rating: B	Isa Superbasin possibly Gun Supersequence Rating: B	Not known Rating: B	100-300m Rating: B	2	
ZIC4	E: 303990 N: 7540060	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640, 1650Ma	Cover Sequence 2 transfer fault and Wonga normal faults at intersection with 1640Ma accommodation zone Rating: B	Not known Rating: B	Isa Superbasin, possibly Gun Supersequence Rating: B	Not known Rating: B	200-500m Rating: C	2	
ZIC5	E: 329630 N: 7630960	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640, 1650Ma	Cover Sequence 2 transfer fault and Barramundi structure plus 1640Ma transtensional accommodation zone Rating: A	Not known Rating: B	Isa Superbasin Gun Supersequence Rating: B	Not known Rating: C	<50m Rating: A	2	Largely outcropping area
ZIC6	E: 338950 N: 7675830	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640, 1650Ma	Cover Sequence 2 transfer zone at intersection with 1640Ma transtensional accommodation zone Rating: A	Steeply dipping metasediments Rating: B	Gun Supersequence Rating: B	Stratabound pyrite and copper occurrences Rating: A	<50m Rating: A	2	Largely outcropping area, south of Mount Isa
ZIC7	E: 290880 N: 7696220	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640, 1650Ma	Wonga normal fault at intersection with ?1640Ma accommodation zone Rating: C	Shallow dipping and plunging folded succession Rating: B	Gun Supersequence Rating: B	Not known Rating: B	50-100m Rating: A	3	
ZIC8	E: 316510 N: 7694770	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640, 1650Ma	Cover Sequence 2 transfer fault and Wonga normal faults plus 1640Ma accommodation zone Rating: A	Steeply dipping, strong D2 deformation Rating: B	Gun Supersequence Rating: B	Minor copper and uranium mineralisation Rating: B	<50m Rating: A	2	
ZIC9	E: 340110 N: 7724480	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1650Ma	Folded Wonga normal faults and Cover Sequence 2 normal fault intersecting 1640Ma transtensional zone Rating: A	Moderately to steeply dipping, faulted succession Rating: B	Thick Gun Supersequence, Urquhart Shale. Carbonaceous and pyritic lutites Rating: A	Hilton and George Fisher Zn-Pb-Ag deposits. Highly pyritic, dolomitic carbonaceous stratigraphy Rating: A	<50m. Deeper targets? Rating: A	2	Current Mount Isa Zn-Pb-Ag mining; heavily explored to substantial depths

ZIC10	E: 315640 N: 7757990	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640, 1650Ma	Possible Wonga normal faults intersecting 1640Ma accommodation and normal structures Rating: B	Moderately deformed syncline Rating: B	Relatively thick Gun Supersequence, Gunpowder Creek Formation Rating: B	Not known Rating: C	<50m Rating: A	3	Largely outcropping area
ZIC11	E: 331960 N: 7845690	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640, 1650Ma	Wonga normal fault at intersection with ?1640Ma accommodation zone Rating: B	Moderately deformed synform Rating: B	Gun Supersequence, Gunpowder Creek Formation Rating: B	Not known Rating: C	<50m Rating: A	3	Largely outcropping area
ZIC12	E: 318550 N: 7806650	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640, 1650Ma	Wonga normal fault at intersection with ?1640Ma accommodation zone Rating: B	Moderately dipping Rating: B	Gun Supersequence, Gunpowder Creek Formation Rating: B	Minor copper showings Rating: C	<50m Rating: A	3	Largely outcropping area
ZIC13	E: 308070 N: 7792950	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640, 1650Ma	Wonga normal faults with multiple 1640Ma accommodation zones Rating: A	Moderately dipping Rating: B	Platformal facies. Gun Supersequence, Gunpowder Creek Formation Rating: C	Minor copper showings Rating: C	<50m Rating: A	3	Largely outcropping area
ZIC14	E: 301360 N: 7813930	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640Ma	Buried Wonga normal fault with 1640Ma transfer systems Rating: A	Shallow-moderately dipping Rating: B	Loretta Supersequence Rating: A	Adjacent to Lady Loretta Zn-Pb-Ag system Rating: B	<50m, thin superficial cover Rating: A	2	
ZIC15	E: 288540 N: 7809560	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640Ma; Isan D1-D3	Buried Wonga normal faults with 1640Ma transfer systems Rating: A	Shallow-moderately dipping Rating: B	Loretta Supersequence Rating: A	Adjacent to Lady Loretta Zn-Pb-Ag system Rating: B	<50m Rating: A	2	
ZIC16	E: 275730 N: 7812470	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640Ma; Isan D1-D3	Wonga normal faults and 1640Ma accommodation structures and possible Cover Sequence transfer system Rating: A	Probably shallow dipping Rating: B	River Supersequence. Possibly platformal Rating: B	Not known Rating: B	50-250m Rating: B	2	
ZIC17	E: 286210 N: 7789160	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640Ma; Isan D1-D3	Buried Wonga normal fault with 1640Ma accommodation systems Rating: A	Probably shallow dipping Rating: B	River Supersequence. Possibly platformal Rating: B	Not known Rating: B	<50m thin surficial cover Rating: A	2	
ZIC18	E: 277180 N: 7843360	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640Ma; Isan D1-D3	Wonga normal faults, Cover Sequence 2 transfer faults and 1640Ma accommodation zones Rating: A	Probably shallow dipping Rating: B	River Supersequence. Possibly platformal Rating: B	Not known Rating: B	<50m Rating: A	2	
ZIC19	E: 286800 N: 7861420	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640Ma; Isan D1-D3	Major Cover Sequence 2 accommodation zone with 1640Ma accommodation structure and transfer faults Rating: A	Complexly faulted and folded zone Rating: B	Loretta and River Supersequences Rating: B	Not known Rating: B	0-70m Rating: A	2	
ZIC20	E: 263780 N: 7886190	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640Ma	Possible Cover Sequence 2 transfer fault plus 1640Ma accommodation zone and normal fault Rating: A	Shallow dipping Rating: B	River to Term Supersequences Rating: A	Adjacent to Grevillea Zn-Pg-Ag system Rating: A	0-50m on margin of Cambrian basin Rating: A	1	
ZIC21	E: 379740 N: 7924060	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640 1650 (and later events?)	Major Cover Sequence 2 transfer fault system. 1640Ma accommodation zone Rating: A	Not known Rating: B	Isa Superbasin Rating: B	Not known Rating: B	200-400m Rating: C	2	

TABLE 11.1 (continued)

Identifier	Location (AMG)	Styles	Regional structural setting	Local structural setting	Lithostratigraphic setting	Alteration/Mineralisation indicators	Cover thickness	Overall rating	Comments
	E N	**Target Style and Mineralising Events**	**Key structural elements, geometries and kinematic histories relevant to target style, ie target zone in regional structural context.**	**Key structural elements, geometries and kinematic histories relevant to target style – at scale of target zone or prospect**	**Unit(s), lithologies, ages Any key features with respect to target styles)**	**Mineral occurrences of styles related to target Geochemical anomalism Any significant local lithological and alteration features)**	**Depth to Proterozoic basement Estimate of target depths, if possible**		**Any relevant comments, opinions, qualifiers from target generator Historical exploration data, if available**
ZIC22	E: 280970 N: 7894930	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1650, 1640, 1620Ma and Isan D1-D3	Covered 1640Ma accommodation zone and also normal fault systems Rating: B	Moderately deformed and faulted Rating: B	Loretta, but mainly River Supersequences Rating: A	Not known Rating: C	<50m Rating: A	3	Largely outcropping
ZIC23	E: 265240 N: 7917070	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1650, 1640, ?1620Ma, Isan D1-D3	Cover Sequence 2 transfer fault plus 1640Ma accommodation zone and normal fault system Rating: A	Moderately to shallowly dipping Rating: B	River Supersequences Rating: A	Adjacent to Kamarga mineralisation Rating: B	<50m shallow surficial cover Rating: A	2	Largely subcropping area
ZIC24	E: 236390 N: 7923770	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1620Ma, Isan D1	Cover Sequence 2 transfer fault plus 1640Ma accommodation zone Rating: A	Shallow dipping Rating: B	Wide Supersequence partly covered by South Nicholson Basin Rating: A	Some Pb-Zn vein occurrences Rating: B	<50m to Proterozoic; some South Nicholson cover Rating: A	2	
ZIC25	E: 299620 N: 7946790	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640Ma and later events	Cover Sequence 2 and 1640Ma accommodation structures Rating: A	Not known Rating: B	Loretta and River Supersequences Rating: A	Not known Rating: B	50-200m Rating: B	2	
ZIC26	E: 294950 N: 7983500	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640Ma and later events	Targets localised around Cover Sequence 2 accommodation zones and possible Wonga normal faults plus 1640Ma accommodation zones Rating: A	Thrust imbricated package Rating: B	River, Term and Lawn Supersequences Rating: A	Some apparently stratabound Zn-Pb-Ag prospects in target region Rating: B	<50-200m Rating: B	2	
ZIC27	E: 246880 7940960	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640Ma and later events	Cover Sequence 2 transfer faults and 1640Ma accommodation plus normal fault zones Rating: B	Moderately-shallowly dipping Rating: B	Lawn and Wide Supersequences Rating: A	Not known Rating: C	<50m Rating: A	3	
ZIC28	E: 275430 N: 8037110	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640Ma and later events	Within this broad target zone, targets are localised around the intersection of NW-trending 1640Ma accommodation zones and E-W trending normal faults, some of which reactivate Wonga structures Rating: A	Relatively shallow dipping Rating: B	River (and Term, Lawn and Wide) Supersequences Rating: A	Not known Rating: B	0-300m, increasing to the east Rating: B	3	Targets localised around 1640Ma normal fault systems toward southern margin of zone
ZIC29	E: 2882550 N: 8016130	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640Ma and later events	Within this broad target zone, targets are localised around the intersection of NW-trending 1640Ma accommodation zones and E-W trending normal faults, some of which reactivate Wonga structures Rating: A	Relatively shallow dipping Rating: B	River, Term and Lawn Supersequences Rating: A	Not known Rating: B	Depth to Proterozoic 50-400m, increasing eastward. Underlying thick South Nicholson Group Cover Rating: C	3	Broad target zone mainly under thick South Nicholson Group and younger cover

ZIC30	E: 236390 N: 8013220	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640Ma and later events	Cover Sequence 2 normal faults reactivated as 1640Ma transfer faults plus 1640Ma normal faults Rating: B	Relatively shallow dipping Rating: B	Wide Supersequence Rating: A	Minor Pb-Zn occurrences Rating: B	0-50m. Patchy South Nicholson Group Cover Rating: A	2	
ZIC31	E: 219790 N: 8003600	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640Ma and later events	Within this broad target zone, targets are localised around the intersection of NW-trending 1640Ma accommodation zones and E-W trending normal faults, some of which reactivate Wonga structures Rating: A	Relatively shallow dipping Rating: B	Wide Supersequence Rating: A	Minor Pb-Zn occurrences Rating: B	Targets covered by South Nicholson Group Rating: B	2	
ZIC32	E: 195310 N: 8027780	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640, 1620, Isan D1-D3	1640Ma accommodation and normal fault zones over Wonga normal faults Rating: A	Shallow dipping, faulted area Rating: B	River Supersequence, thin on-lap sequence Rating: B	Walford Creek and other Pb-Zn occurrences Rating: A	<50m Rating: A	2	Heavily explored area
ZIC33	E: 345940 N: 8017590	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1640, 1620, Isan D1	1640Ma accommodation and normal fault zones; reactivated Wonga normal faults and Cover Sequence 2 accommodation zones Rating: A	Possible thrust slices of River, Term, Lawn Supersequences. ?Shallowly dipping Rating: B	River, Term and Lawn Supersequences Rating: A	Not known Rating: B	300-1000m Rating: C	3	
ZIC34	E: 337490 N: 7863170	Zinc-lead-silver: Sediment-hosted, Isa-Century style Mineralising Event(s): 1650, 1640Ma	1640Ma accommodation zone and reactivated Wonga fault Rating: B	Open to moderate folding Rating: B	Gun and Loretta Supersequences Rating: B	Minor occurrences of vein-breccia Zn-Pb-Ag Rating: B	<50m Rating: A	2	

