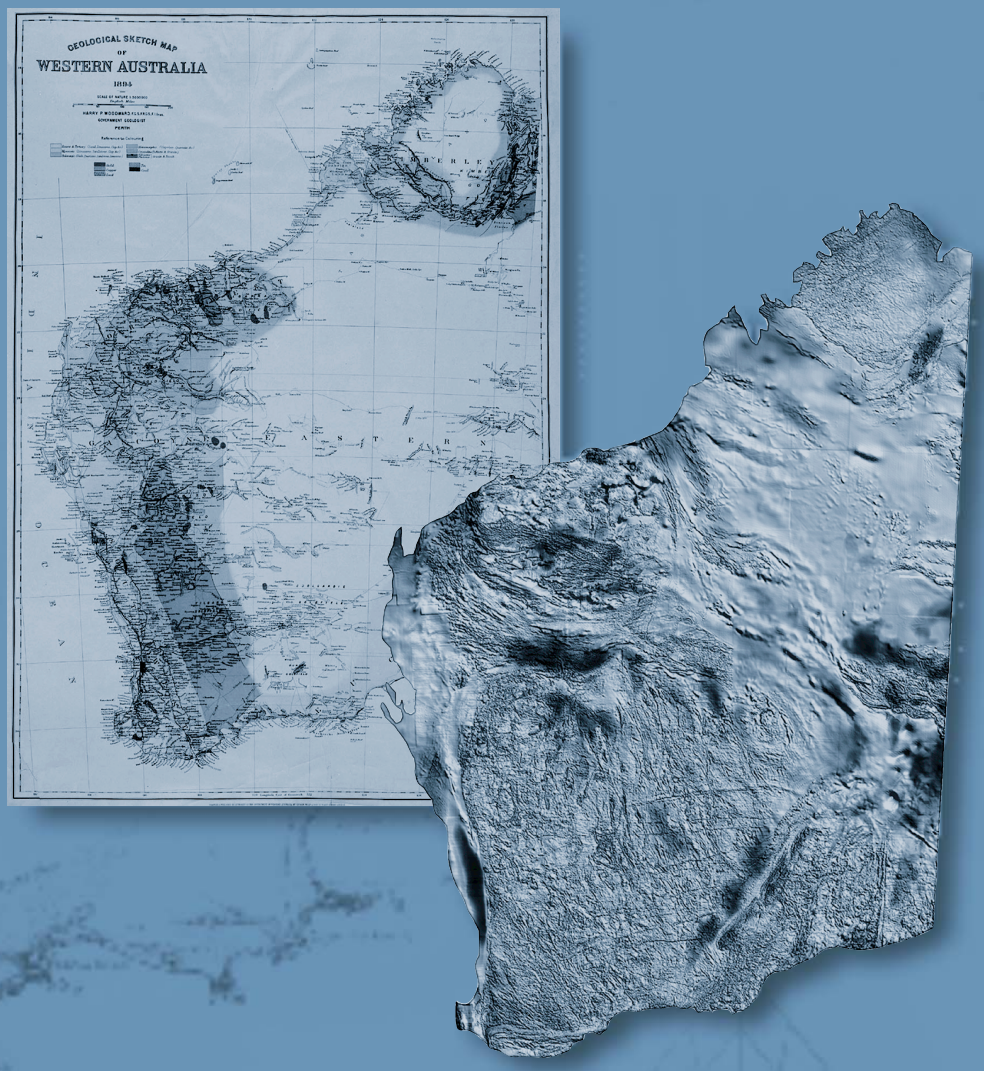
Department of
Mineral and Petroleum Resources

RECORD
2002/3

GEOLOGY AND MINERAL RESOURCES OF THE SOUTHERN CROSS – ESPERANCE REGION OF WESTERN AUSTRALIA

by P. B. Abeysinghe, D. J. Flint, J. Luckett, S. A. McGuinness, J. Pagel, D. B. Townsend, and F. Vanderhor



Geological Survey of Western Australia

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Record 2002/3

GEOLOGY AND MINERAL RESOURCES OF THE SOUTHERN CROSS – ESPERANCE REGION OF WESTERN AUSTRALIA

compiled by
P. B. Abeysinghe, D. J. Flint, J. Luckett[1], S. A. McGuinness[1], J. Pagel, D. B. Townsend, and F. Vanderhor[2]

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REFERENCE
The recommended reference for this publication is:
Abeysinghe, P. B., Flint, D. J., Luckett, J., McGuinness, S. A., Pagel, J., Townsend, D. B., and Vanderhor, F., 2002, Geology and mineral resources of the Southern Cross – Esperance Region of Western Australia: Western Australia Geological Survey, Record 2002/3, 119p.

National Library of Australia Card Number and ISBN 0 7307 5736 6

Grid references in this publication refer to the Geocentric Datum of Australia 1994 (GDA94). Locations mentioned in the text are referenced using Map Grid Australia (MGA) coordinates, Zone 50. All locations are quoted to at least the nearest 100 m.

Printed by Curtin Print & Design, Perth, Western Australia

Published 2002 by Geological Survey of Western Australia

Copies available from:
Information Centre
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100 Plain Street
EAST PERTH, WESTERN AUSTRALIA 6004
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Contents

Abstract 1

Chapter 1 Background

Data sources and methods of study 3
Geological maps at 1:500 000 scale 3
Mineral deposits and occurrences 4
Mineral potential 6

Chapter 2 Mineral tenure

Legislative framework 7
Mineral tenure 7
Mineral exploration 7

Chapter 3 Geological setting

Yilgarn Craton 13
Albany–Fraser Orogen 13
Bremer Basin 15
Cainozoic regolith 15

Chapter 4 Precious metals

Gold 17
Yilgarn Goldfield 17
Distribution and style of gold mineralization 28
Production and resources 29
Exploration potential 29
Higginsville–Norseman area 29
Distribution and style of gold mineralization 29
Production and resources 30
Exploration potential 31
Ravensthorpe area 31
Distribution and style of gold mineralization 31
Production and resources 31
Exploration potential 31
Potential for gold mineralization 31
Historical trends in production 32
Current trends 34

Chapter 5 Iron ore

Banded iron-formation 35
Koolyanobbing 35
Bungalbin and Mount Jackson 35
Windarling Peak 37
Honman Ridge – Round Top Hill 37
Mount McMahon 37
Mayfield 38
Southdown 38
Other iron ore deposits 38

Chapter 6 Alloying and speciality metals

Nickel 39
Geology 39
Southern Cross – Forrestania area 41

Forrestania nickel deposits 41
Trough Well prospect 41
Lake Johnston area 41
Maggie Hays 42
Emily Ann 42
Ravensthorpe area 42
RAV8 42
Ravensthorpe–Bandalup 42
Norseman area 42
Redross 42
Pioneer prospects 44
Mount Thirsty 45
Production and resources 45
Nickel potential 45
Tungsten 47
Higginsville 47
Dallisons Reward 47
Hopes Hill 47
Lake Seabrook 47
Vanadium 47
Medcalf – Vesuvius Hill 47
Tin 47
Mount Deans 47
Mount Thirsty 48
Holleton 48
Cattlin Creek 48
Tantalum–lithium–beryllium 48
Cattlin Creek 48
Mount Thirsty 48
Mount Day 48
Cocanarup 49
Mount Deans 49
Titanium–zirconium (heavy mineral sands) 49
Cheyne Bay 49
Gordon Inlet 49
Wray Bay 49
Condingup – Cape Arid National Park 50
Southern Hills 51
Dillon Bay 51
Oldfield Inlet 51
Margaret Cove 51
Stokes Inlet 51
Alexander River 51
Barker Inlet 51
Kundip 51
Heavy mineral sands potential 51
Manganese 52
Mount Chester 52
Elverdton 52
Kundip 52
Hamersley Gorge 52
Coppermine Creek (Naendip) 52
Manganese potential 52
Molybdenite 52
Needilup 52
Buldania 52
Kumarl Siding 52

Chapter 7 Base metals

Yilgarn Craton 53
Ravensthorpe area 53
Mount Desmond 53
Mount Cattlin 55
Mount McMahon 56
Kundip 56
West River 56
Mosaic 56
Other base metal deposits and occurrences 56
Jerramungup 56
Carterton 56
Marda 56

Beete 56
Mount Thirsty 56
Koolyanobbing 57
Hatters Hill 57
Albany–Fraser Orogen 57
Trilogy 57
Grass Patch 57
Hamersley Gorge 57
Naendip 57
Bremer Bay 57
Fraser Range area 58

Chapter 8 Energy minerals

Lignite 59
O'Sullivan 59
Scaddan 59
Fitzgerald River 59
Lort 60
Neridup 60

Chapter 9 Industrial minerals

Salt 61
Lake Deborah East 61
Pink Lake 61
Lake Biddy 61
Salt potential 61
Gypsum 61
Lake Cobham 62
Lake Cowan 62
Scaddan 62
Lake Tay 62
Moorine Rock 62
Lake Seabrook 62
Lake Gulson 65
Lake Camm 65
Lake Kathleen 65
Beete 65
Lake Julia 65
Pyramid Lake 65
Lake King 65
Lake Buchan 66
Gypsum potential 66
Magnesite 67
Ravensthorpe area 67
Archaean ultramafic and mafic association 67
Bandalup Creek 68
Kundip 68
Ravensthorpe 68
Bandalup Hill 68
Quality 68
Origin 68
Eocene Pallinup Siltstone association 69
Bandalup 69
Quality 69
Origin 69
Other magnesite occurrences in the Ravensthorpe area 69
Munglinup 69
Magnesite potential 69
Clays 69
Kerrigan and Bradley 70
Bromus 71
Lort River 71
Gibson 71
Other occurrences 72
Boxwood Hill 72
Lake Magenta 72
Noombenberry Rock 72
Skeleton Rocks 72
Karlgarin 72

Mount Mallet ... 72
Pingaring ... 72
Ongerup ... 73
Pallinup River ... 73
Gairdner South ... 73
Jacup Creek ... 73
West River ... 73
Boraginna Soak ... 73
Ryans Find (Mount Walter) ... 73
Potential for kaolin and construction-industry clay ... 73
Spongolite ... 73
Limestone ... 73
Lake Cowan – Buldania Rocks ... 74
Hopetoun ... 74
Boyadup Swamp (Esperance) ... 74
Limestone and limesand potential ... 74
Graphite ... 74
Munglinup River ... 74
Young River ... 75
Hyden ... 75
Dolomite ... 75
Vermiculite ... 75
Young River ... 75
Heany Find ... 75
Silica ... 75
Marbellup Hill (Esperance) ... 75
Lake Seabrook ... 75
Talc ... 75
Kundip ... 75
Fluorite ... 76
Lake Seabrook ... 76
Mount Norcott ... 76
Mount Ridley ... 76
Kyanite ... 76
Pyrite and pyrrhotite ... 76
Jarosite ... 76

Chapter 10 Construction materials and dimension stone

Construction materials ... 77
Ravensthorpe ... 77
Newdegate ... 77
Jackson ... 77
Hyden ... 77
Norseman ... 77
Esperance ... 77
Dimension stone ... 77
Fraser Range ... 78
Esperance ... 78
Karlgarin ... 78
Dimension stone potential ... 78

Chapter 11 Gem and semi-precious stones

Chalcedony ... 79
Rubellite ... 79

Chapter 12 Mineral potential

Methodology ... 81
Assessment results ... 93

Summary ... 95

Acknowledgements ... 97

References ... 99

Appendices

1. Gazetteer of locations of mines, deposits, prospects, and occurrences in the Southern Cross – Esperance Region 105
2. Mineral potential assessment criteria and weighting factors for major deposit types in the Southern Cross – Esperance Region 117
3. Definition of levels of resource potential and levels of certainty 118