TABLE 11.2: BROKEN HILL-CANNINGTON STYLE AG-PB-ZN TARGETS

Identifier	Location (AMG)	Styles	Regional structural setting	Local structural setting	Lithostratigraphic setting	Alteration/Mineralisation indicators	Cover thickness	Overall rating	Comments
	E N	**Target Style and Mineralising Event(s):**	**Key structural elements, geometries and kinematic histories relevant to target style, ie target zone in regional structural context**	**Key structural elements, geometries and kinematic histories relevant to target style – at scale of target zone or prospect**	**Unit(s), lithologies, ages Any key features with respect to target styles)**	**Mineral occurrences of styles related to target Geochemical anomalism Any significant local lithological and alteration features)**	**Depth to Proterozoic basement Estimate of target depths, if possible**		**Any relevant comments, opinions, qualifiers from target generator Historical exploration data, if available**
ZBC1	E: 504830 N: 7537520	Target Style: Silver-lead-zinc: Metasediment- hosted, Broken Hill-Cannington style Mineralising Event/Sequence: D1675, SC2	Adjacent to Cover Sequence 3 transfer fault with right-hand bend Rating: B	Not known Rating: B	Upper Soldiers Cap 2/lower Soldiers Cap 3. Distinctive magnetic low similar to Cannington area. Rating: A	Not known Rating: B	150-200 Rating: A	2	
ZBC2	E: 492900 N: 7583480	Target Style: Silver-lead-zinc: Metasediment-hosted, Broken Hill-Cannington style Mineralising Event/Sequence: D1675, SC2	Complex right-step in Cover Sequence 3 transfer fault. At intersection with Cover Sequence 2 normal fault and transfer fault. Rating: A	Shallow to moderately dipping, folded stratigraphy. Rating: A	Upper Soldiers Cap 2. Broadly psammitic lithologies with interlayered Fe-Ca-Mn rich lithologies. Distinctive magnetically low zone. Rating: A	Cannington Ag-Pb-Zn deposit and Cowie mineralisation. Distinctive Fe-Ca-Mn rich lithologies. Rating: A	<100 Rating: A	1	BHPs successful exploration in this resulted from useful target models and geophysical data
ZBC3	E: 486300 N: 7876760	Target Style: Silver-lead-zinc: Metasediment-hosted, Broken Hill-Cannington style Mineralising Event/Sequence: D1675, SC2	Right-step in Cover Sequence 3 transfer fault. On Cover Sequence 3 normal fault at intersection with Cover Sequence 2 transfer fault. Rating: A	Not known Rating: B	Upper Soldiers Cap 2/lower Soldiers Cap 3. Rating: A	Not known Rating: B	400-500 Rating: C	2	
ZBC4	E: 469790 N: 7841210	Target Style: Silver-lead-zinc: Metasediment-hosted, Broken Hill-Cannington style Mineralising Event/Sequence: D1675, SC2	Adjacent to major Cover Sequence 3 normal fault. At intersection with Cover Sequence 2 normal fault. Rating: A	Not known Rating: B	Upper Soldiers Cap 2/lower Soldiers Cap 3. Rating: A	Not known Rating: B	400-500 Rating: C	2	
ZBC5	E: 469290 N: 7581960	Silver-lead-zinc: Metasediment-hosted, Broken Hill-Cannington style	Major right-step in Cover Sequence 3 transfer fault. Cover Sequence 3 normal fault. Cover Sequence 2 normal fault and transfer fault intersection. Rating: A	Shallow dipping form surfaces. East to east-north-east strike consistent with inversion of Cover Sequence 3 normal. Post-mineralisation granite has cut out significant proportion of target stratigraphy. Rating: B	Upper Soldiers Cap 2 outcropping banded iron formation. Rating: A	Outcropping Broken Hill-Cannington style mineralisation. Distinctive stratabound Fe-rich lithologies around Pegmont. Rating: A	0-50 Rating: A	1	Historically heavily explored, but target zones not exhausted
ZBC6	E: 522740 N: 7655510	Target Style: Silver-lead-zinc: Metasediment-hosted, Broken Hill-Cannington style Mineralising Event/Sequence: D1675, SC2	Cover Sequence 3 normal fault at intersection with: major Cover Sequence 2 transfer fault; and Cover Sequence 2 normal faults. Rating: A	Domal structures with Soldiers Cap 2 in core. Rating: A	Upper Soldiers Cap 2/lower Soldiers Cap 3 - Soldiers Cap 2 only preserved in domes. Rating: B	Not known Rating: B	100-300 Rating: B	2	
ZBC7	E: 493430 N: 7665160	Target Style: Silver-lead-zinc: Metasediment-hosted, Broken Hill-Cannington style Mineralising Event/Sequence: D1675, SC2	Major complex right-step in Cover Sequence 3 transfer fault. Inverted Cover Sequence 3 normal fault. Intersection with Cover Sequence 2 normal faults. Rating: A	Footwall syncline beneath reverse fault (inverted normal). Rating: B	Upper Soldiers Cap 2/lower Soldiers Cap 3. Favourable lithologies in drilling around Eloise. Rating: A	Not known Rating: B	0-150 Rating: A	2	
ZBC8	E: 464000 N: 7714140	Target Style: Silver-lead-zinc: Metasediment-hosted, Broken Hill-Cannington style Mineralising Event/Sequence: D1675, SC2	Major right-step in Cover Sequence 3 transfer fault. Inverted Cover Sequence 3 normal fault. At intersection with Cover Sequence 2 normal fault and transfer fault. Rating: A	Pumpkin Gully fold structure interpreted as inverted Cover Sequence 3 normal fault. Rating: B	Upper Soldiers Cap 2/lower Soldiers Cap 3. Favourable lithologies in outcrop. Rating: A	Minor Pb-Zn mineralisation at Monakoff. Rating: A	0-50 Rating: A	1	
ZBC9	E: 501860 N: 7468400	Target Style: Silver-lead-zinc: Metasediment-hosted, Broken Hill-Cannington style Mineralising Event/Sequence: D1675, SC2	Adjacent to Cover Sequence 3 transfer fault, but no obvious step/bend. At intersection with Cover Sequence 2 transfer fault. Rating: B	Not known Rating: B	Upper Soldiers Cap 2/lower Soldiers Cap 3. Rating: A	Not known Rating: B	400-500 Rating: B	2	

TABLE 11.3: ISA STYLE COPPER TARGETS

Identifier	Location (AMG)	Styles	Regional structural setting	Local structural setting	Lithostratigraphic setting	Alteration/Mineralisation indicators	Cover thickness	Overall rating	Comments
	E **N**	**Target Style and Mineralising Event(s):)**	**Key structural elements, geometries and kinematic histories relevant to target style, ie target zone in regional structural context**	**Key structural elements, geometries and kinematic histories relevant to target style – at scale of target zone or prospect**	**Unit(s), lithologies, ages** **Any key features with respect to target styles**	**Mineral occurrences of styles related to target** **Geochemical anomalism** **Any significant local lithological and alteration features**	**Depth to Proterozoic basement** **Estimate of target depths, if possible**		**Any relevant comments, opinions, qualifiers from target generator** **Historical exploration data, if available**
CUI1	E: 302980 N: 7536720	Isa-style copper Mineralising Event(s): D2-D3	Cover Sequence 2 transfer and Wonga normal faults and D2 thrust fault Rating: A	N-S D2 thrust fault and antiform Rating: A	Isa Superbasin Rating: B	Minor copper showing Rating: B	200-500M Rating: B	2	
CUI2	E: 337520 N: 7557450	Isa-style copper Mineralising Event(s): D2-D3	D2 thrust fault system and projected Wonga normal fault Rating: A	N-S D2 thrust faults Rating: A	Isa Superbasin Rating: B	Not known Rating: B	50-100m Rating: A	2	
CUI3	E: 339440 N: 7579710	Isa-style copper Mineralising Event(s): D2-D3	Buried Cover Sequence 2 accommodation Wonga normal fault D2 thrust faults and D3 transpressional zone Rating: A	N-S D2 thrust faults and faulted antiformal-synformal system Rating: A	Isa Superbasin, probably Prize and Gun Supersequences Rating: B	Minor copper showings in Cover Sequence 2 basement to north Rating: B	<50m, outcropping Rating: A	2	No known surface copper showings in potential host stratigraphy
CUI4	E: 329460 N: 7629046	Isa-style copper Mineralising Event(s): D2-D3	Cover Sequence 2 transfer fault and Barramundi structure plus 1640Ma accommodation zone D2 and D3 thrust fault systems Rating: A	Strongly deformed Steeply dipping Faulted Rating: B	Gun Supersequence Rating: B	Minor copper occurrences in Cover Sequence 3 rocks Uranium copper showings in basement Rating: B	Largely outcropping Rating: A	2	Heavily explored area
CUI5	E: 340590 N: 7684310	Isa-style copper Mineralising Event(s): D2-D3	Possible Cover Sequence 2 normal faults at northern end 1710Ma structures in basement D2 and D3 fault/fold system Rating: A	Steeply dipping Faulted Rating: B	Gun Supersequence, thick and carbonaceous in part Rating: A	Known occurrences of Isa-style copper mineralisation Stratabound pyritic zones Zn-Pb-Ag mineralisation Rating: A	Largely outcropping Rating: A	2	Heavily explored area
CUI6	E: 316220 N: 7694100	Isa-style copper	Wonga normal faults D2-D3 fold/fault systems Rating: B	Tightly folded and faulted Rating: B	Gun Supersequence Rating: B	Minor copper occurrence Rating: B	Largely outcropping Rating: A	3	
CUI7	E: 340790 N: 7718470	Isa-style copper Mineralising Event(s): D2-D3	Cover Sequence 2 accommodation system in north, normal faults in south Wonga normal fault and 1640Ma accommodation structures D2-D3 fold/fault system Rating: A	Moderately-steeply dipping metasediments D3 fold/fault systems Adjacent to N-S Isa fault system Shallow dipping Cover Sequence 2-Cover Sequence 3 fault contact Rating: A	Thick Gun Supersequences Rating: A	Mount Isa copper system Extensive silica-dolomite Pyritic, carbonaceous and dolomite metasediments Rating: A	Proterozoic is largely outcropping Targets are deep, above Cover Sequence 2 basement contact Rating: B	1	Further potential for deep copper targets in Isa-system, south of Hilton
CUI8	E: 314300 N: 7759550	Isa-style copper Mineralising Event(s): D2-D3	E-W, 1640Ma normal fault/D1 thrust fault N-S D2 thrust fault D3 transpressional zone Rating: B	Moderately folded, faulted area Rating: B	Prize and Gun Supersequences Rating: A	Minor Isa-style copper showings Uranium-copper showings in Cover Sequence 2 basement Rating: B	Largely outcropping Rating: A	2	
CUI9	E: 272650 N: 7786420	Isa-style copper Mineralising Event(s): D2-D3	Wonga normal fault D2 thrust fault systems D3 transpressional zone Rating: A	Broad open structures Rating: B	Isa Superbasin Gun Supersequence, mainly (?) Paradise Creek Formation Rating: C	Not known Rating: B	50-200m Rating: B	3	
CUI10	E: 311230 N: 7794480	Isa-style copper Mineralising Event(s): D2-D3	1640 Ma normal faults D2 thrust fault system D3 transpressional fault/fold system Rating: A	Open-moderately folded, reverse faulted area Rating: A	Prize and Gun Supersequences Rating: A	Isa-style copper showings and Mount Kelly copper deposits Local silica-dolomite alteration Rating: A	<50m, outcropping Rating: A	1	Heavily explored area

TABLE 11.3 (continued)

Identifier	Location (AMG)	Styles	Regional structural setting	Local structural setting	Lithostratigraphic setting	Alteration/Mineralisation indicators	Cover thickness	Overall rating	Comments
	E N	Target Style and Mineralising Event(s):)	Key structural elements, geometries and kinematic histories relevant to target style, ie target zone in regional structural context	Key structural elements, geometries and kinematic histories relevant to target style – at scale of target zone or prospect	Unit(s), lithologies, ages Any key features with respect to target styles	Mineral occurrences of styles related to target Geochemical anomalism Any significant local lithological and alteration features	Depth to Proterozoic basement Estimate of target depths, if possible		Any relevant comments, opinions, qualifiers from target generator Historical exploration data, if available
CUI11	E: 324280 N: 7804070	Isa-style copper Mineralising Event(s): D2-D3	Wonga and 1640Ma normal faults D2 thrust faults D3 transpressional fault/fold system Rating: A	Folded, faulted and steeply dipping Rating: B	Prize and Gun Supersequences Rating: A	Numerous Isa-style copper showings Silica-dolomite systems Rating: A	<50m, outcropping Rating: A	1	Extensively explored
CUI12	E: 300290 N: 7803110	Isa-style copper	D2 thrust faults D3 transpressional zone including reverse fault systems Rating: B	Open-to-moderately folded D3 reverse faulted Rating: B	Gun and Loretta Supersequences Rating: A	Minor copper showings Rating: B	<50m Rating: A	3	
CUI13	E: 290500 N: 7810410	Isa-style copper Mineralising Event(s): D2-D3	Buried Wonga normal fault D2 thrust fault and transpressional zone D3 transpressional zone Rating: A	Moderate folding and significant D2-D3 faulting Rating: B	Prize, Gun, Loretta and River Supersequences Rating: A	Stratabound pyrite and Zn-Pb-Ag in carbonaceous and pyritic Lady Loretta Formation Some copper showings and silica-dolomite Rating: A	<100m, some outcropping Proterozoic in east Rating: A	1	Heavily explored area, mainly for Zn-Pb-Ag
CUI14	E: 271500 N: 7813480	Isa-style copper Mineralising Event(s): D2-D3	Cover Sequence 2 accommodation Wonga normal fault D2 thrust faults D3 transpressional zone Rating: A	Open folding and some faulting Rating: B	? River Supersequences Rating: B	Not known Rating: B	100-250m Rating: B	3	
CUI15	E: 328700 N: 7826340	Isa-style copper Mineralising Event(s): D2-D3	?Wonga 1640Ma normal faults D2 thrust faults D3 transpressional zone Rating: A	Target folding and complex faulting Rating: B	Prize and Gun Supersequences Rating: A	Esperanza copper deposit Pyritic and carbonaceous Cover Sequence 3 Local siliceous alteration. Demagnetised zones in basement Rating: A	<50m, outcropping Rating: A	1	
CUI16	E: 334450 N: 7846680	Isa-style copper	Wonga normal fault systems D2 thrust faults D3 transpression and thrusting Rating: A	Open folding, but complexly faulted in Mount Gordon zone Rating: B	Prize and Gun Supersequences Rating: A	Mount Gordon oxide copper system Numerous other small copper showings and siliceous alteration Hydrothermal pyritic zones Rating: A	<50m Rating: A	1	Heavily explored area but further potential for moderate-sized targets
CUI17	E: 280900 N: 7843420	Isa-style copper	Cover Sequence 2 accommodation system Wonga normal fault N-S, D2-D3 fault systems Rating: A	(?) Open folding Rating: B	Loretta and River Supersequences Rating: A	Not known Rating: B	0-250m Rating: B	3	
CUI18	E: 334450 N: 7862230	Isa-style copper	Wonga normal fault D2 thrust faults D3 transpression and thrusting Rating: A	Moderately folded, but complexly faulted in vicinity of Mount Gordon Fault System Rating: B	Prize and Gun Supersequences Rating: A	Minor copper showings Zn-Pb-Ag vein breccia systems Rating: B	<50m Rating:	2	
CUI19	E: 387810 N: 7882290	Isa-style copper Mineralising Event(s): D2-D3	D2 thrust faults D3 transpression and thrust zones Rating: B	D2 open folds D3 thrust imbrication Rating: B	Isa Superbasin Rating: B	Not known Numerous small copper showings in similar settings to south Rating: B	<50m south to >500m in north Rating: B	3	Potential targets in this large area are confined to areas of intersection of D2-D3 structures in appropriate lithostratigraphy
CUI20	E: 300480 N: 7889670	Isa-style copper Mineralising Event(s): D1-D3	1640Ma normal faults reactivated as D1 thrust faults D2 fold systems Rating: B	Open-to-moderate folding Rating: B	Gun, Loretta and River Supersequences Rating: A	Minor copper occurrences Rating: B	<50m Rating: A	3	

CUI21	E: 266130 N: 7914810	Isa-style copper Mineralising Event(s): D1-D3	Cover Sequence 2 accommodation zone 1640Ma normal and buried transfer fault system, reactivated in D1 Rating: B	Open-to-moderate folding Rating: B	Gun, Loretta and River Supersequences Rating: A	Minor copper and Pb-Zn-Ag showings Rating: B	<50m Rating: A	3	
CUI22	E: 301400 N: 7905500	Isa-style copper Mineralising Event(s): D1-D2	As for ZIC Targets 21, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33 Rating: C	As for ZIC Targets 21, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33 Rating: C	As for ZIC Targets 21, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33 Rating: C	Not known or minor, fault-related copper showings Rating: C	As for ZIC Targets 21, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33 Rating: C	3	Copper targets in these areas, which correspond to Isa-Century style target zones, are long shots. Most of these areas lack strong D2-D3 structures and deformation and are of subgreenschist facies metamorphic grades. However, mineralisation comparable with Isa-copper styles, but forming at lower temperatures and involving pyrite replacement is possible in the Zn-Pb-Ag target areas. Minor, fault-related occurrences are known to the west of Walford Creek. Possible targets relate to E-W, D1 fault systems, particularly where these intersect NW-oriented structures. Appropriate target lithostratigraphy would be carbonaceous, pyritic units.