Plate

1. Geology and mineral resources of the Southern Cross – Esperance Region

Figures

1. Location of study area, local government authorities, and operating mines within the Southern Cross – Esperance Region 5
2. Tenements granted or applied for under the Mining Act 1978, Southern Cross – Esperance Region 8
3. Exploration and production expenditure (Form 5 of the Mining Act, 1978) during the last three years for current tenements, with operating mines 10
4. Simplified geology and tectonic units of the study area, with operating mines 14
5. Gold deposits and occurrences in the Southern Cross – Esperance Region 18
6. Gold — total recorded production (kg), by project 20
7. Gold — total contained gold (kg) in measured and indicated resources, by project 26
8. Gold — total contained gold (kg) in inferred resources, by project 27
9. Gold deposits and occurrences in the Southern Cross area 28
10. Gold deposits and occurrences in the Norseman area 30
11. Gold deposits and occurrences in the Ravensthorpe area 32
12. Gold — pre-mining resources (recorded production plus gold remaining in existing resources), by project 33
13. Iron ore deposits and occurrences in the Southern Cross – Esperance Region 36
14. Nickel deposits and occurrences in the Southern Cross – Esperance Region 40
15. Geological map showing main tectonostratigraphic subdivisions of the Ravensthorpe greenstone belt 43
16. Nickel and base metal deposits and occurrences in the Ravensthorpe area 44
17. Heavy mineral sand deposits and occurrences in the Southern Cross – Esperance Region 50
18. Gypsum deposits and occurrences in the Southern Cross – Esperance Region 63
19. Magnesite deposits and occurrences in the Southern Cross – Esperance Region 66
20. Kaolin deposits and occurrences in the Southern Cross – Esperance Region 70
21. Areas prospective for orogenic gold deposits in the Southern Cross – Esperance Region 82
22. Areas prospective for iron ore in the Southern Cross – Esperance Region 83
23. Areas prospective for nickel sulfides in komatiites in the Southern Cross – Esperance Region 84
24. Areas prospective for nickel sulfides in layered intrusions in the Southern Cross – Esperance Region 85
25. Areas prospective for nickel-bearing laterites in the Southern Cross – Esperance Region 86
26. Areas prospective for base metals in volcanogenic massive sulfide deposits in the Southern Cross – Esperance Region 87
27. Areas prospective for stratabound base metal deposits in the Southern Cross – Esperance Region 88
28. Areas prospective for heavy mineral sands in the Southern Cross – Esperance Region 89
29. Areas prospective for lignite deposits in the Southern Cross – Esperance Region 90
30. Areas prospective for diamonds in the Southern Cross – Esperance Region 91
31. Cumulative prospectivity for the Southern Cross – Esperance Region 92

Tables

1. Quantity and value of minerals produced from the Southern Cross – Esperance Region for 1999 4
2. Mineral tenement statistics as at April 2001: tenements granted and tenements under application 9
3. Cumulative drilling statistics from within the Southern Cross – Esperance Region 9
4. Discoveries of mineral deposits in the Southern Cross – Esperance Region since January 1995 11
5. Gold production from the Southern Cross – Esperance Region for 1999, by project and site 19
6. Total gold and silver production of the Southern Cross – Esperance Region to December 1985 21
7. Gold resources for deposits in the Southern Cross – Esperance Region 22
8. Gold productivity of greenstone belts in the Southern Cross – Esperance Region 34
9. Iron ore resources in the Southern Cross – Esperance Region 37
10. Portman Ltd's iron ore production plan for the period 2000–05 37
11. Production of nickel concentrate from Forrestania, from 1993 to 1999 45
12. Nickel resources for deposits in the Southern Cross – Esperance Region 46
13. Copper production from the Southern Cross – Esperance Region 54
14. Gypsum production in the Southern Cross – Esperance Region 62

15. Minor gypsum deposits and occurrences in the Southern Cross – Esperance Region 64
16. Resources of gypsum at the Lake Cowan deposit 65
17. Resources of gypsum at the Beete deposit 65
18. Minor occurrences of magnesite in the Southern Cross – Esperance Region 67
19. Partial chemical analyses of magnesite associated with ultramafic–mafic rocks and the Pallinup Siltstone 68
20. Characteristics of kaolin from the Bradley deposit 71
21. Limestone in the Southern Cross – Esperance Region 74

Geology and mineral resources of the Southern Cross – Esperance Region of Western Australia

compiled by
P. B. Abeysinghe, D. J. Flint, J. Luckett, S. A. McGuinness, J. Pagel, D. B. Townsend, and F. Vanderhor

Abstract

This assessment of the geology and mineral resources of the Southern Cross – Esperance Region comprises several elements: compilation of a new 1:500 000-scale geological map of the area (presented at 1:1 000 000 scale); collation of data on mineral occurrences and deposits; a review of the controls on mineralization; and a preliminary assessment of the mineral potential for ten of the major deposit types that are known to occur or are likely to occur within the region. A new 1:1 000 000-scale geological map and an extensive digital dataset on CD accompany this Record.

The study area covers 147 089 km^2 and represents 5.9% of onshore Western Australia. About 30% of the study area is presently (as at April 2001) covered by mining tenements; 1549 tenements are granted (20 883 km^2) and a further 806 tenements (27 566 km^2) are under application. The large number of pending tenement applications partly reflects the impact of Native Title negotiations on the process of granting tenure.

Mineral production in the study area during 1999 was worth about $388 million, representing 3.2% of the State's total value of mineral and petroleum production. Gold is the predominant mineral commodity in the Southern Cross – Esperance Region, representing 71.2% of the total value for the region and 9.5% of the State's gold production. Other significant commodities produced and their proportion of the State's output (by value of 1999 production) are granite dimension stone (85.5%), dolomite (100%), gypsum (2.7%), iron ore (0.8%), limesand and limestone (15.7%), nickel (7.2%), salt (2.9%), and sand (0.2%).

The Southern Cross – Esperance Region contains 38 mine sites that are operating or under development. In addition, there are about 600 current mineral exploration projects. The total number of occurrences, prospects, and mines covered in this report is about 2350.

The exploration history of the area shows that gold has been the primary commodity sought — about 75% of all past and current exploration expenditure is for gold. Gold still offers major opportunities for further exploration and new discoveries.

Total cumulative mining and exploration expenditure within the study area for the last ten years is dominated by gold and totals about $3 billion, about 10% of the State figure for the same period. Although the Southern Cross – Esperance Region constitutes only about 5.9% of the State, it has attracted 10% of mineral exploration expenditure. It should be noted, however, that these figures include mining production costs, and are therefore not directly indicative of the amount of exploration expenditure.

Minerals that have been produced from the Southern Cross – Esperance Region, but are not currently produced, include copper (Ravensthorpe area), magnesite (Bandalup), tin (Norseman, Mount Deans, Mount Thirsty, and Holleton), tungsten (Higginsville, Dallisons Reward, and Hopes Hill), tantalite and spodumene (Cattlin Creek, Cocanarup), manganese (Mount Chester), heavy mineral sands (Cheyne Bay), graphite (Munglinup River), vermiculite (Young River and Heany Find), pyrite and pyrrhotite as a source of sulfur (Iron King mine and Mount Caudan, respectively), and jarosite as a potash fertilizer (Cordingup Creek). In addition there are minerals in the Southern Cross – Esperance Region that have potential for production, but for which there is no recorded production: these include lignite, kaolin, spongolite, molybdenite, silica sand, talc, fluorite, and kyanite.

The mineral projects most likely to be developed or to undergo extensive exploration and/or evaluation within the next ten years are: gold in the Forrestania – Lake Cowan area and along the margin of the Yilgarn Craton; nickel in the Lake Johnston and Ravensthorpe areas; tantalum from the Norseman and Ravensthorpe areas; lignite at O'Sullivan and Scaddan in the Bremer Basin; expansion of iron ore mining at Koolyanobbing; magnesite in the Phanerozoic Bremer Basin and over the Archaean greenstone belts; base metals in the Proterozoic Mount Barren Beds and Albany–Fraser Orogen; gypsum; and new varieties of dimension stone.

KEYWORDS: Yilgarn Craton, Albany–Fraser Orogen, Bremer Basin, Southwest Gneiss Terrane, Southern Cross Terrane, Eastern Goldfields Granite–Greenstone Terrane, mineral resources, mineral production, mineral potential, gold, iron ore, alloying and speciality metals, energy minerals, base metals, industrial minerals, construction materials and dimension stone, gem and semi-precious stones.

Chapter 1

Background

This Record evolved from the Southern Cross – Esperance Regional Minerals Study, which examined the development potential and infrastructure needs of Western Australia's Southern Cross – Esperance Region (Fig. 1), and was undertaken on a partnership basis between the Commonwealth, State Government, and industry as part of the Federal Government's Regional Minerals Program. That report, with its associated maps and digital data, was used by the consultant (Connell Wagner Pty Ltd) appointed by the Department of Resources Development* (DRD) to carry out the second part of the Southern Cross – Esperance Regional Minerals Study. Connell Wagner undertook a detailed assessment of the development scenarios and infrastructure requirements for the mining industry in the region.

The minerals sector is important to the economy of the region and, in 1999, mining in the study area of the Southern Cross – Esperance Region was worth about $388 million, of which the gold sector represents 71.2% of the total (Table 1). Commodities currently mined in the Southern Cross – Esperance Region (in alphabetical order and with the percentage of the State's total production for 1999) are granite dimension stone (85.5%), dolomite (100%), gold (9.5%), gypsum (2.7%), iron ore (0.8%), limesand and limestone (15.7%), nickel (7.2%), salt (2.9%), and sand (0.2%). Summary details of the production (quantity, value, and Local Government Authorities) are shown in Table 1. This 1999 production is from the shires of Coolgardie, Dundas, Esperance, Kondinin, Lake Grace, Ravensthorpe, and Yilgarn (Fig. 1).

Data sources and methods of study

The study was entirely office based, using the following databases and datasets as the prime sources of information:

- The Department of Mineral and Petroleum Resources' (MPR) MINEDEX database (Mines and mineral deposits information database) is the prime source of information on major mineral deposits, locations, mineral resources, production, deposit type, and stage of development;
- Company statutory mineral exploration reports submitted annually to MPR and held within the Geological Survey of Western Australia's (GSWA) M-Series archival dataset, and indexed through the Western Australian mineral exploration database (WAMEX), are the main source of historical exploration activity, mineral occurrence information, and site-specific geology;
- GSWA publications;
- MPR's current and archived tenements in the TENGRAPH database, with related information (e.g. Mining Act Form 5 expenditure) from TENDEX;
- The MINMET database provides comprehensive coverage of all reports by publicly listed companies to the Australian Stock Exchange (ASX). Similar but not identical information is also obtained through trade magazines such as Paydirt, Gold Gazette, and Metals Gazette. These are backed up by a comprehensive press cuttings library of project development information;
- Literature-review facilities, both within GSWA and through subscription (e.g. WINSPIRS);
- The Geological Survey's WAMIN database (Western Australian mineral occurrence database) contains extensive data on mineral occurrences, ranging from large mines to small occurrences. The main source of data for WAMIN is company statutory exploration reports indexed within the Geological Survey's WAMEX system. WAMIN also includes data from published literature and from MINEDEX.

Geological maps at 1:500 000 scale

Compilation of the geology of the area at 1:500 000 scale involved two main components — a compilation of a composite geological legend from the twelve 1:250 000-scale mapsheets, two 1:1 000 000 mapsheets and the 1:2 500 000 State geological map; and a new interpretation of the bedrock geology using the available magnetic data. The new interpretation of the bedrock geology was required as the published geological map sheets show outcrop geology and extensive areas of regolith (surficial) units that overlie bedrock units.

The study area covers all or part of twelve 1:250 000 map sheets — BOORABBIN* (Hunter, 1988), BREMER BAY

* Department of Resources Development merged with Department of Minerals and Energy in 2001 to form the Department of Mineral and Petroleum Resources

* Capitalized names refer to standard 1:250 000 map sheets

Table 1. Quantity and value of minerals produced from the Southern Cross – Esperance Region for 1999

Commodity	*LGA*	*Quantity of ore or concentrate*	*Unit of quantity*	*Contained metal (t, kg) or grade of ore (%)*	*Value ($A)*	*% of State total by quantity*	*% of State total by value*
CONSTRUCTION MATERIALS							
Sand	Yilgarn	3 406	t		17 033	0.2	0.2
Dimension stone (granite)	Dundas	3 886	t		784 280	83.2	85.5
GOLD	Coolgardie		kg	1 147	16 545 594	0.5	0.6
	Dundas		kg	3 472	48 254 624	1.7	1.7
	Yilgarn		kg	15 231	211 252 430	7.3	7.2
	Total			**19 850**	**276 052 648**	**9.5**	**9.5**
GYPSUM	Dundas	17 024	t		102 145	1.3	0.4
	Esperance	14 562	t		87 372	1.1	0.4
	Lake Grace	43 484	t		346 795	3.3	1.5
	Ravensthorpe	9 484	t		66 388	0.7	0.3
	Yilgarn	2 220	t		18 010	0.2	0.1
	Total	**86 774**			**620 710**	**6.5**	**2.7**
IRON ORE	Yilgarn	1 285 502	t	46.96%	27 187 418	0.9	0.8
LIMESAND–LIMESTONE–DOLOMITE							
Dolomite	Lake Grace	3 086	t		67 892	100.0	100.0
Limesand–limestone	Dundas	137 008	t		2 055 120	4.7	15.7
NICKEL	Kondinin	64 245	t	8 881	75 507 939	8.1	7.2
SALT	Esperance	10 274	t		501 131	0.1	0.3
	Yilgarn	119 470	t		4 818 872	1.3	2.6
	Total	**129 744**			**5 320 003**	**1.4**	**2.9**
TOTAL					**387 613 043**		**3.2**

NOTES: $A value is that prevailing in 1999
LGA: Local Government Authority
SOURCE: modified from Statistics digest of mineral and petroleum production, 1999 (DME, 2000)

(Thom and Chin, 1984a), ESPERANCE – MONDRAIN ISLAND (Morgan, 1972), HYDEN (Chin et al., 1984a), JACKSON (Chin et al., 1983), KALGOORLIE (Wyche, 1993), LAKE JOHNSTON (Gower and Bunting, 1974), NEWDEGATE (Thom et al., 1984a), NORSEMAN (Doepel et al., 1972), RAVENSTHORPE (Thom and Lipple, 1974), SOUTHERN CROSS (Gee, 1981), and WIDGIEMOOLTHA (Griffin and Hickman, 1988). The outcrop geology was then re-interpreted on-screen using magnetic data — mainly total magnetic intensity data, with a line spacing of 1500 m, from Geoscience Australia (GA), formerly Australian Geological Survey Organisation (AGSO). The interpretation of the geology of the JACKSON area follows the recently published AGSO map (Mackey, 1999), which is based on total magnetic intensity data, with a line spacing of 400 m. Recent GSWA mapping of the JACKSON sheet at 1:100 000 scale was also incorporated into the interpretation (Riganti and Chen, 2000).