TABLE 11.4: CU-AU TARGETS

Identifier	Location (AMG)	Styles	Regional structural setting	Local structural setting	Lithostratigraphic setting	Alteration/ Mineralisation indicators	Cover thickness	Overall rating
	E N	Target Style and Mineralising Event(s)	Key structural elements, geometries and kinematic histories relevant to target style, ie target zone in regional structural context	Key structural elements, geometries and kinematic histories relevant to target style – at scale of target zone or prospect	Unit(s), lithologies, ages Any key features with respect to target styles	Mineral occurrences of styles related to target Geochemical anomalism Any significant local lithological and alteration features	Depth to Proterozoic basement Estimate of target depths, if possible	
CGM1	E 467760 N 7438490	Magnetite-rich, Ernest Henry style Mineralising Event: Wonga? Or Williams age plutonism	within a zone of detachment faults, Wonga aged, folded during D2 with NE-trending fold axis. Pre D2 extensional structures reactivated during D2 & D3, with interpreted reverse displacements Rating: B	Magnetic bodies cluster within fold axis, north of complexly reactivated older faults including late D2 transfer faults. Rating: A	Unit(s): ?Corella age metasediments and Wonga age felsic igneous bodies in close proximity. Lithologies: Not exposed, units based on magnetic interpretation Rating: A	high amplitude magnetic anomalies within a broad zone of anomalously high magnetism Rating: A	500-1000m, Phanerozoic cover Rating: C	3
CGM2	E 453030 N 7477850	Magnetite-rich, Ernest Henry style Mineralising Event: Wonga? Or Williams age plutonism	within a zone of detachment faults, Wonga aged, folded during D2 with NE-trending fold axis. Pre D2 extensional structures reactivated during D2 & D3, with interpreted reverse displacements Rating: B	Magnetic bodies cluster within fold axis but slightly–moderately discordant to the regional structural grain. Rating: A	Unit(s): ?Corella age metasediments and Wonga age felsic igneous bodies in close proximity. Lithologies: Not exposed, units based on magnetic interpretation Rating: A	high amplitude magnetic anomalies Rating: A	500-1000m, Phanerozoic cover Rating: C	3
CGM3	E 469030 N 7482170	Magnetite-rich, Ernest Henry style Mineralising Event: Wonga? Or Williams age plutonism	within the upper plate stratigraphy of the regional Wonga aged detachment fault zone Pre D2 extensional structures reactivated during D2 & D3, with interpreted reverse displacements Rating:B	Magnetic bodies cluster along a D2 reverse fault zone & slightly –moderately discordant to the regional structural grain. Rating:A	Unit(s): ?Corella age metasediments and Wonga age felsic igneous bodies in close proximity. Lithologies: Not exposed, units based on magnetic interpretation Rating:A	high amplitude magnetic anomalies Rating:A	200-400m, Phanerozoic cover Rating:B	3
CGM/CGR4	E 463950 N 7499690	Magnetite-rich, Ernest Henry style Mineralising Event: Wonga? Or Williams age plutonism	within the upper plate stratigraphy of the regional Wonga aged detachment fault zone Pre D2 extensional structures reactivated during D2 & D3 with reverse and strike slip displacements Based on gravity, located in the roof on the western edge of the Williams Batholith interpreted at depth Rating: A	Late NW trending fault, interpreted active during D3 features of interest located in left step of fault with interpreted left lateral displacement (ie dilational step) Williams age igneous body interpreted at depth Rating: A	Unit(s): Answer slate metasediment equivalents and Williams age igneous body interpreted at depth Lithologies: Not exposed, units based on magnetic interpretation Rating: A	Small intrusive body, not unroofed, with a high amplitude magnetic zone in roof Southern most intrusion, part of a series which cluster along deformed & reactivated extensional structures. Osborne & Starra Cu-Au deposits located on these intrusions to north Rating:A	200-500m, Phanerozoic cover Rating: B	2
CGM5	E 460140 N 7487250	Magnetite-rich, Ernest Henry style Mineralising Event: Wonga? Or Williams age plutonism	within the upper plate stratigraphy of the regional Wonga aged detachment fault zone Pre D2 extensional structures reactivated during D2 & D3 with reverse and strike slip displacements Rating: B	Possible magnetic zone along a D2 reverse fault zone Interpreted magnetic body within regional structural bend (interpreted Fe-stone bends NW-N-NW. North trending segment potentially dilational. Rating: A	Unit(s): ?Corella age metasediments and Wonga age felsic igneous bodies in close proximity. Lithologies: Not exposed, units based on magnetic interpretation Rating: A	high amplitude magnetic anomaly. Rating: A	400-500m, Phanerozoic cover Rating: C	3
CGM6	E 453290 N 7498670	Magnetite-rich, Ernest Henry style Mineralising Event: Wonga? Or Williams age plutonism	within a zone of detachment faults, Wonga aged, folded during D2 with NE-trending fold axis. Pre D2 extensional structures reactivated during D2 & D3, with interpreted reverse displacements Rating: B	Along a regional detachment fault zone, on the eastern limb of a NE trending anticline High amplitude magnetic body located where minor NE and ENE trending late structures possibly offset & deform the older detachment surface. Rating: A	Unit(s): ?Corella age metasediments and Wonga age felsic igneous bodies in close proximity. Lithologies: Not exposed, units based on magnetic interpretation Rating: A	high amplitude magnetic anomaly within a broad zone of elevated magnetic response Rating: A	500-1000m, Phanerozoic cover Rating: C	3
CGM/CGR7	E 464210 N 7526860	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	within the upper plate stratigraphy of the regional Wonga aged detachment fault zone (possibly reflected by the broad wavelength magnetic high underlying the area Pre D2 extensional structures reactivated during D2 & D3 with reverse and strike slip displacements Based on gravity, located in the roof on the western edge of the Williams Batholith interpreted at depth Rating: A	NE-trending, D2-D3 transfer faults, possibly reactivating along earlier normal fault, controlling deposition of interpreted Answer Slate equivalents. Thrust fault stacking of older levels of soldiers cap stratigraphy to the N-NW Rating: A	Unit(s): Soldiers Cap metasediments, (including likely graphitic siltstones). Stratigraphy thrust stacked and likely isoclinally folded Lithologies: Not exposed, units based on magnetic interpretation Rating: A	Small intrusive body, not unroofed, with a moderate amplitude magnetic zone in roof One of several intrusions, part of a series which cluster along deformed & reactivated extensional structures & D2 reverse faults. Osborne & Starra Cu-Au deposits located on this series of intrusions to north. Rating: A	50-400m, Phanerozoic cover Rating: A	2

CGM/CGR8	E 454050 N 7555040	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	within the upper plate stratigraphy of the regional Wonga aged detachment fault zone (possibly reflected by the broad wavelength magnetic high underlying the area) Pre D2 extensional structures reactivated during D2 & D3 with reverse and strike slip displacements Based on gravity, located in the roof on the western edge of the Williams Batholith interpreted at depth Rating: A	NE-trending, D2-D3 transfer faults, possibly reactivating along earlier normal fault, controlling deposition of interpreted Answer Slate equivalents. Thrust fault stacking of older levels of soldiers cap stratigraphy to the N-NW Rating: A	Unit(s): Soldiers Cap metasediments, (including likely graphitic siltstones). Stratigraphy thrust stacked and likely isoclinally folded Lithologies: Not exposed, units based on magnetic interpretation Rating: A	Small intrusive body, not unroofed, with a high amplitude anomaly of the northern edge, in roof One of several intrusions, part of a series which cluster along deformed & reactivated extensional structures & D2 reverse faults. Osborne & Starra Cu-Au deposits located on this series of intrusions to NW. Rating: A	0-300m, Phanerozoic cover Rating: A	2
CGM/CGR9	E 437040 N 7560880	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	within the upper plate stratigraphy of the regional Wonga aged detachment fault zone (possibly reflected by the broad wavelength magnetic high underlying the area) Pre D2 extensional structures reactivated during D2 & D3 with reverse and strike slip displacements Based on gravity, located in the roof on the western edge of the Williams Batholith interpreted at depth Rating: A	NE-trending, D2-D3 transfer faults, possibly reactivating along earlier normal fault, controlling deposition of interpreted Answer Slate equivalents. Stratigraphy thrust stacked and likely isoclinally folded Rating: A	Unit(s): Soldiers Cap metasediments, (including likely graphitic siltstones). Stratigraphy thrust stacked and likely isoclinally folded Lithologies: Not exposed, units based on magnetic interpretation Rating: A	Small intrusive body, not partially unroofed, with a high amplitude magnetic aureole and magnetic anomalies along older extensional and D2/D3 thrust faults One of several intrusions, part of a series which cluster along deformed & reactivated extensional structures & D2 reverse faults. Covers Osborne Cu-Au deposit Rating: A	200-1000m, Phanerozoic cover Rating: B	2
CGM/CGR10	E 440690 N 7576750	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	Northern edge of pluton, possibly in roof zone, above pluton edge (magnetic signature) NS trending, E dipping faults and folds Rating: A	NE-trending, moderately dipping shear zones interpreted minor NW trending D2/D3 structures (transfer faults) Rating: A	Unit(s): Soldiers Cap age metasediments and metadolerite Lithologies: Possible carbonaceous metasiltstones Rating: A	magnetic aureole to pluton with high amplitude magnetic anomaly on the northern contact and extending along a NNE structure covers the Osborne Cu-Au deposit. Rating: A	<200m, Phanerozoic cover Rating: A	1
CGM/CGR/ CGH11	E 444220 N 7597000	Magnetite-rich, Ernest Henry style and Magnetite-poor, reduced & hematitic Mineralising Event: Williams age plutonism	a northerly trending high strain zone interpreted as a detachment fault around the edge of older and Williams age plutons Rating: A	Magnetite bodies in regional inflections or folds or discordant to the regional northerly trend of most interest Detachment fault zone interpreted to juxtaposing Corella age calcsilcates and lower Soldiers Cap metasediments; therefore detachment either Wonga with reactivation during D2 shortening, or ~1670Ma extension detachment fault. Rating: A	Unit(s): Corella &Soldiers Cap aged metasediments and metadolerite Lithologies: Possible carbonaceous metasiltstones Rating: A	linear magnetic zone containing numerous high amplitude magnetic anomalies ('Fe-stones') partial weak spatial association with positive U anomalies within the northern segment hosts the Starra, Mount Dore etc. Cu-Au deposits Rating: A	Proterozoic subcrop - outcrop and Phanerozoic cover <200m Rating: A	1
CGM/CGR12	E 451280 N 7600290	Magnetite-poor, reduced style Mineralising Event: Williams age plutonism	within hanging wall of NNE trending, E dipping D2 thrust fault sequence isoclinally folded and overturned ?, NNE trending folds Rating: A	Magnetic zone parallel to the interpreted D2 structures at the projected intersection of late D2/D3 NE trending faults Rating: A	Unit(s): Soldiers Cap aged metasediments and metadolerite Lithologies: Includes deformed carbonaceous Rating: A	Small linear high amplitude magnetic anomaly	Proterozoic subcrop - outcrop Rating: A	2
CGM/CGR/ CGH13	E 436920 N 7605710	Magnetite-rich, Ernest Henry style & Magnetite-poor, reduced & hematitic Mineralising Event: Williams age plutonism	the folded northern extent of the northerly trending high strain zone interpreted as a detachment fault which host the Starra deposits to the E around the edge of older and Williams age plutons Rating: A	Magnetite bodies localized in the detachment zone, both discordant and conformable to the regional structure. Detachment fault zone interpreted to juxtaposing Corella age calcsilcates and lower Soldiers Cap metasediments; therefore detachment either Wonga with reactivation during D2 shortening, or ~1670Ma extension detachment fault. Rating: B	Unit(s): Corella & Soldiers Cap aged metasediments and metadolerite Lithologies: Possible carbonaceous metasiltstones Rating: A	folded magnetic zone containing numerous high amplitude magnetic anomalies ('Fe-stones') continuation of the zone hosts the Starra, Mount Dore etc. Cu-Au deposits to the E Rating: A	Proterozoic subcrop - outcrop Rating: A	2
CGM/CGR14, CGM/CGR17 & CGM/CGR18	CGM/CGR14: E 428210 N 7602650 CGM/CGR17: E 424910 N 7622190 CGM/CGR18: E 428690 N 7630080	Magnetite-rich, Ernest Henry style & Magnetite-poor, reduced & hematitic Mineralising Event: Williams age plutonism	on regional structures intersecting and parallel (but just outboard) of Williams aged plutons interpreted N trending fault contact between Argylla and Marraba Volcanics N trending regional fault interpreted as an early extensional sidewall fault, with possible reverse reactivation during D2/D3 Rating: A	NE-trending bends or magnetic zones in the overall N trending stratigraphy Rating: B	Unit(s): contact between Argylla and Marraba Volcanics Lithologies: Not mapped, but potential for thin calcsilicate & deformed carbonaceous metasiltstones Rating: A	numerous small high amplitude magnetic anomalies in a linear belt Rating: B	Proterozoic subcrop - outcrop Rating: A	2

TABLE 11.4 (continued)