The bedrock geology interpretation was then merged with other GSWA digital bedrock geology data for the Parker Range area (Keats, 1986), the Kalgoorlie Terrane (Swager and Griffin, 1990), the Ravensthorpe area (Witt, 1997), and the Albany and Esperance 1:1 000 000 sheet areas (Myers, 1995a,b). The working platform was ArcView, but some of the original digital data capture was in MapInfo. An attempt was made to ensure consistency of linework (where appropriate) of geological boundaries between the outcrop and bedrock geology themes.

The linework detail (geological boundaries) is generally that at 1:250 000 scale, but most units have been combined to provide broader polygons of uniform colour for improved visual presentation at 1:500 000 and 1:1 000 000 scales. However, the more detailed geological linework information for each original mapping unit with its individual geological codes is retained in the digital file (on CD).

The map showing bedrock geology and structure is presented at 1:1 000 000 scale as Plate 1.

Mineral deposits and occurrences

Plate 1, 'Geology and mineral resources of the Southern Cross – Esperance Region', shows operating mines, historical mines, and undeveloped deposits (from the MPR MINEDEX database), as well as mineral occurrences and

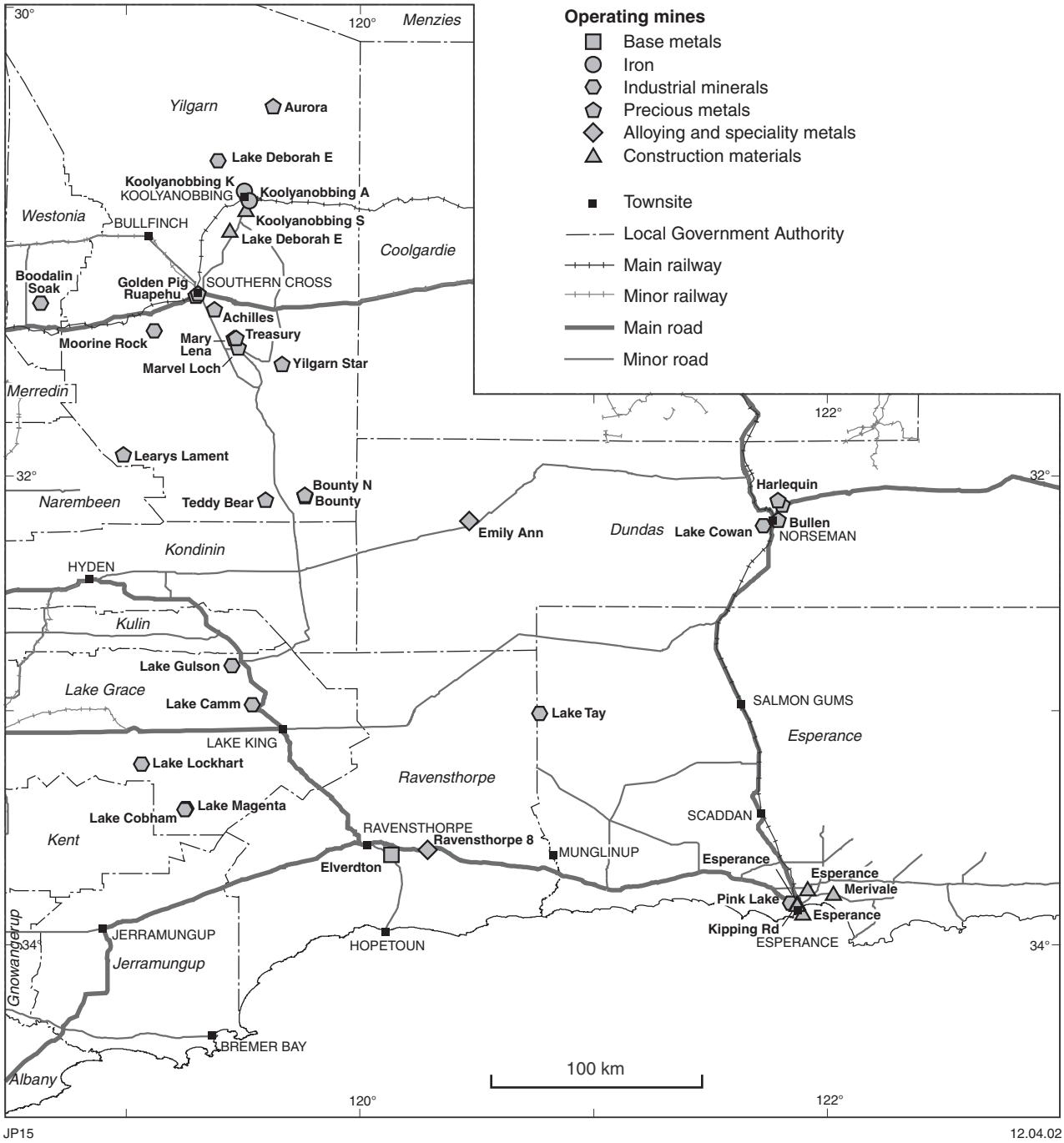

Figure 1. Location of study area, local government authorities, and operating mines within the Southern Cross – Esperance Region

prospects collated from non-confidential company reports and the MINMET database. The gazetteer (Appendix 1) contains locations for all sites. All operating mines and a selection of deposits and occurrences are named on Plate 1. Further deposits and occurrences have been labelled on the appropriate commodity-specific figures. Any deposit or occurrence mentioned in the text may be located on Plate 1 using the gazetteer (Appendix 1). A few occurrences could not be located with sufficient accuracy to be included in the dataset and are therefore not shown on the map. They have been included for completeness and their locations are described in the text.

For this study the geological information on mineral occurrences and prospects has been compiled within the Geological Survey's WAMIN database — a system used successfully by the Geological Survey for recent mineral occurrence and exploration potential studies of the West Pilbara (Ruddock, 1999), the East Kimberley (Hassan, 2000), and the East Pilbara (Ruddock, 2001). These studies have included a digital spatial index of mineral exploration activities in open-file WAMEX reports (e.g. areal extent and exact locations of drillholes, geochemical surveys, and geophysical survey lines). Because of the time constraints and the very large area of

this survey, indexing and digitizing of exploration activities was not undertaken. The study concentrated on the compilation of locations, plus information on the more significant mineral occurrences. For larger deposits, for example a current mine or a deposit with estimated resources, information already exists within the MPR MINEDEX database. The definition of a 'mineral occurrence', as used in the above-mentioned prospectivity studies, was also adopted for this study. The emphasis here is very much on drilled prospects (with anomalous results). Minimum intersections for mineral occurrences in drillholes or trenches for a number of commodities are given in the file **datadict.pdf** (located on the CD). These lower limits for a mineral occurrence are most reliably based on company exploration information in WAMEX; however, professional judgement was used if shorter intercepts at higher grade (or vice versa) were involved. Any diamonds or gemstones constitute a mineral occurrence, including diamondiferous kimberlite.

Because of the time constraints on the Southern Cross – Esperance study, WAMIN data entry has been condensed (less detail has been compiled compared to the Geological Survey's normal prospectivity studies). Material collated included:

- essential site-location details
- prospect name
- commodity group
- commodities
- prospect expression (e.g. outcrop, geochemical anomaly, and drillhole intersection)
- mineralization style
- comments
- references, and
- links to other data (e.g. mineral resources listed in MINEDEX).

Information in the WAMIN database was compiled from a variety of sources, the main source being the open-file statutory mineral exploration reports (WAMEX). There are about 7000 mineral exploration reports indexed in WAMEX for the study area, but only about 2500 of these are on open-file. Priority was given to those reports containing drilling information (about 1900) and to the most recent reports on major exploration projects. About 380 mineral occurrences were identified from these reports. For mineral occurrences and deposits mentioned in confidential statutory reports of WAMEX, only publicly available information from the MINMET database and public announcements to the Australian Stock Exchange were used. These procedures identified about fifty additional mineral occurrences, but there is a drawback in that the publicly available information is often too incomplete for the purposes of this study. In such cases, rather than breach confidentiality, some known occurrences have been omitted from this report.

The total number of occurrences, prospects, and mines for the Southern Cross – Esperance study is about 2350, of which 430 sites are in WAMIN and 1927 sites are in MINEDEX. There is some overlap and repetition between the two databases. Although much information has been collated, it should be noted that it is still incomplete, and hence some care is required when interpreting the data and drawing conclusions.

In order to highlight the distribution of the major commodity groupings on the maps, mineral occurrences and prospects have been differentiated into eight major commodity categories. The categorization is determined by the major mineral targeted or identified in the deposit or occurrence. Shown below are the commodity groups with the minerals or elements that are included in each category:

Commodity group	*Commodity*
Alloying and speciality metals	Beryllium, lithium, manganese, molybdenum, nickel, tantalum, tin, titanium, tungsten, vanadium, zirconium
Base metals	Copper, lead, zinc
Construction materials	Sand, gravel, aggregate, ornamental dimension stone
Energy minerals	Lignitic coal
Gem and semi-precious stones	Chalcedony, rubellite (tourmaline)
Industrial minerals	Clays, dolomite, fluorite, graphite, gypsum, jarosite, kyanite, limestone, magnesite, pyrite, pyrrhotite, salt, silica, spongolite, talc, vermiculite
Iron	Iron ore
Precious metals	Gold, silver

Mineral potential

The mineral potential of the study area was assessed by determining the types of mineral deposits likely to be found under the geological conditions known or believed to exist within the area. The general methodology used was developed by the United States Geological Survey (USGS), and is described by Marsh et al. (1984), Taylor and Steven (1983) and Dewitt et al. (1986). The method has been utilized successfully for mineral resource assessments of State Forest areas in the South West of the State (Bureau of Resource Sciences and GSWA, 1998). The appraisal for the Southern Cross – Esperance area was carried out by a panel of geologists drawn from industry and the Geological Survey of Western Australia.

Chapter 2

Mineral tenure

Legislative framework

In Western Australia all minerals and petroleum are owned by the Crown, except for those on land alienated in fee simple before 1899, in which case minerals other than gold, silver, and precious metals are the property of the land owner.

The rights to explore for and develop minerals are granted and administered under legislation different from that for petroleum. Minerals are considered under 'onshore' legislation and 'offshore' legislation (for areas of seas adjacent to Western Australia). The definition of 'onshore' includes all on-land Western Australia to the coastline and a three nautical mile extension out to sea. The coastline is strictly defined as 'Australia's territorial sea baseline', which is generally low-watermark along the coast but includes in places bays, indentations, and islands that are considered integral or enclosed within the more general line of the coastline.

For minerals, the 'onshore' areas are considered within the Western Australian Mining Act 1978. Major mining projects may also be controlled by a Special Agreement Act entered into between the developers and the State, and ratified by Parliament. There are currently no such State Agreements within the study area, although preliminary discussions have commenced between the State government and Portman Ltd about an Agreement Act to cover the Koolyanobbing iron ore project.