Identifier	Location (AMG)	Styles	Regional structural setting	Local structural setting	Lithostratigraphic setting	Alteration/ Mineralisation indicators	Cover thickness	Overall rating
	E N	Target Style and Mineralising Event(s)	Key structural elements, geometries and kinematic histories relevant to target style, ie target zone in regional structural context	Key structural elements, geometries and kinematic histories relevant to target style – at scale of target zone or prospect	Unit(s), lithologies, ages Any key features with respect to target styles	Mineral occurrences of styles related to target Geochemical anomalism Any significant local lithological and alteration features	Depth to Proterozoic basement Estimate of target depths, if possible	
CGM/CGR15	E 447280 N 7619600	Magnetite-poor, reduced & hematitic Mineralising Event: Williams age plutonism	within hanging wall of NNE trending, E dipping D2 thrust fault within a regional scale inflection in the strike of D2 structures (thrusts & folds) sequence isoclinally folded and overturned ?, NNE trending folds Rating: A	NNW-trending D2 thrust fault Near the edge of Williams age batholith Rating: A	Unit(s): Soldiers Cap aged metasediments and metadolerite Lithologies: Possible carbonaceous metasiltstones Rating: A	high amplitude magnetic anomalies strong spatial association with U in airborne radiometrics area covers Mount Elliot Cu-Au deposit Rating: A	Proterozoic subcrop - outcrop Rating: A	1
CGM/CGR16	E 441510 N 7622190	Magnetite-poor, reduced & hematitic Mineralising Event: Williams age plutonism	within hanging wall of NNE trending, E dipping D2 thrust fault within a regional scale inflection in the strike of D2 structures (thrusts & folds) sequence isoclinally folded and overturned ?, NNE trending folds Rating: A	On or footwall of NNW-trending D2 thrust fault Near the edge of Williams age batholith Rating: B	Unit(s): Lower & upper Soldiers Cap aged metasediments and metadolerite Lithologies: Possible carbonaceous metasiltstones Rating: A	Small isolated high amplitude magnetic anomalies Rating: B	Proterozoic subcrop - outcrop Rating: A	2
CGM/CGR19	E 441750 N 7635970	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	within hanging wall of NNE trending, E dipping D2 thrust faults within a regional scale inflection in the strike of D2 structures (thrusts & folds) sequence isoclinally folded and overturned ?, NNE trending folds Rating: A	magnetic targets located along a late NNW trending D2/ D3? Fault Rating: B	Unit(s): Lower & upper Soldiers Cap aged metasediments and metadolerite Lithologies: Possible carbonaceous metasiltstones Rating: A	small high amplitude magnetic anomalies weak spatial association with U in airborne radiometrics Rating: B	Proterozoic subcrop – outcrop Rating: A	2
CGM20	E 474830 N 7589580	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	within Williams age batholith Rating: A	within a corridor of WNW trending late D2/D3 faults Rating: A	Unit(s): Squirrel Hills Granite Rating: B	Medium sized high amplitude magnetic anomaly Rating: B/A	Proterozoic subcrop – outcrop Rating: A	2
CGM21	E 499900 N 7585110	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	Within an interpreted late Williams aged pluton At the intersection of a complex zone of reactivated early extensional faults, reactivated as D2 reverse faults and D3 strike slip faults Rating: A	within a corridor of NW trending late D2/D3 faults Rating: A	Unit(s): Upper Soldiers Cap aged metasediments and metadolerite Lithologies: Possible carbonaceous metasiltstones Rating: A	Medium sized high amplitude magnetic anomaly Rating: A	<100m, Phanerozoic cover Rating: A	1
CGM/CGR22	E 504970 N 7612770	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	At the edge of an interpreted late Williams aged pluton Rating: B	within a corridor of NW trending late D2/D3 faults Rating: B	Unit(s): Upper Soldiers Cap aged metasediments and metadolerite Lithologies: Possible carbonaceous metasiltstones Rating: A	small medium amplitude magnetic high Rating: A	200-250m, Phanerozoic cover Rating: A	2
CGM/CGR23	E 501320 N 7639140	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	major N trending, east dipping thrust stack thrusting is localized along a Soldiers Cap age basin margin fault zones (e.g. Cloncurry Fault) which are reactivated Rating: A	at the intersection of a NW trending fault and an interpreted D2 thrust duplex. Rating: A	Unit(s): Upper Soldiers Cap aged metasediments and metadolerite Lithologies: Possible carbonaceous metasiltstones Rating: A	small high amplitude magnetic high discordant to the dominant northerly structural/stratigraphic grain Rating: A	50-100m, Phanerozoic cover Rating: A	1
CGR24	E 448460 N 7643740	Magnetite poor, reduced style Mineralising Event: Williams age plutonism	Zone of N trending faults Rating: A	N trending, E dipping D2 fault, possibly reactivated during D3 Rating: B	Unit(s): Kuridala Formation metasediments & metadolerite (ie upper Soldiers Cap equivalent) Lithologies: carbonaceous slates/metasiltstones Rating: A	Very small high & low amplitude magnetic anomalies along the N trending fault zone Cu-Au mineralisation confirmed along the fault zone (historical mining Hampden mine) Rating: A	Proterozoic subcrop – outcrop Rating: A	2
CGM/CGR25	E 493550 N 7661390	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	major N trending, east dipping thrust stack thrusting is localized along a Soldiers Cap age basin margin fault zones (e.g. Cloncurry Fault) which are reactivated Rating: A	within a pluton, and in the roof zone above pluton edge – pluton possibly partly unroofed Rating: A	Unit(s): Lower Soldiers Cap aged metasediments and metadolerite Lithologies: Possible carbonaceous metasiltstones Rating: A	small high amplitude magnetic high discordant to the dominant northerly structural/stratigraphic grain regional structural grain Rating: B	<100m, Phanerozoic cover Rating: A	2

CGM/CGR26	E 493550 N 7684940	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	major N trending, east dipping thrust stack Rating: A	Within a corridor of minor NW trending, late D2/D3 faults at the intersection the N trending thrust faults Rating: A	Unit(s): Upper Soldiers Cap aged metasediments and metadolerite Lithologies: Possible carbonaceous metasiltstones Rating: A	small high amplitude magnetic anomalies Covers the Osborne Cu-Au deposit area. Rating: A	0-200m, Phanerozoic cover Rating: A	1
CGM/CGR27	E 479540 N 7676350	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	In the hanging wall of N trending, E dipping thrusts Rating: A	near the contact of a Williams aged pluton Rating: A	Unit(s): Lower Soldiers Cap aged metasediments and metadolerite - Mount Norna Quartzite Lithologies: Rating: A	small high amplitude magnetic high discordant to the dominant northerly structural/stratigraphic grain regional structural grain strong spatial association with U in airborne radiometrics A Rating: B	Proterozoic subcrop – outcrop Rating: A	2
CGM/CGR28	E 475540 N 7641730	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	near the contact of a Williams aged pluton, possibly in the roof of a larger sheet like intrusive body complex zone of early extensional faults reactivated as reverse faults during D2 and strike-slip faults during D3 (Cloncurry Fault) Rating: A	Within the contact of a Williams aged pluton Late D2/D3 steps in the Cloncurry fault across similarly late NW trending faults Rating: A	Unit(s): ?Corella age metasediments and calcsilicate breccias Lithologies: Possible carbonaceous metasiltstones Rating: A	Numerous small-medium sized, complex & folded, high amplitude magnetic anomalies within broader domains of anomalous highs Some magnetic bodies with weak to strong spatial association with U in airborne radiometrics Rating: A	Proterozoic subcrop – outcrop Rating: A	1
CGM/CGR29	E 466120 N 7641500	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	near the contact of a Williams aged pluton, possibly in the roof of a larger sheet like intrusive body Rating: B	Within corridor of NW trending late D2/D3 faults Rating: B	Unit(s): ?Corella age metasediments and calcsilicate breccias Lithologies: Possible carbonaceous metasiltstones Rating: A	Numerous small-medium sized, complex & folded, high amplitude magnetic anomalies Some magnetic bodies with a strong spatial association with U in airborne radiometrics Rating: A	Proterozoic subcrop – outcrop Rating: A	2
CGM/CGR30	E 464000 N 7659280	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	possibly in the roof of a large sheet like Williams aged intrusive body (as per the Squirrel Hills Granite) Rating: B	near the contact of a Williams aged pluton Rating: B	Unit(s): ?Corella age metasediments and calc-silicate breccias Lithologies: Rating: A	small high amplitude magnetic anomalies weak spatial association with U in airborne radiometrics numerous historical Cu-Au workings (e.g. Bosca Mine) Rating: A	Proterozoic subcrop – outcrop Rating: A	2
CGM/CGR31	E 455880 N 7651390	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	possibly in the roof of a large sheet like Williams aged intrusive body (as per the Squirrel Hills Granite) Rating: B	NW trending late D2/D3 fault Rating: B	Unit(s): ?Corella age metasediments and calcsilicate breccias Lithologies: Possible carbonaceous metasiltstones Rating: A	small high amplitude magnetic anomalies strong spatial association with U in airborne radiometrics numerous historical Cu-Au workings (e.g. Bosca Mine) Rating: A	Proterozoic subcrop – outcrop Rating: A	2
CGM/CGR32	E 459410 N 7659630	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	possibly in the roof of a large sheet like Williams aged intrusive body (as per the Squirrel Hills Granite) Rating: B	NW trending late D2/D3 fault Rating: B	Unit(s): ?Corella age metasediments and calcsilicate breccias Lithologies: Possible carbonaceous metasiltstones Rating: A	small high amplitude magnetic anomalies Numerous historical Cu-Au workings (e.g. Bosca Mine) Rating: A	Proterozoic subcrop – outcrop Rating: A	2
CGM/CGR33	E 450690 N 7660810	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	possibly in the roof of a large sheet like Williams aged intrusive body (as per the Squirrel Hills Granite) Rating: B	NE trending late D2/D3 fault Near the contact of a small Williams aged pluton Rating: B	Unit(s): ?Corella age metasediments and calcsilicate breccias Lithologies: Possible carbonaceous metasiltstones Rating: A	small high amplitude magnetic anomalies strong spatial association with U in airborne radiometrics numerous historical Cu-Au workings (eg. Bosca Mine) Rating: A	Proterozoic subcrop – outcrop Rating: A	3
CGM/CGR34	E 455520 N 7667050	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	possibly in the roof of a large sheet like Williams aged intrusive body (as per the Squirrel Hills Granite) Rating: B	NW trending late D2/D3 fault Rating: B	Unit(s): ?Corella age metasediments and calcsilicate breccias Lithologies: Possible carbonaceous metasiltstones Rating: A	small high amplitude magnetic anomalies strong spatial association with U in airborne radiometrics numerous historical Cu-Au workings (e.g. Bosca Mine) Rating: A	Proterozoic subcrop – outcrop Rating: A	2
CGM/CGR35	E 445630 N 7671990	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	western edge/ roof of a large sheet like Williams aged intrusive body (as per the Squirrel Hills Granite) Rating: B	NNW trending, E dipping D2 thrust faults Rating: B	Unit(s): ?Corella age metasediments and calcsilicate breccias Lithologies: Possible carbonaceous metasiltstones Rating: A	small high amplitude magnetic anomalies strong spatial association with U in airborne radiometrics numerous historical Cu-Au workings (e.g. Bosca Mine) Rating: A	Proterozoic subcrop – outcrop Rating: A	2

TABLE 11.4 (continued)

Identifier	Location (AMG)	Styles	Regional structural setting	Local structural setting	Lithostratigraphic setting	Alteration/ Mineralisation indicators	Cover thickness	Overall rating
	E N	Target Style and Mineralising Event(s)	Key structural elements, geometries and kinematic histories relevant to target style, ie target zone in regional structural context	Key structural elements, geometries and kinematic histories relevant to target style – at scale of target zone or prospect	Unit(s), lithologies, ages Any key features with respect to target styles	Mineral occurrences of styles related to target Geochemical anomalism Any significant local lithological and alteration features	Depth to Proterozoic basement Estimate of target depths, if possible	
CGM/CGR36	E 456820 N 7678580	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	possibly in the roof of a large sheet like Williams aged intrusive body (as per the Squirrel Hills Granite) Rating: B	minor NNW trending late D2/D3 fault, parallel to the Cloncurry fault Rating: B	Unit(s): ?Corella age metasediments and calcsilicate breccias Lithologies: Possible carbonaceous metasiltstones Rating: A	small high amplitude magnetic anomalies strong coincident association with U in airborne radiometrics numerous historical Cu-Au workings (e.g. Bosca Mine) Rating: A	Proterozoic subcrop – outcrop Rating: A	2
CGM/CGR37	E 466350 N 7674110	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	complex zone of early extensional faults reactivated as reverse faults during D2 and strike-slip faults during D3 (Cloncurry Fault) Rating: A	Magnetic zones partly concentrated along Williams age pluton contact Rating: B	Unit(s): ?Corella age metasediments and calcsilicate breccias, and lower (mainly Llewellyn Creek Formation & Mount Norna Quartzite) and some upper Soldiers Cap Lithologies: Possible carbonaceous metasiltstones Rating: A	Numerous small-medium sized, complex & folded, high amplitude magnetic anomalies within broader domains of anomalous highs weak to moderate spatial association with U in airborne radiometrics numerous historical Cu-Au workings in proximity Rating: A	Proterozoic subcrop – outcrop Rating: A	2
CGM/CGR38	E 475420 N 7684470	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	minor N trending, east dipping thrust stack in the Weatherly Creek Toole Creek Syncline Rating: A	Within a corridor of minor NW trending, late D2/D3 faults at the intersection the N trending thrust faults Thrust cut the contact of a Williams aged pluton Rating: A	Unit(s): Upper Soldiers Cap aged metasediments and metadolerite – Base of the Toole Creek Volcanics – same stratigraphic level hosts Osborne Cu-Au deposit to SE Lithologies: Possible carbonaceous metasiltstones Rating: A	small high amplitude magnetic anomalies strong coincident association with U in airborne radiometrics numerous historical Cu-Au workings (e.g. Bosca Mine) Rating: A	Proterozoic subcrop – outcrop Rating: A	1
CGM/CGR39	E 440450 N 7672340	Magnetite-rich & Magnetite-poor, reduced Mineralising Event: Williams age plutonism	Wonga ? aged regional scale N trending high strain zone/detachment fault, Soldiers Cap aged basin sidewall fault Rating: A	Older structure reactivated and focus for ~ N trending, E dipping D2 reverse faults, resulting in basin inversion of Marimo slates etc. to the east N trending faults intersect Williams aged pluton to the south Rating: A	Unit(s): Marraba Volcanic, Overhang Jasperlite, ?Corella metasediments and calcsilicate breccias Lithologies: Possible carbonaceous metasiltstones Rating: A	numerous small linear & complexly folded high amplitude magnetic bodies weak to moderate spatial association with U in airborne radiometrics Minor historical Cu-Au working throughout the area Rating: A	Proterozoic subcrop – outcrop Rating: A	1
CGM/CGR40	E 434210 N 7661510	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	magnetic zone along the northern contact of a large zoned Williams aged pluton Rating: B	Magnetite alteration possibly controlled by early (cover sequence 2 ? normal) extensional fault oriented ENE. Rating: B	Unit(s): Argylla and Marraba metavolcanic and sediments Lithologies: Possible carbonaceous metasiltstones Rating: A	Broad zone of elevated magnetism with large high amplitude magnetic bodies Segments of the peaks of the high with similar orientation to the Ernest Henry anomaly Rating: A	Proterozoic subcrop – outcrop Rating: A	2
CGM/CGR41	E 401720 N 7652800	Magnetite-rich, Ernest Henry style Mineralising Event: Williams age plutonism	magnetic zone extending from the contact of a large zoned Williams aged pluton Rating: B	Magnetite alteration possibly controlled by early extensional fault oriented ENE. Rating: C/A	Unit(s): Argylla and Marraba metavolcanic and sediments Lithologies: Possible carbonaceous metasiltstones Rating: A	Broad zone of elevated magnetism with a large high amplitude magnetic body, a segment of the anomaly discordant to the structural grain Rating: A	Proterozoic subcrop – outcrop Rating: A	3
CGM/CGR42	E 378290 N 760090	Magnetite-rich, Ernest Henry style Mineralizing Event: Wonga? Or Williams age plutonism	Within the Wonga detachment zone Proximal to Wonga aged intrusions Complex zone of regional scale N and NE trending D3 wrench faults Rating: B	intersecting N and NE trending D3 faults structure N & S outside of target box also of interest despite subdued magnetic response Rating: A	Unit(s): Argylla and Corella metasediments and metavolcanics Lithologies: Possible carbonaceous metasiltstones Rating: A	small high amplitude magnetic anomalies Rating: B	Proterozoic subcrop – outcrop Rating: A	2
CGM/CGR43	E 385470 N 7671400	Magnetite-rich, Ernest Henry style Mineralizing Event: Wonga? Or Williams age plutonism	Within the Wonga detachment zone Proximal to Wonga aged intrusions Complex zone of regional scale N and NE trending D3 wrench faults Rating: B	intersecting N trending stratigraphy/structures and NE trending D3 faults Rating: A	Unit(s): Argylla and Corella metasediments and metavolcanics Lithologies: Possible carbonaceous metasiltstones Rating: A	small high amplitude magnetic anomalies Rating: B	Proterozoic subcrop – outcrop Rating: A	2