'Offshore' minerals are governed by the Commonwealth of Australia's Offshore Minerals Act 1994, which was enacted on 1 March 1994 replacing the Minerals (Submerged Lands) Act that had operated since 1 February 1990. Prior to 1990, there was no effective legislation to deal with offshore mineral exploration and development. The Commonwealth and State Governments jointly manage the Offshore Minerals Act.

Petroleum titles are issued under three pieces of legislation. The area additional to that for minerals is in the separation of the zone between the territorial sea baseline and the line three nautical miles offshore. Onshore is administered under the State's Petroleum Act 1967; the territorial sea by the Petroleum (Submerged Lands) Act 1982; and the offshore areas by the Commonwealth Petroleum (Submerged Lands) Act 1967. In the latter case, the same joint management and designated administrative responsibilities apply as those indicated for minerals. All of the petroleum acts share a common code in Western Australia. There are no current petroleum titles within the study area.

Mineral tenure

The Southern Cross – Esperance study area covers 147 089 km^2, which constitutes 5.9% of the Western Australian landmass. The coverage and distribution of mining tenements is shown on Figure 2. Tenements have been divided into two groups:

- Tenements current as at April 2001
- Tenements under application as at April 2001.

About 30% of the study area is covered by mineral tenements (granted and pending) compared with about 20% for the whole State. The total number of tenements in force for the study area is 1549 (covering 20 883 km^2). A further 806 mining tenements are under application (covering 27 566 km^2). The large number of pending applications reflects the impact of Native Title negotiations on the process of granting tenure.

Statistics for the different types of mineral tenements are listed in Table 2. This table shows that for most categories, the percentages for titles and areas compared with totals for Western Australia are greater than the 5% (up to 11.4%) that constitute the size of the study area in relation to the size of Western Australia. This may well reflect the relatively high prospectivity of granite–greenstones.

Tenure in the study area covers mainly the Archaean greenstone belts of the Yilgarn Craton that contain gold, nickel, and base metal deposits. Tenure in these areas is mature and this is reflected in the relatively high number of Mining Leases. Tenure outside the greenstone belts mostly covers Proterozoic rocks along the southern and eastern boundary of the Yilgarn Craton, where most of the tenements are held for base metal exploration. Much of this interest in base metals is recent and this is reflected in the high number of Exploration Licence applications.

Mineral exploration

The exploration history of the area confirms that gold has been the predominant commodity sought. About 900 projects have been released to open file in WAMEX and,

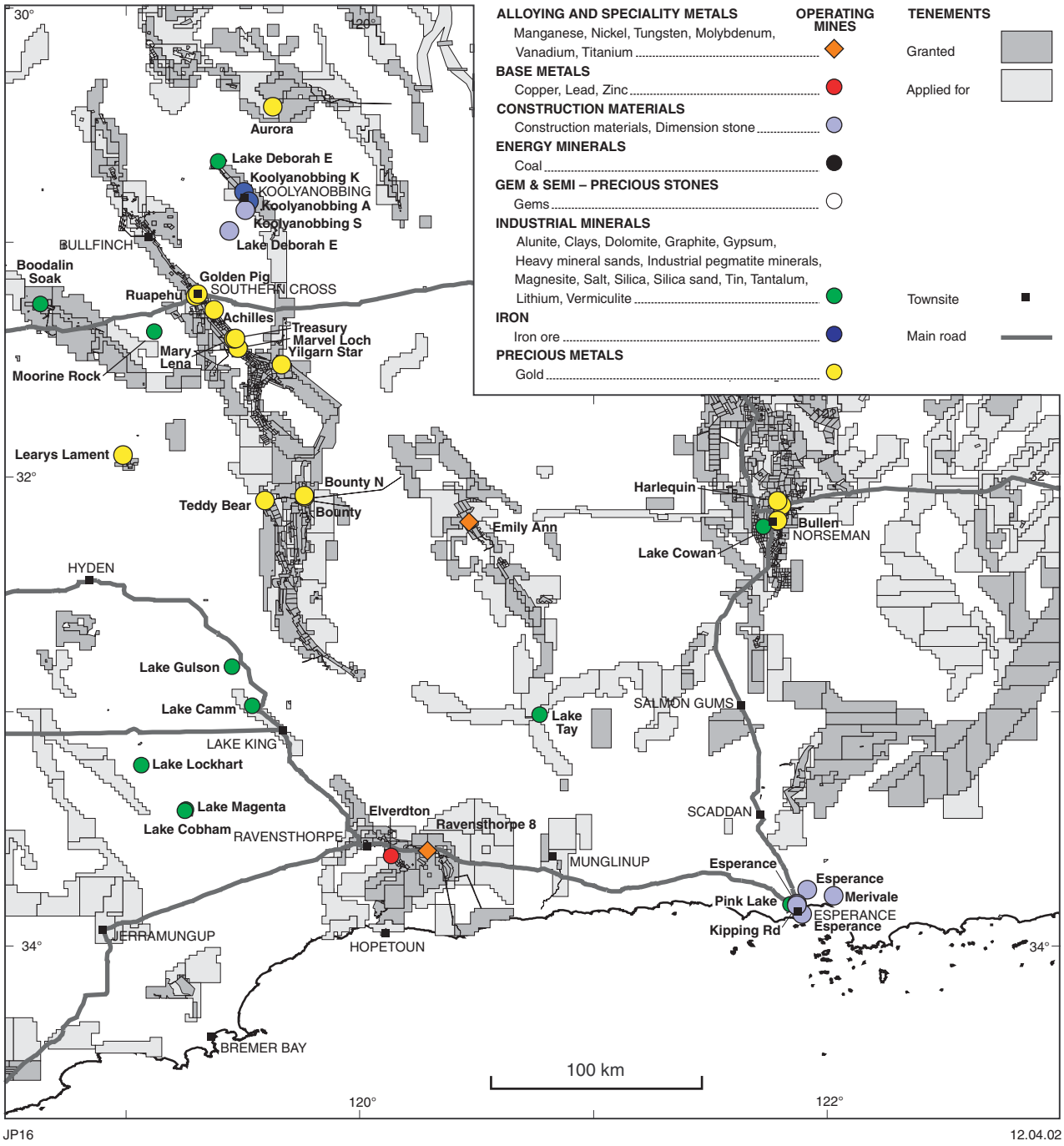

Figure 2. Tenements granted or applied for under the Mining Act 1978, Southern Cross – Esperance Region

of these, over 600 were gold exploration projects. There are about 550 current exploration projects in the study area, 450 of which are predominantly for gold. The other commodities sought are nickel, base metals, iron, industrial minerals, and coal–lignite.

Interest in gold over much of the area has remained steady over a long time, whereas exploration interest for other commodities has shown marked fluctuations. Nickel and base metals exploration was strong in the 1970s (over 150 projects on open file). Recently, there has been an upsurge in exploration for lateritic nickel and base metals except in the Forrestania area where nickel mining operations ceased in 1999.

Total cumulative expenditure within the study area for the last three years is about $500 million. The figure for the State for the same period is about $11 billion. The region constitutes about 5.9% of the State's area, and it has attracted about 5% of expenditure. It should be noted, however, that this expenditure includes production costs on mining leases, and is therefore not directly indicative

Table 2. Mineral tenement statistics as at April 2001: tenements granted and tenements under application

	Tenement type			*Area of tenure (km²)*		
	Study area	*WA*	*%*	*Study area*	*WA*	*%*
			Tenements granted			
Exploration licence	309	3 354	9.2	17 962	203 215	8.8
Prospecting licence	466	5 761	8.0	505	7 252	7.0
Mining lease	555	4 850	11.4	2 300	17 991	12.8
Other	219	3 813	5.7	116	35 626	0.3
Total	**1 549**	**17 778**	**8.7**	**20 883**	**264 084**	**7.9**
			Tenement applications			
Exploration licence	239	3 058	7.8	24 668	290 539	8.5
Prospecting licence	91	1 790	5.1	109	2 465	4.4
Mining lease	458	5 306	8.6	2 036	25 142	8.0
Other	18	468	3.8	753	11 602	6.5
Total	**806**	**10 622**	**7.6**	**27 566**	**289 748**	**9.5**

of relative exploration expenditure. The distribution of reported expenditure (specifically Form 5 of the Mining Act) over the last three years for current tenements is shown on Figure 3.

Another method of assessing the level of exploration activity carried out within an area is to consider the total metres drilled for the different types of drilling (diamond (DD), reverse circulation (RC), and rotary airblast (RAB)). Drilling statistics for 1989–99 are shown in Table 3, and are derived from mineral exploration reports submitted to MPR under Section 115A of the Mining Act, 1978. The figures have been grouped together for the main mining and exploration areas, and are based on map sheet areas. Data for the Southern Cross area combine all drilling reported for SOUTHERN CROSS, JACKSON, and HYDEN; the Ravensthorpe and Lake Johnston areas contain data on their respective 1:250 000 sheets; and figures for Norseman combine drill data from NORSEMAN and three adjacent 1:100 000 mapsheets (COWAN, YARDINA, and YARDILLA). The figures show that compared with metres drilled for the entire State, both diamond drilling and RC drilling are fairly high, reflecting more mature projects, especially around Norseman. Most of the greenfields

Table 3. Cumulative drilling statistics from within the Southern Cross – Esperance Region

Area	*Drill type*	*No. of holes*	*Metres drilled*	*Average depth (m)*	*% of WA (metres drilled)*
Southern Cross	Diamond	1 450	178 982	123	2.8
	RC	26 130	1 081 670	41	3.5
	RAB	55 897	1 458 940	26	5.3
Ravensthorpe	Diamond	70	9 280	133	0.1
	RC	2 222	87 693	39	0.3
	RAB	1 471	48 930	33	0.2
Lake Johnston	Diamond	382	130 316	341	2.1
	RC	669	64 746	97	0.2
	RAB	4 431	113 987	26	0.4
Norseman	Diamond	3 701	1 127 225	305	17.8
	RC	41 431	3 375 849	81	10.9
	RAB	18 469	612 553	33	2.2
Subtotal	**Diamond**	**5 603**	**1 445 803**	**258**	**22.8**
(study area)	**RC**	**70 452**	**4 609 958**	**65**	**14.8**
	RAB	**80 268**	**2 234 410**	**28**	**8.1**
WA total	**Diamond**	**34 874**	**6 342 666**	**182**	
	RC	**591 464**	**31 104 412**	**53**	
	RAB	**902 885**	**27 706 893**	**31**	

NOTES: Information from statutory mineral exploration reports submitted to DME between 1989 and 1999
Department of Minerals and Energy now Department of Mineral and Petroleum Resources (MPR)

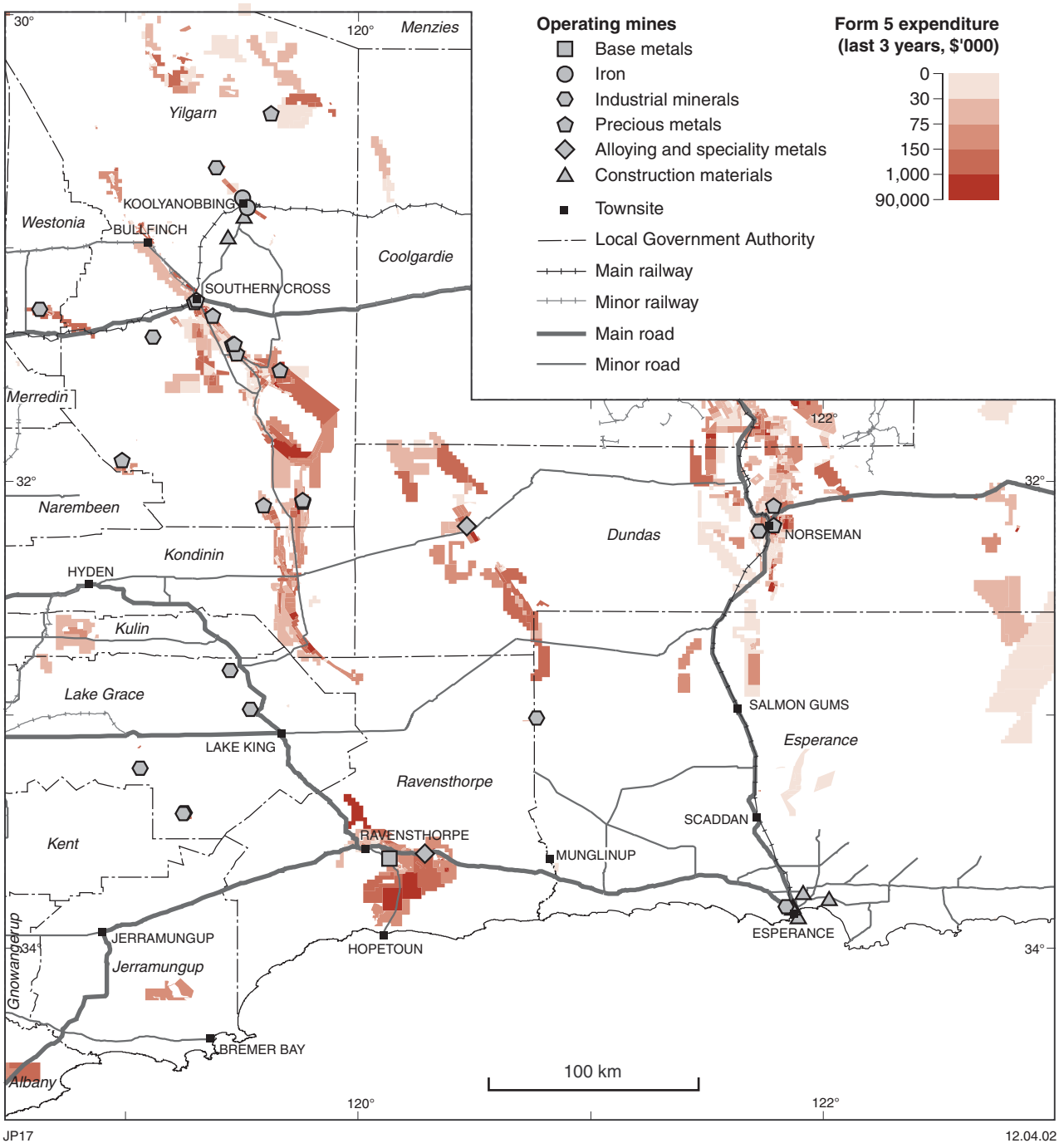

Figure 3. Exploration and production expenditure (Form 5 of the Mining Act, 1978) during the last three years for current tenements, with operating mines