CGM/CGR44	E 387480 N 7694000	Magnetite-rich, Ernest Henry style Mineralizing Event: Wonga? Or Williams age plutonism	Proximal to Wonga aged intrusions Complex zone of regional scale N and NE trending D3 wrench faults Rating: C	intersecting N trending stratigraphy/structures and NE trending D3 faults complex, folded "ironstones" Rating: B	Unit(s): Argylla and Corella metasediments and metavolcanics Lithologies: Possible carbonaceous metasiltstones Rating: A	small high amplitude magnetic anomalies Rating: B	Proterozoic subcrop – outcrop Rating: A	3
CGM/CGR45	E 395130 N 7693180	Magnetite-rich, Magnetite-poor, reduced Mineralizing Event: Wonga? Or Williams age plutonism	Proximal to Wonga & Williams aged intrusions Complex interaction zone of regional scale early extensional faults Along a major D3 fault zone Rating: B	Complex zone of folded magnetic anomalies at the intersection of major NE trending D3 fault and NS structures/stratigraphy Rating: A	Unit(s): Argylla and Corella metasediments and metavolcanics Lithologies: Possible carbonaceous metasiltstones Rating: A	small high amplitude magnetic anomalies Rating: A	Proterozoic subcrop – outcrop Rating: A	1
CGM/CGR46	E 402780 N 7692590	Magnetite-rich, Magnetite-poor, reduced Mineralizing Event: Wonga? Or Williams age plutonism	Wonga ? aged regional scale N trending high strain zone/detachment fault, on western overturned limb of D2 fold Rating: A	Older structure reactivated and focus for~ N NE trending, E dipping D2 reverse faults, and subsequently reactivated as D3 Wrench fault. Rating: A	Unit(s): Marraba Volcanic, Overhang Jasperlite, ?Corella metasediments and calcsilicate breccias Lithologies: Possible carbonaceous metasiltstones Rating: A	Thin linear & complexly folded high amplitude magnetic bodies Minor historical Cu-Au working throughout the area Rating: A	Proterozoic subcrop – outcrop Rating: A	1
CGM/CGR47	E 407250 N 7698010	Magnetite-rich, Magnetite-poor, reduced Mineralizing Event: Wonga? Or Williams age plutonism	Wonga ? aged regional scale N trending high strain zone/detachment fault, Rating: A	Older structure reactivated and focus for ~ NE trending, NW dipping D2 reverse faults (back thrusts), Adjacent to a regional NE trending D3 fault Proximal to small Williams aged intrusions Rating: A	Unit(s): Marraba Volcanic, Overhang Jasperlite, ?Corella metasediments and calcsilicate breccias Lithologies: Possible carbonaceous metasiltstones Rating: A	thin linear high amplitude magnetic body Minor historical Cu-Au mine along strike Rating: A	Proterozoic subcrop – outcrop Rating: A	1
CGM/CGR48	E 407960 N 7701540	Magnetite-rich, Ernest Henry style Mineralizing Mineralizing Event: Wonga? Or Williams age plutonism	Proximal to Wonga & Williams aged intrusions Adjacent to - along a major NE trending D3 fault zone Rating: B	Proximal to small Williams aged intrusions Rating: C	Unit(s): Corella metasediments and Tommy Creek metasediments & volcanic/intrusive rocks Lithologies: Possible carbonaceous metasiltstones Rating: A	small linear moderate to high amplitude magnetic bodies weak to moderate spatial association with U in airborne radiometrics Minor historical Cu-Au working to the east Rating: A	Proterozoic subcrop – outcrop Rating: A	3
CGM/CGR49	E 411490 N 7710960	Magnetite-rich, Ernest Henry style Mineralizing Event: Wonga? Or Williams age plutonism	Proximal to Wonga & Williams aged intrusions Within a complex interaction zone of regional scale early extensional faults Along a major D3 fault zone Rating: A	NE geometry of the broader magnetic and NE trends of the high amplitude magnetic bodies similar to Ernest Henry Proximal to small Williams aged intrusions Rating: A	Unit(s): Corella metasediments and Tommy Creek metasediments & volcanic/intrusive rocks Lithologies: Possible carbonaceous metasiltstones Rating: A	small high amplitude magnetic anomalies Rating: A	Proterozoic subcrop – outcrop Rating: A	1
CGM/CGR50	E 406670 N 7733440	Magnetite-rich, Ernest Henry style Mineralizing Event: Wonga? Or Williams age plutonism	within the upper plate portion of the regional Wonga detachment zone Rating: A	structures draped around the carapace/edge of a partially unroofed Burstall aged granite Rating: A	Unit(s): Corella metasediments - calcsilicates Lithologies: Possible carbonaceous metasiltstones Rating: A	broad zones of positive magnetic anomalism enveloping numerous linear and complex high amplitude magnetic highs Rating: A	Proterozoic subcrop – outcrop Rating: A	1
CGM/CGR51	E 422210 N 7720730	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Complex zone of NW trending D3 faults Rating: B	magnetic zones just outboard of a major Williams aged pluton contact parts of anomalies with similar geometry to the mineralized portion of the Ernest Henry anomaly Rating: A	Unit(s): ?Corella age metasediments and calcsilicate breccias, Argylla (Possible Wonga) aged intrusives/volcanics Lithologies: Possible carbonaceous metasiltstones Rating: A	extensive high amplitude magnetic anomalies within broader domains of anomalous highs historical Cu-Au workings along strike on the NW trending structures Rating: B	Proterozoic subcrop – outcrop Rating: A	2
CGM/CGR52	E 433270 N 7720260	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Complex zone of NW trending D3 faults Rating: B	magnetic zones concentrated along major Williams aged pluton contact parts of anomalies with similar geometry to the mineralized portion of the Ernest Henry anomaly Rating: A	Unit(s): ?Corella age metasediments and calcsilicate breccias, and Tommy Creek beds sediments & microgranite/volcanics Lithologies: Possible carbonaceous metasiltstones Rating: A	extensive high amplitude magnetic anomalies within broader domains of anomalous highs historical Cu-Au workings along strike on the NW trending structures Rating: B	Proterozoic subcrop – outcrop Rating: A	2
CGM/CGR53	E 438220 N 7705660	Magnetite-rich & Magnetite-poor, reduced Mineralizing Event: Williams age plutonism	Wonga ? aged regional scale N trending high strain zone/detachment fault Within the roof, on the western edge, of the buried Williams batholith (batholith at depth based on gravity interpretation) Rating: A	Older structure reactivated and focus for ~ N trending, E dipping D2 reverse faults, Intersection of late D2/D3 WNW trending faults with the Wonga and D2 faults Rating: A	Unit(s): Overhang Jasperlite, ?Corella metasediments and calcsilicate breccias Lithologies: Possible carbonaceous metasiltstones Rating: A	complexly folded high amplitude magnetic bodies Minor historical Cu-Au working throughout the area & `stratigraphically` along strike Rating: A	Proterozoic subcrop – outcrop Rating: A	1

TABLE 11.4 (continued)

Identifier	Location (AMG)	Styles	Regional structural setting	Local structural setting	Lithostratigraphic setting	Alteration/Mineralisation indicators	Cover thickness	Overall rating
	E N	Target Style and Mineralising Event(s)	Key structural elements, geometries and kinematic histories relevant to target style, ie target zone in regional structural context	Key structural elements, geometries and kinematic histories relevant to target style – at scale of target zone or prospect	Unit(s), lithologies, ages Any key features with respect to target styles	Mineral occurrences of styles related to target Geochemical anomalism Any significant local lithological and alteration features	Depth to Proterozoic basement Estimate of target depths, if possible	
CGM/CGR54	E 439040 N 7709310	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Zone of NW trending D3 faults and reactivated Soldiers Cap aged normal faults Within the roof, on the western edge, of the buried Wliliams batholith (batholith at depth based on gravity interpretation) Rating: A	magnetic zones concentrated adjacent to a major Williams aged pluton contact parts of anomalies with similar geometry to the mineralized portion of the Ernest Henry anomaly Rating: A	Unit(s): ?Corella age metasediments and calcsilicate breccias, and Tommy Creek beds sediments & microgranite/volcanics Lithologies: Possible carbonaceous metasiltstones Rating: A	extensive high amplitude magnetic anomalies within broader domains of anomalous highs historical Cu-Au workings along strike on the NW trending structures Rating: B	Proterozoic subcrop – outcrop Rating: A	2
CGM/CGR55	E 448340 N 7710250	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Outboard of an exposed major Williams aged pluton contact Within the roof of the buried Williams batholith (batholith at depth based on gravity interpretation) Rating: A	Intersection zone of NW trending D3 faults and reactivated Wonga (& or ~1670) extensional faults Rating: A	Unit(s): ?Corella age metasediments and calcsilicate breccias Lithologies: Possible carbonaceous metasiltstones Rating: A	Medium sized to small high amplitude magnetic anomalies within a broader anomalous area historical Cu-Au mines (Great Australia) Rating: A	Proterozoic subcrop – outcrop Rating: A	1
CGM/CGR56	E 462470 N 7708720	Magnetite-rich, Ernest Henry style, & Magnetite –poor, reduced style Mineralizing Event: Williams age plutonism	Outboard of an exposed major Williams aged pluton contact Along a major N trending D3 fault – Mt Margaret Fault Zone (a reactivated ~1670 extensional sidewall fault) Within the roof, on the eastern edge, of the buried Williams batholith (batholith at depth based on gravity interpretation) Rating: A	Zone of W NW trending D3 faults and reactivated Soldiers Cap aged extensional faults WNW faults a possible control on the Eloise deposit to the SE Rating: A	Unit(s): lower and upper Soldiers Cap metasediments, metavolcanics & metadolerite Lithologies: Possible carbonaceous metasiltstones Rating: A	small high amplitude magnetic anomalies within broader domains of anomalous highs historical Cu-Au workings Rating: A	Proterozoic subcrop – outcrop Rating: A	1
CGM/CGR57	E 460700 N 7719550	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	NE & NW trending D3 faults Magnetite alteration possibly distributed regionally along a NE trending ~1670 normal fault, (as per Ernest Henry Cu-Au deposit) Rating: A	magnetic zones concentrated along major Williams aged pluton contact parts of the magnetic anomaly with similar geometry to the mineralized portion of the Ernest Henry anomaly Rating: B	Unit(s): ?Corella age metasediments and calcsilicate breccias, and Tommy Creek beds sediments & microgranite/volcanics Lithologies: Possible carbonaceous metasiltstones Rating: A	small to medium sized high amplitude magnetic anomalies within broader domains of anomalous highs Rating: B	Proterozoic subcrop – outcrop Rating: A	2
CGM/CGR58	E 475300 N 7716020	Magnetite-rich, Ernest Henry style, & Magnetite –poor, reduced style Mineralizing Event: Williams age plutonism	Zone of NW trending D3 faults and reactivated cover sequence 2 normal faults Along a major N trending D3 fault – Mt Margaret Fault Zone (a reactivated ~1670 extensional sidewall fault) Rating: A	Outboard of an exposed major Williams aged pluton contact; numerous small Williams aged plutons in proximity, some not unroofed Intersection zone of N to NNE trending D3 faults and reactivated Soldiers Cap aged normal faults Rating: A	Unit(s): ?Corella age metasediments and calcsilicate breccias , and lower and upper Soldiers Cap metasediments & metadolerite Lithologies: Possible carbonaceous metasiltstones Rating: A	Medium sized to small high amplitude magnetic anomalies within a broader anomalous area in the proximity of historical Cu-Au working Rating: A	Proterozoic subcrop – outcrop Rating: A	1
CGM59	E 465410 N 7728260	Magnetite-rich, Ernest Henry style & Magnetite-poor, reduced Mineralizing Event: Williams age plutonism	along the edge of a region of small nested plutons, possibly above a larger intrusive body Magnetite alteration halo around pluton to the north extends along NE trending structure to Ernest Henry Cu-Au deposit ?inferred N to NNW trending possible Soldiers Cap age regional side-wall fault zone, reactivated during late D2/D3 as wrench faults Rating: A	N to NNW trending regional late D2/D3 wrench faults; characterized by magnetite destructive alteration evident in the magnetics.	Unit(s): Lower & upper Soldiers Cap aged metasediments and metadolerite Lithologies: Possible carbonaceous metasiltstones Rating: A	high amplitude, thin linear & complexly folded magnetic anomalies with segments discordant to the regional structural grain Zones of magnetite destructive alteration in folded and faulted mafic volcanics/intrusives Rating: A	<50m Phanerozoic cover Rating: A	1
CGM60	E 460820 N 7734740	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	within region of small nested plutons, possibly above a larger intrusive body Magnetite alteration halo around pluton to the north extends along NE trending structure to Ernest Henry Cu-Au deposit ?inferred NE trending possible Soldiers Cap age structure, reactivated during late D2/D3. Rating: A	NE-trending, moderately dipping shear zones; Minor late NW trending D2/D3 faults intersecting felsic-intermediate igneous bodies Rating: B	Unit(s): ?Corella age metasediments and Wonga age igneous bodies (shallow level intrusives/subvolcanics) Lithologies: Potential for carbonaceous metasiltstones abutting competent felsic-intermediate bodies Rating: A	high amplitude magnetic anomaly with a segment discordant to the regional structural grain Rating: A	<50m Phanerozoic cover Rating: A	2