exploration, as expressed through the amount of shallow drilling (RAB), is in the Southern Cross area. The drilling statistics also show a marked difference in average depth for diamond and RC drilling between some areas. In the Lake Johnston area (where most of the drilling is around the Maggie Hays nickel deposit), the average diamond hole depth is 340 m, and this reflects the depth of nickel sulfide mineralization. Whereas, in the Southern Cross area, the average depth of diamond drilling is 123 m, and this reflects much shallower mineralization with less overburden. Exploratory drilling in the Ravensthorpe and Lake Johnston areas has been low compared with State totals; such a low level of drilling activity may be a reason for the low number of discoveries (Table 4) in these areas.

The number of significant discoveries can be used as a measure of exploration success in the region. Table 4 lists discoveries that have been added to the Department's MINEDEX database since January 1995. The majority are gold deposits close to producing mines or known areas of mineralization. The renewed interest in nickel is

Table 4. Discoveries of mineral deposits in the Southern Cross – Esperance Region since January 1995

Commodity	*Project*	*Site*	*Site type*	*Stage of development*
Clay	Bromus	Bromus	Deposit	
Clay	Kerrigan	Bradley	Deposit	
Copper–Lead–Zinc	Trilogy	Trilogy	Deposit	
Dimension Stone	Merivale – Esperance Granite	Merivale	Mine	Operating
Gold	Bounty–Forrestania	Blue Vein	Mine	Closed
Gold	Bounty–Forrestania	Bounty East	Mine	Closed
Gold	Bounty–Forrestania	Bounty South	Mine	Closed
Gold	Bounty–Forrestania	Bush Pig	Mine	Closed
Gold	Bounty–Forrestania	Darjeeling	Mine	Closed
Gold	Bounty–Forrestania	Earl Grey	Mine	Closed
Gold	Bounty–Forrestania	Irish Breakfast	Deposit	
Gold	Bounty–Forrestania	Jasmine	Mine	Closed
Gold	Bounty–Forrestania	Lake Ned	Deposit	
Gold	Bounty–Forrestania	MacMahon	Mine	Closed
Gold	Bounty–Forrestania	Razorback	Mine	Closed
Gold	Bounty–Forrestania	Tasman	Mine	Closed
Gold	Bounty–Forrestania	Teddy Bear	Mine	Closed
Gold	Central Norseman	HV1	Deposit	
Gold	Chalice–Higginsville	Bullseye	Mine	Closed
Gold	Chalice–Higginsville	Graveyard North	Mine	Closed
Gold	Chalice–Higginsville	Pioneer	Deposit	
Gold	Higginsville / Goodes	Higginsville	Mine	Closed
Gold	Holleton – Learys Lament	North End	Mine	Closed
Gold	Marda – Johnston Range	Golden Orb	Deposit	
Gold	Marda – Johnston Range	Pencil Tiger	Deposit	
Gold	Marvel Loch – Southern Cross	Axehandle	Deposit	
Gold	Mount Dimer / Tectonic	Frodo	Mine	Closed
Gold	Mount Dimer / Tectonic	Golden Slipper	Mine	Closed
Gold	Mount Dimer / Tectonic	Karli West	Mine	Closed
Gold	Mount Dimer / Tectonic	Lightning	Mine	Closed
Gold	Mount Rankin	Jaguar	Mine	Closed
Gold	Norseman / Kinross	Aphrodite	Deposit	
Gold	Snowdrop	Snowdrop	Mine	Closed
Gold	Yilgarn Star	Phoenix	Deposit	
Gold	Yilgarn Star	Vintage Crop North	Deposit	
Gypsum	Lake King / Ladyman	Lake King	Deposit	
Gypsum	Lake Lockhart	Lake Lockhart	Mine	Operating
Gypsum	Moorine Rock / Goodhill	Moorine Rock	Mine	Operating
Nickel	Emily Ann – Maggie Hays	Emily Ann	Deposit	
Nickel	Ravensthorpe–Bandalup	Hale Bopp	Deposit	
Nickel	Ravensthorpe–Bandalup	Ravensthorpe 4	Deposit	
Nickel	Ravensthorpe–Bandalup	Shoemaker Levy	Deposit	
Nickel	Ravensthorpe Nickel / Greenstone	Nindilbillup	Deposit	
Nickel	Ravensthorpe Nickel / Greenstone	Ravensthorpe 5	Deposit	
Silica, Silica Sand	Duladgin Quartzite	Duladgin	Deposit	

SOURCE: MINEDEX database

represented by a small number of deposits, mainly in the Ravensthorpe area. The only base metals discovery outside the Archaean greenstone areas was the Trilogy base metals prospect located within the Proterozoic Mount Barren Group.

It is difficult to make projections with respect to future land tenure and exploration. The whole of the mineral exploration industry in Western Australia is currently experiencing difficulties as a result of low commodity prices, low investment in exploration, and continuing questions over land access in relation to various Native Title issues. However, substantial increases in nickel prices have recently made exploration for nickel more attractive. Apart from the prospective areas in the greenstone belts, the region has some existing, albeit so far unproven, prospects along the eastern and southern margins of the Yilgarn Craton and within the Proterozoic rocks of the Albany–Fraser Orogen. The region has reasonable infrastructure, and is relatively close to the mining services of Kalgoorlie.

Chapter 3

Geological setting

The Southern Cross – Esperance Region covers the southeastern part of the Archaean Yilgarn Craton and the central part of the Mesoproterozoic Albany–Fraser Orogen. A thin cover of Eocene sedimentary rocks of the Bremer Basin locally overlies the Archaean and Mesoproterozoic rocks along the southern margin of the area (Fig. 4).

Yilgarn Craton

The Archaean Yilgarn Craton, which underlies most of the northern, western, and central parts of the Southern Cross – Esperance Region, consists of extensive areas of late Archaean gneiss and granitoid that enclose relatively narrow north to northeasterly trending greenstone belts. The Yilgarn Craton has been subdivided into a number of poorly delineated tectonic units which, in the study area, include segments of the terranes defined by Tyler and Hocking (2001) — the South West Terrane, and the Murchison, Southern Cross, and Eastern Goldfields Granite–Greenstone Terranes (Fig. 4). This subdivision is based on general differences in metamorphic grade, lithological characteristics, and interpreted structural history, and age.

The Archaean greenstones in the Yilgarn Craton contain basaltic and komatiitic volcanic rocks, mafic and ultramafic plutonic rocks, felsic volcanic rocks, and sedimentary rocks. Due to limited outcrop and, in many places, a complex deformation history, stratigraphic sequences recognized locally are difficult to correlate on a regional scale. However, a broad pattern of an older sequence of predominantly mafic and ultramafic rocks overlain by younger sedimentary and felsic volcanic rocks has been recognized in the Southern Cross Granite–Greenstone Terrane. The greenstones in the Southern Cross Granite–Greenstone Terrane are probably about 3000 Ma, whereas greenstones in the Eastern Goldfields Granite–Greenstone Terrane are generally younger, with ages of about 2700 Ma. Deposition of greenstones in the Eastern Goldfields Granite–Greenstone Terrane appears to mainly post-date the upper greenstones in the Southern Cross Granite–Greenstone Terrane, which are dated at c. 2730 Ma in the Marda–Diemals area (Pidgeon and Wilde, 1990). The whole region has undergone a major period of probably syn-deformational granitoid intrusion between about 2730 Ma and 2640 Ma (Nelson, 1997; Chen and Wyche, 2001).

The Archaean rocks of the Yilgarn Craton have been intruded by several generations of easterly trending mafic dyke swarms of Proterozoic age. These include the c. 2400 Ma Widgiemooltha dyke swarm, and the c. 1200 Ma Fraser dyke swarm that intruded along the south-eastern margin of the Yilgarn Craton during the Albany–Fraser Orogeny. A third set of northwesterly trending mafic dykes, of Phanerozoic age, intruded Precambrian rocks of both the Yilgarn Craton and the Albany–Fraser Orogen.

Albany–Fraser Orogen

The Albany–Fraser Orogen extends along the southern and southeastern margins of the Yilgarn Craton. It consists mainly of orthogneiss and granitoid, but also includes large sheets of metagabbro (including the Fraser Complex), remnants of mafic dykes, and widespread metasedimentary rocks (including the Mount Barren Group). The orthogneiss is derived from late Archaean and Palaeo- and Mesoproterozoic granitoid rocks that were deformed and metamorphosed during Mesoproterozoic orogenic activity (c. 1345 Ma to 1140 Ma; Nelson et al., 1995; Clark et al., 2000). This activity culminated in the development of southeasterly dipping thrust sheets and duplex structures that transported the high-grade metamorphic rocks of the orogen northwestwards onto the lower grade Archaean rocks of the Yilgarn Craton (Myers, 1995a,b; Clark et al., 2000).

The orogen is divided into two complexes that are dominated by different rock types and structures — the Biranup and Nornalup Complexes (Myers, 1990). The Biranup Complex consists of heterogeneous orthogneisses, isoclinally folded and tectonically interleaved by thrusting with layered mafic intrusions of the Fraser Complex (c. 1300 Ma) and reworked fragments of the Yilgarn Craton (Munglinup Gneiss). The Nornalup Complex contains less intensely deformed high-grade orthogneisses and paragneisses, intruded by sheets of late-tectonic granitoid.