CGM61	E 469650 N 7740150	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	pluton roof zone, above pluton edge (gravity signature) ?inferred NE- to ENE-trending Soldiers Cap age structures reactivated during D3 Rating: A	NE-trending, moderately dipping shear zones intersecting felsic igneous bodies Corridor of small NW trending faults Rating: A	Unit(s): ?Corella age metasediments and Wonga age felsic igneous bodies Lithologies: deformed carbonaceous metasiltstones abutting competent felsic bodies Rating: A	Large, very high amplitude magnetic anomaly shallow EM conductor and IP anomaly magnetite-carbonate and biotite-Kspar alterations Cu-Au anomalous covers the Ernest Henry Cu-Au deposit Rating: A	<50m, Phanerozoic cover Rating: A	1
CGR62	E 478360 N 7754050	Magnetite-rich & Magnetite-poor, reduced type Mineralizing Event: Williams age plutonism	within region of small Williams aged intrusions, possibly above the edge of an interpreted larger intrusive body at depth to the W Major late D2/D3 N trending fault zone Rating: A	N trending regional structure intersecting NE & NW trending faults Steps and bends in the faults which may be dilational Rating: A	Unit(s): Soldiers Cap metasediments Lithologies: folded carbonaceous metasiltstones, 'Fe-stones & mafic igneous rocks Rating: A	thin, linear & folded high amplitude magnetic anomalies along the N trending D3 fault zone magnetite destructive alteration along the N trending faults. Cu-Au mineralisation known along the structure Rating: A	0-200m Phanerozoic cover Rating: A	1
CGM63	E 454930 N 7753810	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Within area of small nested Williams aged plutons with magnetic aureoles indicating possible roof zone to a larger pluton Interpreted NE- to ENE-trending Soldiers Cap age structures reactivated during D3 Rating: A	NE-trending, moderately dipping shear zones intersecting felsic igneous bodies Within a corridor of small NW trending faults that extend through the Ernest Henry deposit (subtle in the magnetics) Rating: A	Unit(s): ?Corella age metasediments and Wonga age felsic igneous bodies Lithologies: possible carbonaceous metasiltstones and competent felsic bodies Rating: A	Medium sized high amplitude magnetic anomaly Cu-Au mineralisation reported from target CGM68 along strike Rating: B	<50m, Phanerozoic cover Rating: A	2
CGM64	E 459290 N 7758280	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Within area of small nested Williams aged plutons with magnetic aureoles indicating possible roof zone to a larger pluton Interpreted NE- to ENE-trending Soldiers Cap age structures reactivated during D3 Rating: A	NE-trending, moderately dipping shear zones intersecting felsic igneous bodies Within a corridor of small NW trending faults that extend through the Ernest Henry deposit (subtle in the magnetics) Rating: A	Unit(s): ?Corella age metasediments and Wonga age felsic igneous bodies Lithologies: possible carbonaceous metasiltstones and competent felsic bodies Rating: A	Small sized high amplitude magnetic anomaly Cu-Au mineralisation reported from target CGM68 along strike Rating: C	<50m, Phanerozoic cover Rating: A	3
CGR65	E 443870 N 7696360	Magnetite poor, reduced style Mineralizing Event: Williams age plutonism	Zone of NW trending D3 faults and reactivated Soldiers Cap aged normal faults Within the roof, on the western edge, of the buried Williams batholith (batholith at depth based on gravity interpretation) Rating: A	NNE to NE-trending interpreted D2 reverse fault; geometry suitable for D3 reactivation Rating: A	Unit(s): Marimo Slates (Upper Soldiers Cap aged equivalent) Lithologies: possible carbonaceous metasiltstones Rating: A	Very small high amplitude magnetic anomaly Strong spatial association of U (from airborne radiometrics)with the magnetic high Rating: A	Proterozoic subcrop – outcrop Rating: A	1
CGM/ CGR66	E 442690 N 7762400	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Within area of small nested Williams aged plutons with magnetic aureoles indicating possible roof zone to a larger pluton Interpreted N- to NNW D3 faults Rating: A	Within the roof/edge of a Williams aged pluton Within a corridor of small NW trending faults that extend through the Ernest Henry deposit (subtle in the magnetics) Several of the high amplitude bodies with geometries similar to the mineralized portion of the Ernest Henry magnetic high Rating: A	Unit(s): ?Corella age metasediments and Wonga age felsic igneous bodies Lithologies: possible carbonaceous metasiltstones and competent felsic bodies Rating: A	Broad magnetic high enveloping several small sized high amplitude magnetic anomalies Rating: C	<50m, Phanerozoic cover Rating: A	3
CGR/CGM67	E 450580 N 7762640	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Within area of small nested Williams aged plutons with magnetic aureoles indicating possible roof zone to a larger pluton Interpreted N- to NNW D3 faults Rating: B	Within a corridor of small NW trending faults that extend through the Ernest Henry deposit (subtle in the magnetics) Segment of magnetic high with similar geometry to the mineralized portion of the Ernest Henry magnetic high Rating: B	Unit(s): ?Corella age metasediments and Wonga age felsic igneous bodies Lithologies: possible carbonaceous metasiltstones and competent felsic bodies Rating: A	Small sized high amplitude magnetic anomaly Rating: C	50m, Phanerozoic cover Rating: A	3
CGM68	E 461170 N 7762640	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Within area of small nested Williams aged plutons with magnetic aureoles indicating possible roof zone to a larger pluton interpreted NE- to ENE-trending Soldiers Cap age structures reactivated during D3 Rating: A	NE-trending, moderately dipping shear zones NW trending D3 fault Intersecting felsic igneous bodies Within a corridor of small NW trending faults that extend through the Ernest Henry deposit (subtle in the magnetics) Rating: A	Unit(s): ?Corella age metasediments and Wonga age felsic igneous bodies Lithologies: possible carbonaceous metasiltstones and competent felsic bodies Rating: A	Large, very high amplitude magnetic anomaly Cu-Au mineralisation reported from exploration drilling Rating: C	50m, Phanerozoic cover Rating: A	3

TABLE 11.4 (continued)

Identifier	Location (AMG)	Styles	Regional structural setting	Local structural setting	Lithostratigraphic setting	Alteration/Mineralisation indicators	Cover thickness	Overall rating
	E N	Target Style and Mineralising Event(s)	Key structural elements, geometries and kinematic histories relevant to target style, ie target zone in regional structural context	Key structural elements, geometries and kinematic histories relevant to target style – at scale of target zone or prospect	Unit(s), lithologies, ages Any key features with respect to target styles	Mineral occurrences of styles related to target Geochemical anomalism Any significant local lithological and alteration features	Depth to Proterozoic basement Estimate of target depths, if possible	
CGM/CGR69	E 463530 N 7767470	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Within area of small nested Williams aged plutons with magnetic aureoles indicating possible roof zone to a larger pluton Rating: B	NW trending D3 fault Intersecting felsic igneous bodies Rating: B	Unit(s): Corella age metasediments and Wonga age felsic igneous bodies Lithologies: possible carbonaceous metasiltstones and competent felsic bodies Rating: A	small high amplitude magnetic anomaly within a broader moderate magnetic high Rating: C	100m, Phanerozoic cover Rating: A	3
CGM70	E 476120 N 7775940	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	within region of small Williams aged intrusions, possibly above the edge of an interpreted larger intrusive body at depth to the W Major late D2/D3 N trending fault zone (reactivated ~1670 extensional fault) Rating: A	N trending regional structure intersecting NE trending faults Magnetic targets within the roof of an interpreted small Williams aged pluton at depth (Ie. not unroofed) Rating: A	Unit(s): Soldiers Cap metasediments Lithologies: carbonaceous metasiltstones & mafic igneous rocks Rating: A	Broad anomaly with small high amplitude peaks Cu-Au mineralisation known along similar N trending structures to the SE Rating: A	200m Phanerozoic cover Rating: B	2
CGM71	E 463170 N 7777940	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Within area of small nested Williams aged plutons with magnetic aureoles indicating possible roof zone to a larger pluton Major late D2/D3 N trending fault zone (reactivated ~1670 extensional fault) Rating: A	NW trending D3 fault Magnetic targets within the roof of an interpreted small Williams aged pluton at depth (Ie. not unroofed) Rating: A	Unit(s): Soldiers Cap metasediments Lithologies: carbonaceous metasiltstones & mafic igneous rocks Rating: A	Broad anomaly with a medium sized, central, very high amplitude magnetic body Rating: A	200m Phanerozoic cover Rating: A	2
CGM/CGR72	E 449050 N 7772410	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Within area of small nested Williams aged plutons with magnetic aureoles indicating possible roof zone to a larger pluton Rating: A	Intersection of a NNE and NW trending D3 fault Intersecting felsic igneous bodies Segment of magnetic high with similar geometry to the mineralized portion of the Ernest Henry magnetic high Rating: B	Unit(s): Corella age metasediments and Wonga age felsic igneous bodies Lithologies: possible carbonaceous metasiltstones and competent felsic bodies Rating: A	small high amplitude magnetic anomalies and a broader moderate magnetic high Rating: C	100m, Phanerozoic cover Rating: A	3
CGM/CGR73	E 449050 N 7783830	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Within area of small nested Williams aged plutons with magnetic aureoles indicating possible roof zone to a larger pluton Rating: A	Intersection of a NNE and NW trending D3? Faults Roof of small interpreted Williams aged plutons Segment of magnetic high with similar geometry to the mineralized portion of the Ernest Henry magnetic high Rating: B	Unit(s): Corella & possible Soldiers Cap metasediments Lithologies: possible carbonaceous metasiltstones and competent felsic bodies Rating: A	small high amplitude magnetic anomalies and broad moderate magnetic highs Rating: C	200-250m, Phanerozoic cover Rating: B	3
CGM/CGR74	E 444460 N 7790780	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Within area of small nested Williams aged plutons with magnetic aureoles indicating possible roof zone to a larger pluton Rating: A	Intersection of a NE and NW trending D3 fault Rating: B	Unit(s): Corella & possible Soldiers Cap metasediments Lithologies: possible carbonaceous metasiltstones and competent felsic bodies Rating: A	small very high amplitude magnetic anomalies within a broader moderate magnetic high Rating: B	250m, Phanerozoic cover Rating: B	3
CGR/CGM/CGH75	E 419140 N 7743920	Magnetite-rich, Magnetite-poor, reduced Mineralizing Event: Wonga? Or Williams age plutonism)	Wonga ? (or ~1670 aged) regional scale N trending high strain zone/detachment fault zone Extensional domes cored by granite (Wonga aged?) intersection with NNE to N trending early extensional faults reactivated in D2/D3 Rating: B	Older structure reactivated and focus for ~ NNE trending, NW dipping D2 reverse faults (back thrusts?), Adjacent to a regional NE trending D3 fault Rating: A	Unit(s): Corella & possible Soldiers Cap Lithologies: Possible carbonaceous metasiltstones Rating: A	A broad curvilinear magnetic zone with numerous small complex and linear high amplitude magnetic bodies Minor historical Cu-Au mine along strike Rating: A	Proterozoic subcrop – outcrop Rating: A	2
CGM/CGR/CGH76	E 418080 N 7759110	Magnetite-rich, Magnetite-poor, reduced	Wonga ? (or ~1670 aged) regional scale N trending high strain zone/detachment fault zone Extensional domes cored by granite (Wonga aged?) Intersection with NNE & N trending regional early extensional faults reactivated in late D2/D3	Detachment reactivated and focus for ~ NE trending D2 & D3 faults .	Unit(s): Corella & possible Soldiers Cap Lithologies: Possible carbonaceous metasiltstones	An elongate extensive elongate magnetic zone with numerous small complex and linear high amplitude magnetic bodies Minor historical Cu-Au mine along strike	Proterozoic subcrop – outcrop	2

		Mineralizing Event: Wonga? Or Williams age plutonism)	Rating: B	Rating: A	Rating: A	Rating: A	Rating: A	
CGM/CGR/CGH77	E 429270 N 7802670	Magnetite-rich, Magnetite-poor, reduced Mineralizing Event: Wonga? Or Williams age plutonism	Wonga ? (or ~1670 aged) regional scale N trending high strain zone/detachment fault zone Extensional domes cored by granite (Wonga aged?) Intersection with NNE to N trending early extensional faults reactivated in D2/D3 Rating: B	Intersection of a NNE and NW trending D3 fault Rating: A	Unit(s): Corella & possible Soldiers Cap Lithologies: Possible carbonaceous metasiltstones Rating: A	Large areas magnetic alteration with numerous small Minor historical Cu-Au mine along strike Rating: A	0-200m, Phanerozoic cover Rating: A	2
CGM/CGR78	E 439280 N 7817730	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Within the edge of a dome, with an interpreted Williams aged intrusion, partially unroofed in the core (intrusions may alternatively be older Sybella granite or basement) Major late D2/D3 NNE trending fault zone Rating: B	Older structure reactivated and focus for ~ NNE trending, NW dipping D2 reverse faults (back thrusts?), Adjacent to a regional NE trending D3 fault Rating: B	Unit(s): Soldiers Cap metasediments Lithologies: possible carbonaceous metasiltstones and competent felsic bodies Rating: A	small high amplitude magnetic anomalies within a broader moderate magnetic highs Rating: B	300m, Phanerozoic cover Rating: C	3
CGM/CGR79	E 441510 N 7824330	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Within area of small nested Williams aged plutons with Within the edge of a dome, with an interpreted Williams aged intrusion, partially unroofed in the core (intrusions may alternatively be older Sybella granite or basement) Major late D2/D3 NNE trending fault zone Rating: B	Intersection of a NE and NW trending D3 fault Rating: B	Unit(s): Soldiers Cap metasediments Lithologies: possible carbonaceous metasiltstones and competent felsic bodies Rating: A	small very high amplitude magnetic anomalies within a broader moderate magnetic high Rating: B	350m, Phanerozoic cover Rating: C	3
CGM80	E 455990 N 7862120	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Within the edge of a dome, with an interpreted Williams aged intrusion, partially unroofed in the core (intrusions may alternatively be older Sybella granite or basement) Major late D2/D3 NNE trending fault zone Rating: B	N trending regional structure intersecting possible older WNW extensional faults (Wonga normals?) Rating: B	Unit(s): Soldiers Cap metasediments Lithologies: Carbonaceous metasiltstones & mafic igneous rocks Rating: A	Very large high amplitude magnetic anomaly Rating: A	>500m Phanerozoic cover Rating: C	3
CGM/CGR81	E 399600 N 7790540	Magnetite-rich, Ernest Henry style Mineralizing Event: Wonga? Or Williams age plutonism	Within the Wonga detachment zone Proximal to Wonga aged intrusions Complex zone of regional scale N and NE trending D3 wrench faults Rating: A	Intersecting NNW and NNE trending faults (originally upper plate Wonga extensional faults) possibly in the roof of an interpreted pluton (Wonga aged ?) at depth? Rating: A	Unit(s): Argylla and Corella metasediments and metavolcanics Lithologies: Possible carbonaceous metasiltstones Rating: A	large medium amplitude magnetic high with several small and one large very high amplitude magnetic anomalies Minor historical Cu-Au mine along strike Rating: A	Proterozoic subcrop – outcrop Rating: A	2
CGM/CGR82	E 402550 N 7806790	Magnetite-rich, Ernest Henry style Mineralizing Event: Wonga? Or Williams age plutonism	Within the Wonga detachment zone Proximal to Wonga aged intrusions Complex zone of regional scale N and NE trending D3 wrench faults Rating: A	Intersecting NNW and NNE trending faults (originally upper plate Wonga extensional faults) in the roof of an interpreted pluton (Wonga aged ?) at depth? Rating: A	Unit(s): Argylla and Corella metasediments and metavolcanics Lithologies: Possible carbonaceous metasiltstones Rating: A	large medium amplitude magnetic high with several small and one large very high amplitude magnetic anomalies Minor historical Cu-Au mine along strike Rating: A	Proterozoic subcrop – outcrop Rating: A	2
CGM/CGR 83	E 396780 N 7837750	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Regional corridor of N trending faults (early basement faults, with multiple stages of reactivation, including during the Wonga & D3 events) Wonga-Burstall aged intrusions in the proximity Upper plate to the Wonga detachment fault zone Rating: B	Zone of NW trending faults Bend & offset in approximately N trending magnetic stratigraphic /structural grain Rating: B	Unit(s): Corella metasediments and metavolcanics Lithologies: possible carbonaceous metasiltstones and competent felsic bodies Rating: A	small high amplitude magnetic anomaly Rating: C	100m, Phanerozoic cover Rating: A	3
CGM/CGR 84	E 403840 N 7843630	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Regional corridor of N trending faults (early basement faults, with multiple stages of reactivation, including during the Wonga & D3 events) Within the immediate upper plate to the Wonga detachment fault zone Rating: A	A north trending D2 anticlinal fold axis, folding the Wonga detachment zone Adjacent to a NNW trending D3 fault zone Adjacent to a partially unroofed pluton, interpreted as Burstall-Wonga aged, with a highly magnetic aureole Rating: B	Unit(s): Corella metasediments and metavolcanics Lithologies:possible carbonaceous metasiltstones and competent felsic bodies Rating: A	Small to medium sized high amplitude magnetic anomalies within broader moderate magnetic highs Rating: B	200m, Phanerozoic cover Rating: B	3

TABLE 11.4 (continued)