Psammitic and subordinate pelitic metasedimentary rocks of the Palaeoproterozoic Mount Barren Group were deposited along the southern margin of the Yilgarn Craton in the northern foreland of the Albany–Fraser Orogen. The Group unconformably overlies Archaean granitoids and greenstones, and its tectonic structures — characterized

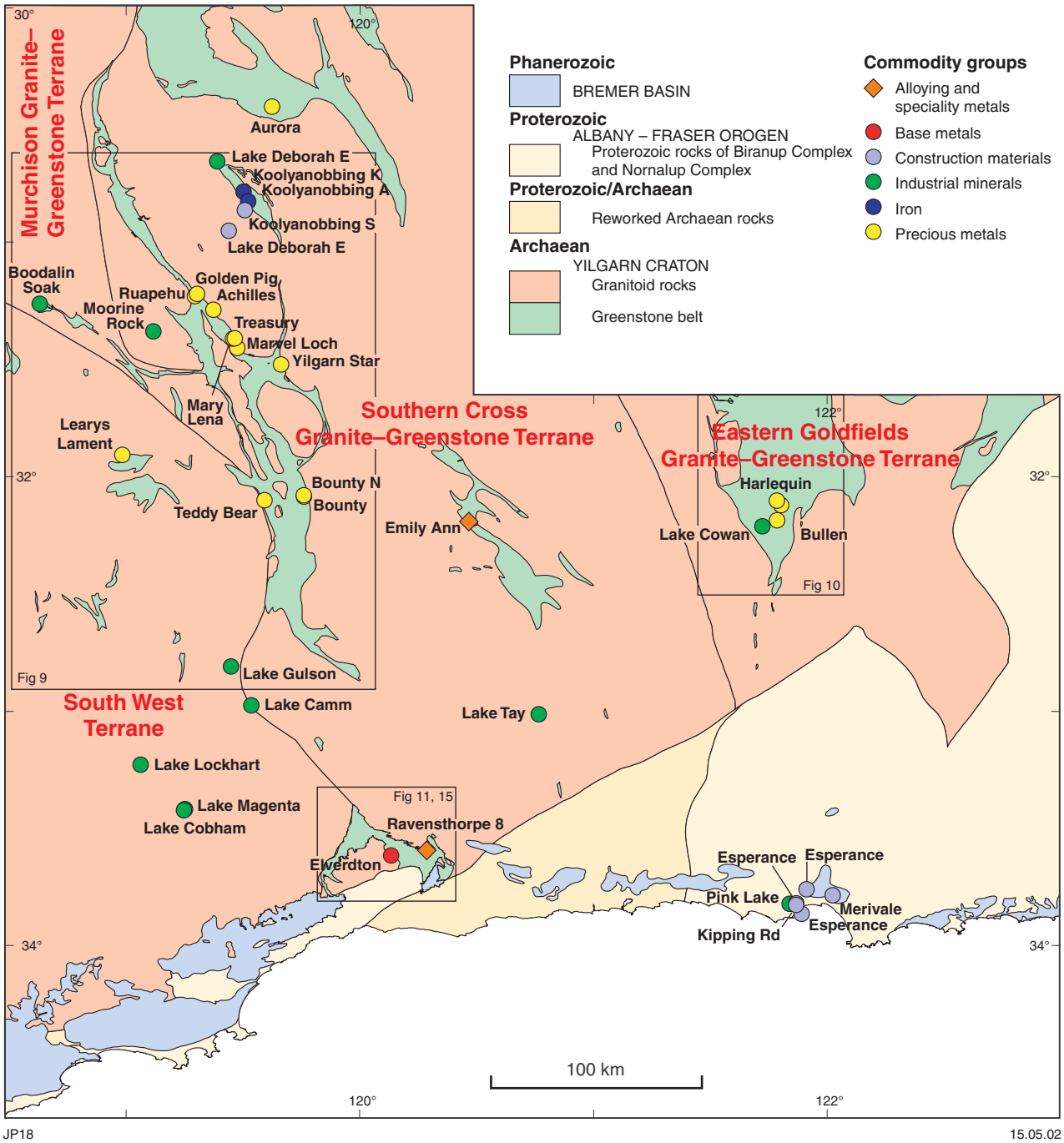

Figure 4. Simplified geology and tectonic units of the study area, with operating mines. The locations of Figures 9, 10, 11, and 15 are also shown

by imbricate thrusting (Myers, 1995; Witt, 1998) — and metamorphism are thought to relate to Mesoproterozoic deformation and metamorphism within the Biranup and Nornalup Complexes (Myers, 1995).

Nelson et al. (1995) identified four major episodes of plutonic activity at c. 2630 Ma, 1700–1600 Ma, c. 1300 Ma, and c. 1160 Ma. These authors asserted that the 1700–1600 Ma orthogneisses are clearly older than the Albany–Fraser Orogen, but are unrelated to wide-spread c. 2630 Ma granitoid intrusion in reworked Archaean basement, and may have formed part of an east Antarctic continent that was thrust onto the margin of the Yilgarn Craton during the collision of these two continents at 1300 Ma.

Bremer Basin

The sedimentary rocks of the Bremer Basin were deposited during the Eocene along the southern margin of the Southern Cross – Esperance Region, and offshore across the continental shelf to the continental margin (Hocking, 1990; Myers, 1995). The Eocene rocks exposed onshore form an extensively eroded veneer, mostly less than 60 m thick. The rocks infill palaeodrainage valleys and depressions, blanketing the smooth, low topography on the Albany–Fraser Orogen and adjacent Yilgarn Craton.

The exposed rocks of the Bremer Basin consist of part of the Pallinup Siltstone of the Plantagenet Group of Sequence Cz2 (Hocking, 1990). The rocks comprise marine siltstone, sandstone, and spongolite that, in the south, are locally richly fossiliferous with bivalve, gastropod, echinoid, bryozoan, and sponge fossils. Inland there is a facies change to less fossiliferous rocks (Myers, 1995a).

Cainozoic regolith

Prolonged erosion has led to generally subdued topography that is extensively covered by Cainozoic regolith materials comprising sand, laterite, alluvium, colluvium, and eolian and residual calcareous clay.

Chapter 4

Precious metals

Gold is the dominant precious metal found in the Southern Cross – Esperance Region, with silver produced as a minor byproduct.

Gold

The Southern Cross – Esperance Region has more than 100 years of gold mining history from three gold-producing centres: the Yilgarn Goldfield, the Higginsville–Norseman area, and the Ravensthorpe area. In 1999, the region produced 19 850 kg of gold, which represents 9.5% of Western Australia's total production. Current mining projects (mines with common infrastructure and/or ownership) in order of gold production are: Marvel Loch – Southern Cross, Central Norseman, Yilgarn Star, Bounty, and Copperhead–Bullfinch (Fig. 5). During 1999, the Chalice mine ceased operations. Production for 1999 is listed by project in Table 5.

Total recorded production (cumulative) to the end of 1985 from the study area is 383 257 kg of gold from 102.5 Mt of ore, at an average recovered grade of 3.74 g/t Au. Most of the gold has come from the Yilgarn Goldfield and the Higginsville–Norseman area. The most significant deposits within the study area include the Central Norseman deposits (Bullen), the Bullfinch–Copperhead deposits (Great Bingin and Copperhead), the Marvel Loch – Southern Cross deposits (Great Victoria, Parbo, Golden Pig, and Marvel Loch), Chalice, Bounty, Yilgarn Star, and Westonia (Fig. 6). Production (cumulative) figures to the end of 1985 for projects with production greater than 14 kg (500 fine ounces) are listed in Table 6 (see the database on the CD accompanying this report for projects with production less than 14 kg).

Total reported measured and indicated resources for gold at the end of 1999 for the Southern Cross – Esperance Region are 64 Mt of ore containing 189 300 kg of gold. There is an additional 21 Mt of mineralization containing 80 362 kg of gold in inferred resources. Table 7 lists the resources for each project — further details, including cutoff grades, are available on the CD accompanying this report. Locations of projects and their combined measured and indicated resources, and inferred resources (on a contained gold basis), are shown in Figures 7 and 8 respectively.

Gold mineralization is principally associated with the Archaean granite–greenstones of the Southern Cross Granite–Greenstone Terrane and the southern portion of the Eastern Goldfields Granite–Greenstone Terrane (Fig. 4). The Eastern Goldfields Granite–Greenstone Terrane, which is Western Australia's most productive gold-mining province, extends from Wiluna to Norseman, and includes the Higginsville–Norseman area. The Southern Cross Granite–Greenstone Terrane covers the central region of the Yilgarn Craton and includes the major mining districts of Southern Cross, Marvel Loch, and Bullfinch.

Supergene enrichment associated with chemical weathering is a common feature of gold mineralization within the region. Reprecipitation of gold can produce discrete high-grade lenses within the oxidized zone of the host rock. These lenses typically occur close to the surface and can contain significant amounts of gold in relatively soft ground, which enables mining costs to be reduced and significantly improves the economics of a project. Also, in such deposits, the dispersion of gold within the weathered horizon can significantly increase the surface expression of the underlying primary deposit, allowing the use of relatively cheap surface geochemical exploration techniques.

Described below are the geology, mineral resources, gold production, and exploration potential of the three main gold-producing centres in the Southern Cross – Esperance Region: the Yilgarn Goldfield, the Higginsville–Norseman area, and the Ravensthorpe area.

Yilgarn Goldfield

The Yilgarn Goldfield lies within the area covered by Jackson, Southern Cross, and Hyden. Gold was initially discovered at Ennuin in 1887, and on 1 October 1888 the Yilgarn Goldfield (the area centred on the Southern Cross township and extending north to Diemals, west to Westonia, and south to Hatters Hill) was declared, making it one of the earliest goldfields to be declared in the State. The goldfield has experienced four major periods of activity: the initial discovery period between 1887 and 1920, the revival of the 1930s, the Great Western Consolidated NL period in the 1950–60s, and the modern era of the 1980–90s.

Locations of gold deposits and gold occurrences within the Yilgarn Goldfield are shown on Figure 9.

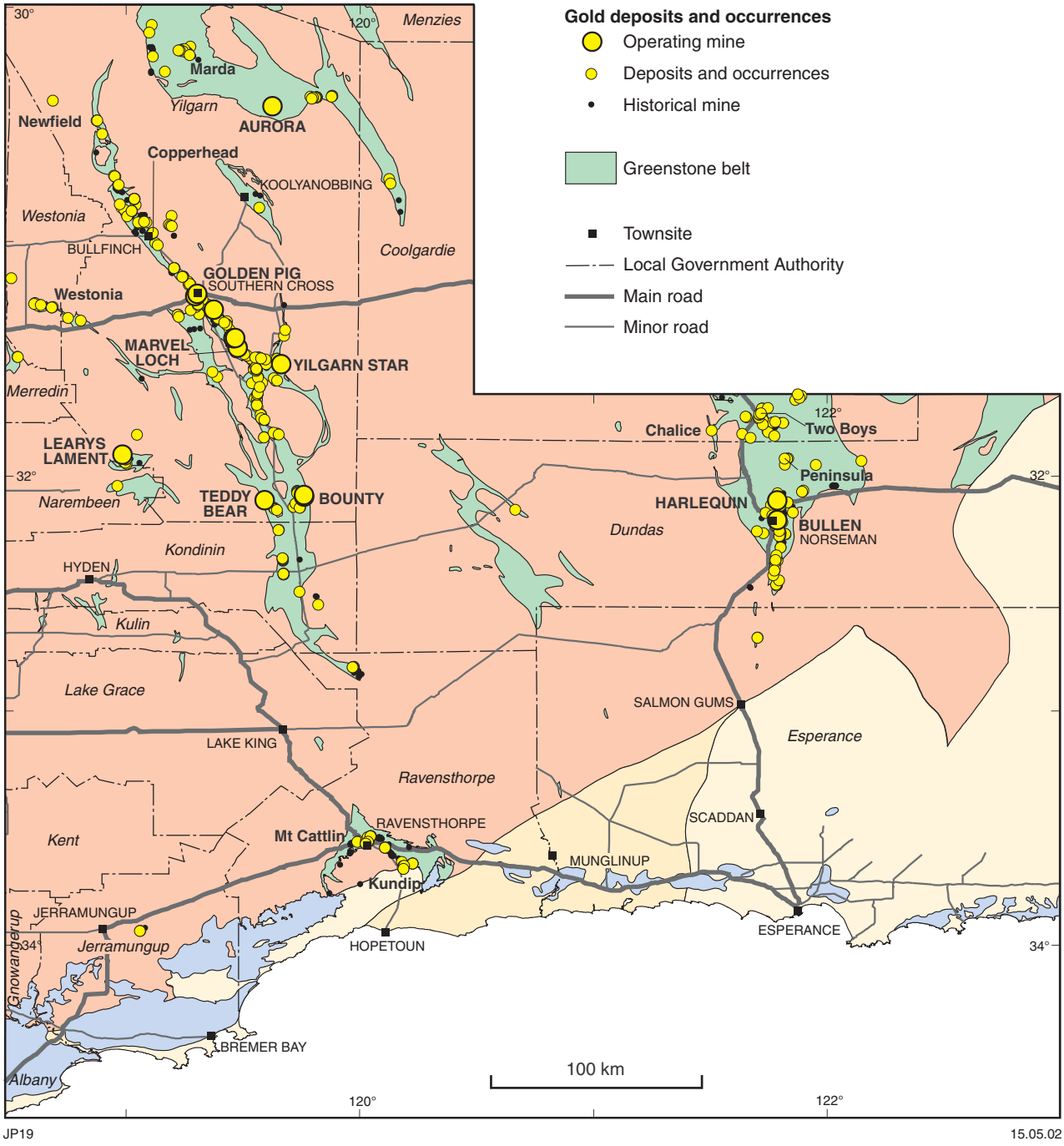

Figure 5. Gold deposits and occurrences in the Southern Cross – Esperance Region. See Figure 4 for complete geological legend

Table 5. Gold production from the Southern Cross – Esperance Region for 1999, by project and site