Identifier	Location (AMG)	Styles	Regional structural setting	Local structural setting	Lithostratigraphic setting	Alteration/Mineralisation indicators	Cover thickness	Overall rating
	E N	Target Style and Mineralising Event(s)	Key structural elements, geometries and kinematic histories relevant to target style, ie target zone in regional structural context	Key structural elements, geometries and kinematic histories relevant to target style – at scale of target zone or prospect	Unit(s), lithologies, ages Any key features with respect to target styles	Mineral occurrences of styles related to target Geochemical anomalism Any significant local lithological and alteration features	Depth to Proterozoic basement Estimate of target depths, if possible	
CGM/CGR 85	E 411370 N 7841400	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Regional corridor of N trending faults (early basement faults, with multiple stages of reactivation, including during the Wonga & D3 events). Upper plate to the Wonga detachment fault zone Rating: B	Adjacent to a NNW trending D3 fault zone Within the roof to a partially unroofed pluton, interpreted as Burstall-Wonga aged, with a highly magnetic aureole Rating: B	Unit(s): Corella metasediments and metavolcanics Lithologies: possible carbonaceous metasiltstones and competent felsic bodies Rating: A	Large & small high amplitude magnetic anomalies within an extensive moderate magnetic highs Rating: A	200m, Phanerozoic cover Rating: B	3
CGM/CGR 86	E 417500 N 7860120	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Regional corridor of N trending faults (early basement faults, with multiple stages of reactivation, including during the Wonga & D3 events) ~1670Ma (or Wonga aged?) extensional detachment fault zone Rating: B	Wonga-Burstall aged intrusions in the proximity Rating: B	Unit(s): Corella metasediments and metavolcanics Lithologies: possible carbonaceous metasiltstones and competent felsic bodies Rating: A	Small to medium sized high amplitude magnetic anomalies within broader moderate magnetic highs Rating: B	<50m, Phanerozoic cover Rating: A	3
CGR/CGM87	E 520380 N 7680820	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	major NS trending D2 thrust with possible rectivation late D2/D3 Rating: A	warp in a regional D2 thrust, possibly ramp in thrust interpreted late Williams aged plutons at depth (ie. not unroofed) Rating: A	Unit(s): SC2/SC3 metasediments and metadolerite – Base of the Toole Creek Volcanics – same stratigraphic level hosts Osborne Cu-Au deposit to W Lithologies: Possible carbonaceous metasiltstones Rating: A	small high amplitude magnetic anomalies, some discordant to the regional stratigraphic - structural grain & trends similar to highs at Osborne Cu-Au mine. Rating: A	100-300m, Phanerozoic cover Rating: A	1
CGH/CGR88	E 528960 N 7831560	Magnetite-poor, reduced & hematite Mineralizing Event: Williams age plutonism	Williams aged pluton located on a major NNW trending D2 transfer fault, reactivated during D3 Rating: A	Bends within NNW trending D2/D3 fault zone Rating: A	Unit(s): Upper Soldiers Cap aged metasediments and metadolerite Lithologies: Possible carbonaceous metasiltstones Rating: A	Linear magnetic zone within a warp in the NNW trending fault & extending from the granite Isolated gravity anomaly with no stratigraphic explanation or magnetic signature, located on fault bend Rating: A	50-300m Phanerozoic cover Rating: A	1
CGH/CGR89	E 571870 N 7879300	Magnetite-rich, Ernest Henry style & Magnetite-poor, hematite,Olympic Dam style Mineralizing Event: Williams age plutonism	Williams aged pluton located on a regional corridor of NW trending faults NW trending faults probably reflecting a major reactivated regional scale basement structure Rating: A	NW trending fault late D2/D3 contact to Williams aged pluton Rating: B	Unit(s): Interpreted Croydon Volcanics and upper Soldiers Cap sediments (not outcropping in this area, based on magnetic signature), and Williams aged pluton Lithologies: felsic volcanics, approximately Williams age extrusive equivalent, & possible carbonaceous metasiltstones Rating: A	Broad zone of moderate magnetic anomalism Williams age volcanics indicate high stratigraphic level, therefore hematite likely dominant Fe-oxide (ie lower magnetic response) Rating: A	200-300m Phanerozoic cover Rating: B	1
CGM/CGH90	E 565010 N 7864320	Magnetite-rich, Ernest Henry style, Magnetite-poor & hematite, Olympic Dam style Mineralizing Event: Williams age plutonism	Williams aged pluton located on a regional corridor of NW trending faults NW trending faults probably reflecting a major reactivated regional scale basement structure Rating: A	Williams aged pluton contact Rating: C	Unit(s): Interpreted Croydon Volcanics (not outcropping in this area, based on magnetic signature), and Williams aged pluton Lithologies: Felsic volcanics, approximately Williams age extrusive equivalent Rating: A	Broad zone of weak magnetic anomalism with a central, linear several km long high amplitude magnetic body Williams age volcanics indicate high stratigraphic level, therefore hematite likely dominant Fe-oxide (ie low magnetic response) Rating: B	200-300m Phanerozoic cover Rating: B	3
CGH91	E 577960 N 7836130	Magnetite-poor, hematite,Olympic Dam style Mineralizing Event: Williams age plutonism	Situated in the center of an interpreted caldera (could alternatively be interpreted as an intrusion) Caldera interpreted to be Williams age(?) Caldera situated at the intersection of regional N & NW trending faults, possibly reflecting regional older basement structures Rating: A	Caldera situated at the intersection of regional N & NW trending faults, possibly reflecting regional older basement structures Rating: A	Unit(s): Interpreted Croydon Volcanics (not outcropping in this area, based on magnetic signature) Lithologies: felsic volcanics, approximately Williams age extrusive equivalent Rating: A	Broad zone of weak magnetic anomalism, coincident with a regional gravity high Williams age volcanics indicate high stratigraphic level, therefore hematite likely dominant Fe-oxide (ie low magnetic response) Rating: A	200-300m Phanerozoic cover Rating: B	1
CGM/CGR/ CGH92	E 604120 N 7758680	Magnetite-rich, Ernest Henry style	Regional scale step in a late D2/D3 regional fault zone	Late D2/D3 high angle faults, juxtaposing SC3 and Croydon volcanics Numerous small Williams aged plutons locally; interpreted to be in the roof of one such pluton	Unit(s): Interpreted Croydon Volcanics and upper Soldiers Cap sediments (not outcropping in this area, based on magnetic signature), and Williams aged pluton Lithologies: felsic volcanics, approximately Williams age extrusive equivalent, & possible carbonaceous metasiltstones	Small `spot` high amplitude magnetic anomalies	200-300m Phanerozoic cover	1

		Mineralizing Event: Williams age plutonism	Rating: A	Rating: A	Rating: A	Rating: A	Rating: B	
CGM/CGR93	E 410120 N 7870410	Magnetite-rich, Ernest Henry style Mineralising Event: Wonga? Or Williams age plutonism	within a zone of detachment faults, Wonga aged Pre D2 extensional structures reactivated during D2 & D3, with interpreted reverse displacements Regional N trending D3 faults Rating: B	Along a regional detachment fault zone, on the eastern limb of a NE trending anticline Magnetic zones within the roof zone and peripheral to interpreted plutons at depth which are not unroofed (Wonga – Williams aged?) Rating: B	Unit(s): ?Corella age metasediments and Wonga age felsic igneous bodies in close proximity Lithologies: Not exposed, units based on magnetic interpretation Rating: A	high amplitude magnetic anomalies (some discordant to the structural grain) within a large area of elevated magnetic response Rating: A	50-400m Rating: A	2
CGM/CGR94	E 418500 N 7902910	Magnetite-rich, Ernest Henry style Mineralising Event: Wonga? Or Williams age plutonism	within a Regional N trending early extensional fault reactivated during D2/D3 Rating: A	A major bend within the NS stratigraphic/structural grain, from NS-NE-NNE Along strike to interpreted plutons at depth (Wonga – Williams aged?) Rating: A	Unit(s): ?Corella age metasediments and Wonga age felsic igneous bodies in close proximity Lithologies: Not exposed, units based on magnetic interpretation Rating: A	high amplitude magnetic anomaly within a large area of elevated magnetic response Rating: A	300-500m Phanerozoic cover Rating: B	1
CGM/CGR95	E 437290 N 7941510	Magnetite-rich, Ernest Henry style Mineralising Event: Wonga? Or Williams age plutonism	Intersection of regional NW- N trending early high angle extensional faults and the Wonga detachment zone Possible reactivation of structures during D2/D3 Rating: A	A major bend within the NS stratigraphic/structural grain, from NNE-NE-N Adjacent to a larger Wonga (?) aged pluton Rating: A	Unit(s): ?Corella age metasediments and Wonga age felsic igneous bodies in close proximity Lithologies: Not exposed, units based on magnetic interpretation Rating: A	Extremely larger and extremely high amplitude magnetic anomaly within a large area of elevated magnetic response Several reconnaissance drill holes, minor Cu-Au style mineralisation intersected Rating: A	500-1000m Phanerozoic cover Rating: C	3
CGM/CGR96	E 478430 N 7901390	Magnetite-rich, Ernest Henry style	Within the roof of an interpreted extension related dome	At the intersection of late NNW and NNE trending faults (possibly reactivated older structures Proximal to Wonga (or Sybella /) aged plutons in the core of domes, & small Williams aged plutons intruding the Soldiers Cap Formation	Unit(s): SC2/SC3 metasediments and metadolerite Lithologies: Possible carbonaceous metasiltstones	Extremely larger and extremely high amplitude magnetic anomaly within a large area of elevated magnetic response Several reconnaissance drill holes, minor Cu-Au style mineralisation intersected	400-500m Phanerozoic cover	3
		Mineralising Event: Wonga? Or Williams age plutonism	Rating: B	Rating: B	Rating: A	Rating: A	Rating: C	
CGR100	E 410550 N 7762760	Magnetite poor, reduced style Mineralising Event: Wonga? Or Williams age plutonism	Zone of N trending faults (Rose Bee Fault) Right step in the fault zone possibly dilational Wonga aged normal fault? Reactivated during D3 in the footwall of Dugald River deposit Rating: A	N trending interpreted D3 strike-slip fault Rating: A	Unit(s): Corella & Dugald River shales Lithologies: carbonaceous slates/metasiltstones Rating: A	Very small high & low amplitude magnetic anomalies along the N trending fault zone Cu-Au mineralisation confirmed along the fault zone (historical mining & exploration, Roseby deposit) Rating: A	Proterozoic subcrop – outcrop Rating: A	1
CGR101	E 446690 N 7586290	Magnetite poor, reduced style Mineralizing Event: Williams age plutonism	Zone of N trending faults Rating: A	N trending, E dipping D2 fault, possibly reactivated during D3 Rating: B	Unit(s): Kuridala Formation metasediments & metadolerite (i.e. upper Soldiers Cap equivalent) Lithologies: carbonaceous slates/metasiltstones Rating: A	Very small high & low amplitude magnetic anomalies along the N trending fault zone Cu-Au mineralisation confirmed along the fault zone (historical mining Hampden mine) Rating: A	Proterozoic subcrop – outcrop Rating: A	2
CGM103	E 542780 N 7452530	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Regional N trending early basement faults with several periods of reactivation, including D2/D3 Within the roof/western edge of an interpreted Williams aged batholith at depth (based on gravity) Rating: A	Intersection of NNE & NE D3 faults Rating: B	Unit(s): Soldiers Cap metasediments & metadolerite Lithologies: carbonaceous slates/metasiltstones Rating: A	Large high amplitude magnetic anomaly Rating: A	~1000m Phanerozoic cover Rating: C	3
CGM103	E 542780 N 7452530	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Regional N trending early basement faults with several periods of reactivation, including D2/D3 Within the roof/western edge of an interpreted Williams aged batholith at depth (based on gravity) Rating: A	Intersection of NNE & NE D3 faults Rating: B	Unit(s): Soldiers Cap metasediments & metadolerite Lithologies: carbonaceous slates/metasiltstones Rating: A	Large high amplitude magnetic anomaly Rating: A	~1000m Phanerozoic cover Rating: C	3

TABLE 11.4 (continued)

Identifier	Location (AMG)	Styles	Regional structural setting	Local structural setting	Lithostratigraphic setting	Alteration/Mineralisation indicators	Cover thickness	Overall rating
	E **N**	**Target Style and Mineralising Event(s)**	**Key structural elements, geometries and kinematic histories relevant to target style, ie target zone in regional structural context**	**Key structural elements, geometries and kinematic histories relevant to target style – at scale of target zone or prospect**	**Unit(s), lithologies, ages** **Any key features with respect to target styles**	**Mineral occurrences of styles related to target** **Geochemical anomalism** **Any significant local lithological and alteration features**	**Depth to Proterozoic basement** **Estimate of target depths, if possible**	
CGM102	E 525830 N 7499330	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Regional N trending early basement faults with several periods of reactivation, including D2/D3 Within the roof/western edge of an interpreted Williams aged batholith at depth (based on gravity) Rating: A	Intersection of NNE & NE D3 faults Rating: B	Unit(s): Soldiers Cap metasediments & metadolerite Lithologies: carbonaceous slates/metasiltstones Rating: A	Small high amplitude magnetic anomalies Rating: A	~750m? Phanerozoic cover Rating: C	3
CGM103	E 542780 N 7452530	Magnetite-rich, Ernest Henry style Mineralizing Event: Williams age plutonism	Regional N trending early basement faults with several periods of reactivation, including D2/D3 Within the roof/western edge of an interpreted Williams aged batholith at depth (based on gravity) Rating: A	Intersection of NNE & NE D3 faults Rating: B	Unit(s): Soldiers Cap metasediments & metadolerite Lithologies: carbonaceous slates/metasiltstones Rating: A	Large high amplitude magnetic anomaly Rating: A	~1000m Phanerozoic cover Rating: C	3