	1999 production						1999 growth			
Site/project	*Ore (t)*	*Grade (g/t)*	*Gold (ounces)*	*Gold (kg)*	*Value ($A)*	*Cash cost ($A/oz)*	*Ore (t)*	*Gold (ounces)*	*Gold (kg)*	*% change*
Marvel Loch – Southern Cross	1 870 000	1.96	117 740	3 662.12	50 841 723	379	-7 000	33 880	1 053.79	40
Cornishman	512 000	6.87	113 127	3 518.63	48 745 261	228	420 000	97 078	3 019.45	605
Central Norseman	538 000	6.45	111 629	3 472.05	48 254 624	202	-73 000	-5 279	-164.20	-5
Yilgarn Star	823 000	4.00	105 727	3 288.48	45 488 551	420	16 000	-17 900	-556.75	-14
Bounty	411 000	7.57	100 002	3 110.42	43 301 605	220	-424 000	-16 502	-513.27	-14
Copperhead–Bullfinch	361 000	4.58	53 105	1 651.75	22 875 290	289	-561 000	-37 123	-1 154.65	-41
Chalice	420 000	2.73	36 873	1 146.88	16 545 594	558	-776 000	-120 070	-3 734.59	-77
Two Boys	0		0	0.00	0		-73 000	-23 919	-743.96	-100
Nevoria	0		0	0.00	0		-415 000	-33 936	-1 055.53	-100
Study area total	**4 935 000**	**4.0**	**638 203**	**19 850.33**	**276 052 648**		**-1 893 000**	**-123 771**	**-3 849.71**	**-16%**
State total	**79 390 000**	**2.64**	**6 739 804**	**209 631.32**	**2 915 413 016**		**-22 710 361**	**-698 723**	**-21 732.70**	
% of State total	**6.2%**		**9.5%**	**9.5%**	**9.5%**		**8.3%**	**17.7%**	**17.7%**	

SOURCE: MINEDEX database

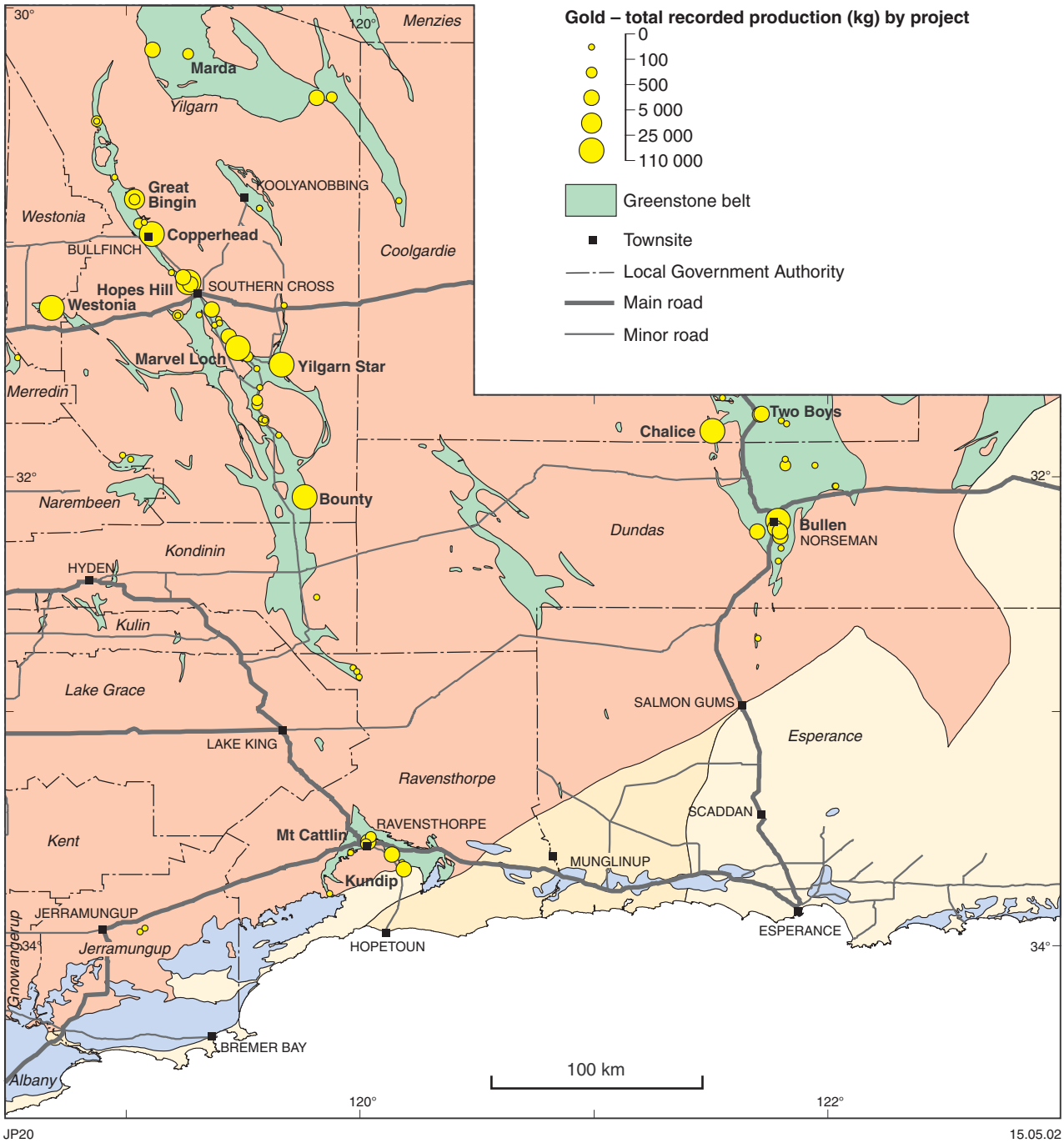

Figure 6. Gold — total recorded production (kg), by project. See Figure 4 for complete geological legend

Table 6. Total gold and silver production of the Southern Cross – Esperance Region to December 1985

Project	*Ore mined (000 t)*	*Gold produced (kg)*	*Gold produced (oz)*	*Silver produced (oz)*
HIGGINSVILLE–NORSEMAN AREA				
Central Norseman	8 134.0	82 205.9	2 643 277	12 319.5
Chalice–Higginsville	9 653.5	36 641.0	1 178 168	5.1
Two Boys North	183.0	2 546.4	81 877	
Norseman/Kinross	514.3	2 000.0	64 308	
Red White and Blue	635.9	1 185.7	38 124	0.8
Peninsula–Waverly	7.5	141.7	4 556	
Beete Gold	2.9	68.4	2 200	20.8
Norseman historical mines	1.4	45.8	1 471	39.6
Peninsula	1.3	28.2	908	0.3
Subtotal	**19 133.8**	**124 863.1**	**4 014 889**	**12 386.1**
RAVENSTHORPE AREA				
Kundip/Tectonic	70.8	1 796.4	57 761	85.0
Ravensthorpe/GME	13.7	525.8	16 908	
Ravensthorpe–Sirdar	7.5	178.3	5 732	
Kundip – Mount Iron	15.7	89.7	2 883	
Ravensthorpe West historical mines	3.7	52.1	1 676	
Subtotal	**111.4**	**2 642.3**	**84 960**	**85.0**
YILGARN GOLDFIELD				
Bullfinch–Copperhead	22 942.3	60 850.5	1 956 606	
Marvel Loch – Southern Cross	20 053.8	51 661.6	1 661 143	
Bounty–Forrestania	6 939.0	34 076.3	1 095 702	
Yilgarn Star	5 718.9	25 772.8	828 708	
Hopes Hill – Corinthia	9 289.9	23 423.5	753 167	
Westonia	6 751.0	20 215.7	650 022	158.8
Nevoria	5 857.8	13 882.3	446 376	23.2
Burbidge – Great Victoria	3 493.6	7 576.5	243 618	11.1
Golden Valley	767.2	5 330.1	171 384	1 028.1
Mount Dimer/Tectonic	780.7	3 933.5	126 478	
Radio–Bullfinch	79.9	3 430.1	110 292	64.5
Pilot	313.8	1 906.8	61 312	135.7
Marda – Johnston Range	56.7	1 046.9	33 663	71.8
Bullfinch historical mines	61.4	811.7	26 101	4 831.0
British Hill – Parker Range	22.9	496.1	15 952	3.5
Parker Range – Olga Rocks	33.6	243.7	7 837	0.0
Southern Cross historical mines	18.4	243.1	7 816	0.8
Francis Furness	8.9	202.2	6 502	
Mount Rankin	9.6	156.9	5 045	0.2
Nevoria South historical mines	5.1	95.9	3 084	
Mount Dimer/Taipan	25.1	86.5	2 780	
Glendower – Evelyn Molly	10.3	63.8	2 050	
Comet Eclipse and Mountain King	3.0	52.2	1 678	
Holleton – Learys Lament	6.8	44.2	1 423	1.1
Hatters Hill	1.3	30.9	992	
Koolyanobbing historical mines	1.7	28.3	911	
Parker Range – Fortuna	3.3	27.6	887	
Burgess Find	0.7	22.0	706	
Birthday–Corinthian	0.5	20.2	648	
Forrestania/Graham	1.7	20.0	643	
Subtotal	**83 258.9**	**255 751.9**	**8 223 526**	**6 329.8**
Total gold and silver production	**102 504.1**	**383 257.3**	**12 323 375**	**18 800.9**

NOTE: Table contains production up to 1985 only, as post-1985 production figures may still be confidential
SOURCE: MINEDEX database

Table 7. Gold resources for deposits in the Southern Cross – Esperance Region

Project	*Site*	*Site code*	*Site type*[(a)]	*Stage of development*[(b)]	*Resource category*[(c)]	*Tonnage (Mt)*	*Grade (g/t Au)*	*Contained metal (kg)*	*(oz)*	*Date of resource estimate*
Higginsville–Norseman area										
Central Norseman	Central Norseman	S00096	MO	C	IND	2.06	3.40	6 987.00	224 662	31/12/1999
	Central Norseman	S00096	MO	C	INF	0.81	2.90	2 343.20	75 344	31/12/1999
	Central Norseman	S00096	MO	C	MES	3.91	0.70	2 737.00	88 006	31/12/1998
	Central Norseman	S00097	MU	O	IND	1.08	13.00	14 001.00	450 192	31/12/1999
	Central Norseman	S00097	MU	O	INF	1.44	9.60	13 824.00	444 501	31/12/1999
	Central Norseman	S00097	MU	O	MES	0.33	14.80	4 869.20	156 566	31/12/1999
Chalice–Higginsville	Franks Find	S00199	DO		INF	0.01	3.50	17.50	563	30/06/1997
	Higginsville	S02290	MB	S	IND	0.88	3.07	2 707.74	87 065	30/06/1999
	Higginsville	S02290	MB	S	INF	1.10	3.49	3 825.04	122 991	30/06/1999
	Higginsville	S02290	MB	S	MES	0.67	0.72	478.80	15 395	30/06/1999
	Widgiemooltha	S17108	DO		IND	0.07	3.34	247.16	7 947	30/06/1999
	Widgiemooltha	S17108	DO		INF	1.37	2.91	3 977.97	127 909	30/06/1999
	Widgiemooltha	S17108	DO		MES	0.06	2.98	187.74	6 037	30/06/1999
	Widgiemooltha	S17108	DO		MES	0.30	3.34	995.32	32 004	30/06/1999
Jeffreys	Jeffreys	S00352	DO		IND	0.35	2.26	784.22	25 216	30/06/1998
Lake Cowan – Versaille	Versaille	S04217	DO		IND	0.53	2.36	1 243.72	39 991	31/12/1997
	Versaille	S04217	DO		INF	0.32	2.57	830.11	26 692	31/12/1997
	Versaille	S04217	DO		MES	0.95	2.40	2 282.40	73 389	31/12/1997
Norseman / Kinross	Norseman	S05647	DB		DEM	36.30	1.30	47 193.90	1 517 487	31/12/1999
Norseman / Maldon	Duke	S18758	DO		INF	0.54	1.90	1 024.10	32 929	30/06/1999
	Surprise	S02100	DO		MES	0.60	1.90	1 136.20	36 534	31/12/1999
Red White and Blue	Red White and Blue	S00609	MO	S	IND	0.28	1.90	524.40	16 862	30/06/1995
	Red White and Blue	S00609	MO	S	MES	0.07	2.77	193.90	6 235	30/06/1997
Two Boys North	Two Boys	S00927	MU	S	MES	0.57	9.20	5 234.80	168 321	13/06/1996
Ravensthorpe area										
Kundip / Tectonic	Kundip	S00868	MB	S	INF	0.63	7.20	4 543.20	146 083	24/02/1997
Ravensthorpe–Sirdar	Sirdar	S02248	DO		IND	0.03	6.00	162.00	5 209	30/06/1993
Ravensthorpe / GME	Marion Martin	S02722	DU		INF	0.05	2.00	96.00	3 087	30/06/1990
	Mount Cattlin	S01431	DU		INF	0.04	6.28	226.08	7 269	30/06/1990