TABLE 11.5: TICK HILL STYLE AU TARGETS

Identifier	Location (AMG)	Styles	Regional structural setting	Local structural setting	Lithostratigraphic setting	Alteration/Mineralisation indicators	Cover thickness	Overall rating	Comments
	E N	Target Style and Mineralising Event(s)	Key structural elements, geometries and kinematic histories relevant to target style, ie target zone in regional structural context	Key structural elements, geometries and kinematic histories relevant to target style – at scale of target zone or prospect	Unit(s), lithologies, ages Any key features with respect to target styles	Mineral occurrences of styles related to target Geochemical anomalism Any significant local lithological and alteration features	Depth to Proterozoic basement Estimate of target depths, if possible	Rating:	Any relevant comments, opinions, qualifiers from target generator Historical exploration data, if available
GTH1	E 392090 N 7590840	Tick Hill Mineralising Event: Wonga extension and plutonism	Wonga age extensional detachment fault zone Intersection zone of Wonga aged detachment and older fault corridors (pre-Barramundi Orogeny and cover sequence 1 structures) Proximal to a Wonga lower plate pluton Rating: A	irregularity in high strain zone /detachment fault which may be dilational – jog/lateral ramp? intersection with ENE-trending structure Rating: B	Unit(s): metasedimentary rocks Corella calc-silicates – Argylla metavolcanic Rating: A	Alteration/mineralisation indicators not evident at the scale of the geophysical interpretation Numerous small gold occurrences regionally within small upper plate brittle structures Rating: B	50-100m Rating: A	2	
GTH2	E 388030 N 7607600	Tick Hill Mineralising Event: Wonga extension and plutonism	Wonga age extensional detachment fault zone Intersection zone of Wonga aged detachment and older fault corridors (pre-Barramundi Orogeny and cover sequence 1 structures) roof zone (edge?) of Wonga lower plate pluton : St Mungo Granite Rating: A	irregularities in high strain zone /detachment fault which may be dilational – jog/lateral ramp? intersection with ENE-trending structure Rating: A	Unit(s): quartz-rich metasedimentary rocks around Corella calc-silicate – Argylla metavolcanic contact hornfelsed zone with numerous pegmatoid sills Rating: A	area includes the Tick Hill Au deposit Pre D_2 quartzo feldspathic veining and pegmatites, variably deformed extensive silicification and sodic alteration, magnetite-hematite bearing metasomatic rocks sourcing BLEG and soil gold anomalies Rating: A	Proterozoic subcrop – outcrop Rating: A	1	
GTH3	E 374320 N 7641630	Tick Hill Mineralising Event: Wonga extension and plutonism	Wonga age extensional detachment fault zone Intersection zone of Wonga aged detachment and older fault corridors (pre-Barramundi Orogeny and cover sequence 1 structures) Proximal to a Wonga lower plate pluton Rating: A	irregularity in high strain zone /detachment fault which may be dilational – jog/lateral ramp? intersection with ENE-trending structure Rating: B	Unit(s): metasedimentary rocks Corella calc-silicates – Argylla metavolcanic Rating: A	Alteration/mineralisation indicators not evident at the scale of the geophysical interpretation Numerous small gold occurrences regionally within small upper plate brittle structures Rating: B	Proterozoic subcrop – outcrop Rating: A	2	
GTH4	E 375590 N 7659910	Tick Hill Mineralising Event: Wonga extension and plutonism	Wonga age extensional detachment fault zone Intersection zone of Wonga aged detachment and older fault corridors (pre-Barramundi Orogeny and cover sequence 1 structures) Proximal to a Wonga lower plate pluton Rating: A	Detachment fault – high strain zone & intersection with ENE-trending structure Rating: C	Unit(s): metasedimentary rocks Corella calc-silicates – Argylla metavolcanic Rating: A	Alteration/mineralisation indicators not evident at the scale of the geophysical interpretation Numerous small gold occurrences regionally within small upper plate brittle structures Rating: B	Proterozoic subcrop – outcrop Rating: A	3	
GTH5	E 379910 N 7669560	Tick Hill Mineralising Event: Wonga extension and plutonism	Wonga age extensional detachment fault zone Intersection zone of Wonga aged detachment and older fault corridors (pre-Barramundi Orogeny and cover sequence 1 structures) Proximal to a Wonga lower plate pluton Rating: A	irregularity in high strain zone /detachment fault which may be dilational – jog/lateral ramp? intersection with ENE-trending structure Rating: B	Unit(s): metasedimentary rocks Corella calc-silicates – Argylla metavolcanic Rating: A	Alteration/mineralisation indicators not evident at the scale of the geophysical interpretation Numerous small gold occurrences regionally within small upper plate brittle structures Rating: B	Proterozoic subcrop – outcrop Rating: A	2	
GTH6	E 396160 N 7694440	Tick Hill Mineralising Event: Wonga extension and plutonism	Wonga age extensional detachment fault zone Intersection zone of Wonga aged detachment and older fault corridors (pre-Barramundi Orogeny and cover sequence 1 structures) Proximal to a Wonga lower plate pluton Rating: A	irregularity in high strain zone /detachment fault which may be dilational – jog/lateral ramp? intersection with ENE-trending structure Rating: B	Unit(s): metasedimentary rocks Corella calc-silicates – Argylla metavolcanic Rating: A	Alteration/mineralisation indicators not evident at the scale of the geophysical interpretation Numerous small gold occurrences regionally within small upper plate brittle structures Rating: B	Proterozoic subcrop – outcrop Rating: A	2	
GTH7	E 393870 N 7707900	Tick Hill Mineralising Event: Wonga extension and plutonism	Wonga age extensional detachment fault zone Intersection zone of Wonga aged detachment and older fault corridors (pre-Barramundi Orogeny and cover sequence 1 structures) Proximal to a Wonga lower plate pluton Rating: A	irregularity in high strain zone /detachment fault which may be dilational – jog/lateral ramp? intersection with ENE-trending structure Rating: B	Unit(s): metasedimentary rocks Corella calc-silicates – Argylla metavolcanic Rating: A	Alteration/mineralisation indicators not evident at the scale of the geophysical interpretation Numerous small gold occurrences regionally within small upper plate brittle structures Rating: B	Proterozoic subcrop – outcrop Rating: A	2	

TABLE 11.5 (continued)

Identifier	Location (AMG)	Styles	Regional structural setting	Local structural setting	Lithostratigraphic setting	Alteration/Mineralisation indicators	Cover thickness	Overall rating	Comments
	E N	Target Style and Mineralising Event(s)	Key structural elements, geometries and kinematic histories relevant to target style, ie target zone in regional structural context	Key structural elements, geometries and kinematic histories relevant to target style – at scale of target zone or prospect	Unit(s), lithologies, ages Any key features with respect to target styles	Mineral occurrences of styles related to target Geochemical anomalism Any significant local lithological and alteration features	Depth to Proterozoic basement Estimate of target depths, if possible	Rating:	Any relevant comments, opinions, qualifiers from target generator Historical exploration data, if available
GTH8	E 396410 N 7754110	Tick Hill Mineralising Event: Wonga extension and plutonism	Wonga age extensional detachment fault zone Intersection zone of Wonga aged detachment and older fault corridors (pre-Barramundi Orogeny and cover sequence 1 structures) Proximal to a Wonga lower plate pluton Rating: A	Large area with interpreted irregularities in detachment fault/ high strain zone which may be dilational – jogs/lateral ramps? A lot of irregularities similar to Tick Hill intersection with ENE-trending structures Rating: A	Unit(s): metasedimentary rocks Corella calc-silicates – Argylla metavolcanic Rating: A	Alteration/mineralisation indicators not evident at the scale of the geophysical interpretation Numerous small gold occurrences regionally within small upper plate brittle structures Rating: B	Proterozoic subcrop – outcrop Rating: A	1	
GTH9	E 416720 N 7757160	Tick Hill Mineralising Event: Wonga extension and plutonism	Wonga age (~1740Ma or ~1670Ma) extensional detachment fault zone Intersection zone of Wonga aged detachment and older fault corridors (pre-Barramundi Orogeny and cover sequence 1 structures) Proximal to a Wonga/Burstall aged pluton contact Rating: B	irregularities in high strain zone which may be dilatational – jog/lateral ramp? Offset along intersection with ENE-trending structure Rating: B	Unit(s): metasedimentary rocks Corella calc-silicates – Argylla metavolcanic Rating: A	Alteration/mineralisation indicators not evident at the scale of the geophysical interpretation Small Au-Cu workings Rating: B	Proterozoic subcrop – outcrop Rating: A	3	
GTH10	E 433740 N 7771130	Tick Hill Mineralising Event: Wonga extension and plutonism	Wonga age (~1740Ma or ~1670Ma) extensional detachment fault zone Intersection zone of Wonga aged detachment and older fault corridors (pre-Barramundi Orogeny and cover sequence 1 structures) Proximal to a Wonga lower plate pluton; possible core complexes to the north central lower plate intrusions Rating: B	irregularities in high strain zone which may be dilatational – jog/lateral ramp? Rating: B	Unit(s): interpreted metasedimentary rocks Corella calc-silicates Rating: A	Alteration/mineralisation indicators not evident at the scale of the geophysical interpretation Rating: B	Proterozoic subcrop – thin Phanerozoic cover, <50m Rating: A	3	
GTH11	E 428400 N 7807950	Tick Hill Mineralising Event: Wonga extension and plutonism	Wonga age (~1740Ma or ~1670Ma) extensional detachment fault zone Proximal to a Wonga lower plate pluton; possible core complex with central lower plate intrusion Rating: B	irregularities in high strain zone which may be dilatational – jog/lateral ramp? Rating: B	Unit(s): interpreted metasedimentary rocks Corella calc-silicates Rating: A	Alteration/mineralisation indicators not evident at the scale of the geophysical interpretation Rating: B	Proterozoic subcrop – 0-200m Rating: A	3	
GTH12	E 425100 N 7825720	Tick Hill Mineralising Event: Wonga extension and plutonism	Wonga age (~1740Ma or ~1670Ma) extensional detachment fault zone Proximal to a Wonga lower plate pluton; possible core complex with central lower plate intrusion Rating: B	irregularities in high strain zone which may be dilatational - jog/lateral ramp? Rating: B	Unit(s): interpreted metasedimentary rocks Corella calc-silicates Rating: A	Alteration/mineralisation indicators not evident at the scale of the geophysical interpretation Rating: B	Proterozoic subcrop – 0-200m Rating: A	3	
GTH13	E 421800 N 7842990	Tick Hill Mineralising Event: Wonga extension and plutonism	Wonga age (~1740Ma or ~1670Ma) extensional detachment fault zone Proximal to a Wonga lower plate pluton; possible core complex with central lower plate intrusion Rating: B	irregularities in high strain zone which may be dilatational - jog/lateral ramp? Rating: B	Unit(s): interpreted metasedimentary rocks Corella calc-silicates Rating: A	Alteration/mineralisation indicators not evident at the scale of the geophysical interpretation Rating: B	Proterozoic subcrop – 0-100m Rating: A	3	
GTH14	E 446220 N 7608540	Tick Hill Mineralising Event: Wonga extension and plutonism	~1670Ma (or Wonga aged?) extensional detachment fault zone Proximal to similar aged lower plate pluton & possible core complex Rating: B	irregularities in high strain zone which may be dilatational - jog/lateral ramp? Rating: B	Unit(s): interpreted metasedimentary rocks Corella calc-silicates Rating: A	Alteration/mineralisation indicators not evident at the scale of the geophysical interpretation Extensive metasomatism/magnetite alteration and Cu-Au mineralisation along the detachment, but largely Williams aged Rating: B	0-200m Phanerozoic cover Rating: A	3	

TABLE 11.6: OTHER PLUTON-RELATED GOLD TARGETS

Identifier	Location (AMG)	Styles	Regional structural setting	Local structural setting	Lithostratigraphic setting	Alteration/Mineralisation indicators	Cover thickness	Overall rating
	E N	Target Style and Mineralising Event(s)	Key structural elements, geometries and kinematic histories relevant to target style, ie target zone in regional structural context)	Key structural elements, geometries and kinematic histories relevant to target style – at scale of target zone or prospect	Unit(s), lithologies, ages Any key features with respect to target styles)	Mineral occurrences of styles related to target Geochemical anomalism Any significant local lithological and alteration features)	Depth to Proterozoic basement Estimate of target depths, if possible	Rating:
GOP1	E 590150 N 7817340	Epithermal-Mesothermal Mineralising Event: Williams age plutonism	Southern section of ring and radiating faults, interpreted as caldera collapse structure (alternative interpretation of ring fracture in the roof of an intrusion) Caldera to the north, interpreted to be Williams batholith age equivalent Rating: B	Intersection of N trending structures and ring structures Rating: B	Unit(s): Interpreted Croydon Volcanics (not outcropping in this area, based on magnetic signature) Lithologies: felsic volcanics, approximately Williams age extrusive equivalent Rating: A	Linear and curvilinear faults magnetic lows, possibly reflecting magnetite destructive alteration Rating: B	200-300m, Phanerozoic cover Rating: B	3

TABLE 11.7: DIAMOND TARGETS

Identifier	Location (AMG)	Styles	Regional structural setting	Local structural setting	Lithostratigraphic setting	Alteration/Mineralisation indicators	Cover thickness	Overall rating	Comments
	E N	Target Style Mineralising Event(s)	Key structural elements, geometries and kinematic histories relevant to target style, ie target zone in regional structural context	Key structural elements, geometries and kinematic histories relevant to target style – at scale of target zone or prospect	Unit(s), lithologies, ages Any key features with respect to target styles	Mineral occurrences of styles related to target Geochemical anomalism Any significant local lithological and alteration features	Depth to Proterozoic basement Estimate of target depths, if possible)	Rating:	Any relevant comments, opinions, qualifiers from target generator Historical exploration data, if available
D1	E 413420 N 7432400	Mineralising Event: None Known	along major basement structures reactivated older structure, active in the Cambrian & likely the Phanerozoic Rating: A	Near structural intersection of E-W trending faults (Wonga to Cambrian) and NNW trending older regional basement structure active during the Cambrian etc. Rating: A	Unit(s): Cambrian sediments. Magnetically quiet Lithologies: Undetermined Rating: B	isolated small bulls-eye magnetic high with possible structural control No known diamond occurrences in the region Rating: B	>1000m Rating: C	2	Possible intrusive pipe, no known review of feature for diamond potential
D2	E 400730 N 7503240	Mineralising Event: None Known	along major basement structures reactivated older structure, active in the Cambrian & likely the Phanerozoic Rating: A	Near structural intersection of NW trending Cambrian fault and NNW trending older regional basement structure active during the Cambrian etc. Rating: A	Unit(s): Cambrian sediments. Magnetically quiet Lithologies: Undetermined Rating: B	isolated small bulls-eye magnetic high with possible structural control No known diamond occurrences in the region Rating: B	500m Rating: C	2	Possible intrusive pipe, no known review of feature for diamond potential
D3	E 384980 N 7530670	Mineralising Event: None Known	along major basement structures reactivated older structure, active in the Cambrian & likely the Phanerozoic Rating: A	at a fault bend/jog in a NNW trending regional basement structure reactivated in the Cambrian etc. Rating: A	Unit(s): Cambrian sediments. Magnetically quiet Lithologies: Undetermined Rating: B	isolated small bulls-eye magnetic high with possible structural control No known diamond occurrences in the region Rating: B	100-200m Rating: A	2	Possible intrusive pipe, no known review of feature for diamond potential
D4	E 403770 N 7540310	Mineralising Event: None Known	along major NNW basement structures reactivated older structure, active in the Cambrian & likely the Phanerozoic Rating: A	at structural intersection of Cambrian NNE faults and NNW older regional basement structures active during the Cambrian etc. Rating: A	Unit(s): Cambrian sediments. Magnetically quiet Lithologies: Undetermined Rating: B	isolated small bulls-eye magnetic high with possible structural control No known diamond occurrences in the region Rating: B	300-500m Rating: B	2	Possible intrusive pipe, no known review of feature for diamond potential
D5	E 489340 N 7863300	Mineralising Event: None Known	along major NNE D3 structure reactivated older structure, active in the Cambrian & likely the Phanerozoic Rating: A	at structural intersection of Cambrian NNE faults and NNW older regional basement structures active during the Cambrian etc. Rating: A	Unit(s): Cambrian sediments. Magnetically quiet Lithologies: Undetermined Rating: B	isolated small bulls-eye magnetic high (reversely polarized?) with possible structural control No known diamond occurrences in the region Rating: C	500m Rating: C	3	Possible intrusive pipe, no known review of feature for diamond potential