Table 7 (continued)

Project	*Site*	*Site code*	*Site type*[a]	*Stage of development*[b]	*Resource category*[c]	*Tonnage (Mt)*	*Grade (g/t Au)*	*Contained metal (kg)*	*(oz)*	*Date of resource estimate*
Yilgarn Goldfield										
Bounty–Forrestania	Blue Haze	S04160	DO		INF	1.51	2.83	4 264.81	137 132	31/12/1999
	Blue Vein	S06419	MO	S	INF	0.31	3.14	960.84	30 895	31/12/1999
	Bounty East	S18827	MO	S	IND	0.06	3.58	225.54	7 252	31/12/1999
	Bounty	S02243	MU	O	DEM	1.08	6.46	6 950.96	223 503	31/12/1999
	Bounty	S02243	MU	O	DEM	0.91	6.04	5 478.28	176 150	31/12/1999
	Bounty	S02243	MU	O	INF	0.69	7.55	5 209.50	167 508	31/12/1999
	Lake Ned	S18885	DO		IND	0.07	4.28	299.60	9 633	31/12/1999
	Lounge Lizard	S01025	MO	S	DEM	0.59	3.93	2 302.98	74 051	31/12/1999
	North Ironcap	S00191	DO		INF	0.56	2.39	1 336.01	42 958	31/12/1999
	Teddy Bear	S05655	MO	S	IND	0.11	2.00	220.00	7 074	31/12/1999
	Twinings	S00922	MO	C	INF	0.60	1.57	943.57	30 340	31/12/1999
	Van Uden	S16699	MO	S	DEM	0.79	2.74	2 175.56	69 954	31/12/1999
	West Quest	S18886	DO		INF	0.10	5.53	525.35	16 892	31/12/1999
British Hill – Parker Range	British Hill	S02542	MO	S	INF	0.85	2.40	2 040.00	65 595	30/08/1995
Bullfinch–Copperhead	Bullfinch–Copperhead	S02022	MB	O	IND	0.33	7.20	2 376.00	76 399	30/06/1999
	Bullfinch–Copperhead	S02022	MB	O	IND	0.73	4.00	2 920.00	93 891	30/06/1999
	Bullfinch–Copperhead	S02022	MB	O	IND	3.08	2.10	6 468.00	207 974	30/06/1999
	Bullfinch–Copperhead	S02022	MB	O	INF	0.13	5.20	676.00	21 736	30/06/1999
	Bullfinch–Copperhead	S02022	MB	O	INF	1.70	2.00	3 400.00	109 325	30/06/1999
	Bullfinch–Copperhead	S02022	MB	O	MES	0.42	1.50	630.00	20 257	30/06/1999
Bungalbin Gold	Aurora	S03478	MO	S	IND	0.03	6.43	173.61	5 582	30/06/1999
	Bungalbin West	S05848	DO		INF					
Burgess Find	Burgess Find	S01926	MO	S	INF					
	Burgess Find	S01926	MO	S	INF					
	Burgess Find	S01926	MO	S	INF					
Cadonia	Cadonia	S03671	DO		MES	0.00	11.70	46.80	1 505	26/03/1992
Cheritons / SOG	Cheritons	S04563	DO		INF	0.10	1.20	120.00	3 859	31/03/1994
	Redwing	S18870	DO		INF	2.01	2.17	4 361.70	140 247	30/06/2000
Comet Eclipse and Mountain King	Comet Eclipse	S02618	DO		DEM	0.02	2.50	50.00	1 608	19/05/1990
Electrum	Devlins Reward	S03904	MO	S	IND	0.30	1.50	450.00	14 469	30/06/1998
Francis Furness	Francis Furness	S03979	MU	S	IND	0.00	45.00	90.00	2 894	30/06/1993
	Francis Furness	S03979	MU	S	IND	0.00	30.00	30.00	965	30/06/1993
	Francis Furness	S03979	MU	S	INF					
Glendower – Evelyn Molly	Glendower	S04216	MO	S	DEM	0.15	2.20	338.80	10 894	30/06/1993
Golden Valley	Great Bingin Tailings	S02336	MT	S	DEM	0.01	0.00	.00	0	01/01/1990
Hatters Hill	Hatters Hill	S01052	MO	S	IND	0.01	7.20	50.40	1 621	02/11/1993
	Hatters Hill	S01052	MO	S	INF	0.00	3.45	6.90	222	02/11/1993
	Hatters Hill	S01052	MO	S	INF	0.00	5.13	20.52	660	02/11/1993
	Hatters Hill	S01052	MO	S	MES	0.00	13.40	40.20	1 293	02/11/1993
	Hatters Hill	S01052	MO	S	MES	0.03	2.74	79.46	2 555	02/11/1993

Table 7 (continued)

Project	*Site*	*Site code*	*Site type*[a]	*Stage of development*[b]	*Resource category*[c]	*Tonnage (Mt)*	*Grade (g/t Au)*	*Contained metal (kg)*	*(oz)*	*Date of resource estimate*
Holleton – Learys Lament	Calzoni	S00332	DO		INF					
	Calzoni	S00332	DO		INF					
	Holleton Tailings	S03509	DT		DEM	0.06	0.90	49.50	1 592	01/01/1981
	Learys Lament	S03794	MO	S	INF	0.14	1.80	252.00	8 103	10/10/1994
	Learys Lament	S03794	MO	S	INF	0.11	2.60	291.20	9 363	30/06/1992
	North End Extended	S04649	DO		INF					
	North End	S18837	MO	S	INF	0.08	1.00	80.00	2 572	05/07/2000
Hopes Hill – Corinthia	Hopes Hill	S00341	MO	S	DEM	0.17	1.70	282.20	9 074	30/06/1994
Marda – Johnston Range	Golden Orb	S06687	DO		INF	0.45	3.00	1 350.00	43 408	31/12/1997
	King Brown	S04468	DO		INF	0.19	3.43	648.27	20 845	03/03/1994
	Marda	S03523	DO		DEM	1.00	0.72	722.16	23 221	31/12/1997
	Marda	S03523	DO		IND	0.59	1.83	1 087.02	34 952	31/12/1997
	Marda	S03523	DO		INF	0.35	1.72	595.12	19 136	31/12/1997
	Marda	S03523	DO		MES	1.26	1.95	2 466.75	79 317	31/12/1997
Marvel Loch – Southern Cross	Greenmount	S00947	DO		IND					
	Greenmount	S00947	DO		INF					
	Marvel Loch – Southern Cross	S02031	MB	O	IND	2.00	4.20	8 400.00	270 096	30/06/1999
	Marvel Loch – Southern Cross	S02031	MB	O	IND	1.41	3.60	5 076.00	163 215	30/06/1999
	Marvel Loch – Southern Cross	S02031	MB	O	IND	2.31	1.80	4 158.00	133 698	30/06/1999
	Marvel Loch – Southern Cross	S02031	MB	O	INF	4.89	2.30	11 247.00	361 639	30/06/1999
	Marvel Loch – Southern Cross	S02031	MB	O	MES	2.68	1.00	2 680.00	86 174	30/06/1999
	Marvel Loch – Southern Cross	S02031	MB	O	MES	7.39	2.30	16 997.00	546 527	30/06/1999
	Marvel Loch – Southern Cross	S02031	MB	O	MES	0.79	1.90	1 501.00	48 264	30/06/1999
	Mary Lena – Treasury	S16647	DU		INF	0.45	2.50	1 125.00	36 174	31/12/1998
	Tamarin	S04711	DO		IND	0.23	2.55	599.25	19 268	31/12/1999
	Tamarin	S04711	DO		IND	0.17	1.06	175.96	5 658	31/12/1999
Mountain Devil – Dulcie	Mountain Devil	S04051	DO		IND	0.02	0.75	12.00	386	01/04/1993
Mount Dimer / Taipan	Mount Dimer	S04377	MO	C	DEM	0.05	3.65	197.10	6 338	30/06/1995
Mount Dimer / Tectonic	Frodo	S05834	MO	S	MES	0.02	7.59	136.62	4 393	17/06/1997
	Anomaly 2	S04982	DO		IND	0.01	3.80	45.60	1 466	30/06/1996
Mount Rankin	Jaguar	S05057	MO	S	IND	0.01	3.40	20.40	656	30/06/1995
	Jaguar	S05057	MO	S	INF	0.01	3.00	36.00	1 158	30/06/1995
	Jaguar	S05057	MO	S	MES	0.03	4.30	124.70	4 010	30/06/1995
	Mount Rankin	S00569	MO	S	DEM					
Parker Range – Olga Rocks	Spring Hill	S03764	DO		MES	0.40	2.60	1 050.40	33 775	30/06/1999
Radio–Bullfinch	Radio	S03510	MB	S	INF	0.05	11.00	517.00	16 624	30/06/1997
Westonia	Westonia	S00770	MO	S	INF					
	Westonia	S00770	MO	S	INF					
	Westonia	S00770	MO	S	INF					
Westonia Heap Leach	Rutherfords Reward	S04001	DO		MES	0.23	1.00	230.00	7 395	30/09/1993

Table 7 (continued)

Project	*Site*	*Site code*	*Site type*[(a)]	*Stage of development*[(b)]	*Resource category*[(c)]	*Tonnage (Mt)*	*Grade (g/t Au)*	*Contained metal (kg)*	*(oz)*	*Date of resource estimate*
Yilgarn Star	Anomaly 2	S04673	DO		IND	0.04	2.81	109.59	3 524	30/06/1994
	Anomaly 2	S04673	DO		INF	0.08	2.70	224.10	7 206	30/06/1994
	Anomaly 22	S04213	DO		IND	0.04	2.54	101.60	3 267	30/06/1993
	Blacksnake	S18748	DO		INF	0.14	7.16	988.08	31 771	31/12/1999
	Burbidge – Great Victoria	S02060	MB	C	DEM	0.41	1.72	703.48	22 620	18/02/1991
	Burbidge East	S04214	DO		IND	0.02	2.67	64.08	2 060	30/06/1993
	Great Victoria North	S04674	DO		IND	0.13	1.80	234.00	7 524	30/06/1994
	Great Victoria	S00847	MO	S	IND	0.20	2.77	554.00	17 813	30/06/1995
	Great Victoria	S00847	MO	S	INF	0.75	3.21	2 407.50	77 411	30/06/1995
	Great Victoria	S00847	MO	S	MES	0.14	2.50	350.00	11 254	30/06/1993
	Great Victoria	S00847	MO	S	MES	0.76	2.67	2 029.20	65 248	30/06/1995
	Great Victoria	S00282	MU	O	DEM	4.40	2.54	11 176.00	359 356	31/12/1998
	Parbo	S00591	MO	S	IND	0.52	6.22	3 259.28	104 800	30/03/2000
	Yilgarn Star	S02852	MB	O	IND	2.53	6.00	15 174.00	487 909	30/06/1999
	Yilgarn Star	S02852	MB	O	IND	0.34	2.50	857.50	27 572	30/06/1999
	Yilgarn Star	S02852	MB	O	IND	2.40	4.90	11 760.00	378 135	30/06/1999
	Yilgarn Star	S02852	MB	O	INF	1.49	7.40	10 996.40	353 582	30/06/1999
	Yilgarn Star	S02852	MB	O	INF	0.23	2.60	595.40	19 145	30/06/1999
	Yilgarn Star	S02852	MB	O	MES	0.80	4.70	3 760.00	120 900	30/06/1999
	Yilgarn Star	S02852	MB	O	MES	0.07	2.20	156.20	5 023	30/06/1999
	Yilgarn Star	S02852	MB	O	MES	1.31	2.30	3 022.20	97 177	30/06/1999
	Yilgarn Star	S05649	MB	O	MES	0.01	1.60	22.40	720	30/06/1999
	Yilgarn Star	S05649	MB	O	MES	0.91	1.70	1 553.80	49 961	30/06/1999

NOTES:

(a) Site type
- DO deposit openpit
- DU deposit underground
- DB deposit both (openpit and underground)
- DT deposit tails (tailings and/or dumps retreatment)
- MO mine openpit
- MU mine underground
- MB mine both (openpit and underground)
- MT mine tails (tailings and/or dumps retreatment)

(b) Stage of development
- C care and maintenance
- O operating
- S shut down

(c) Resource category
- MES measured
- IND indicated
- INF inferred
- DEM demonstrated (sum of measured and indicated where undifferentiated)

SOURCE: Townsend et al. (2000)

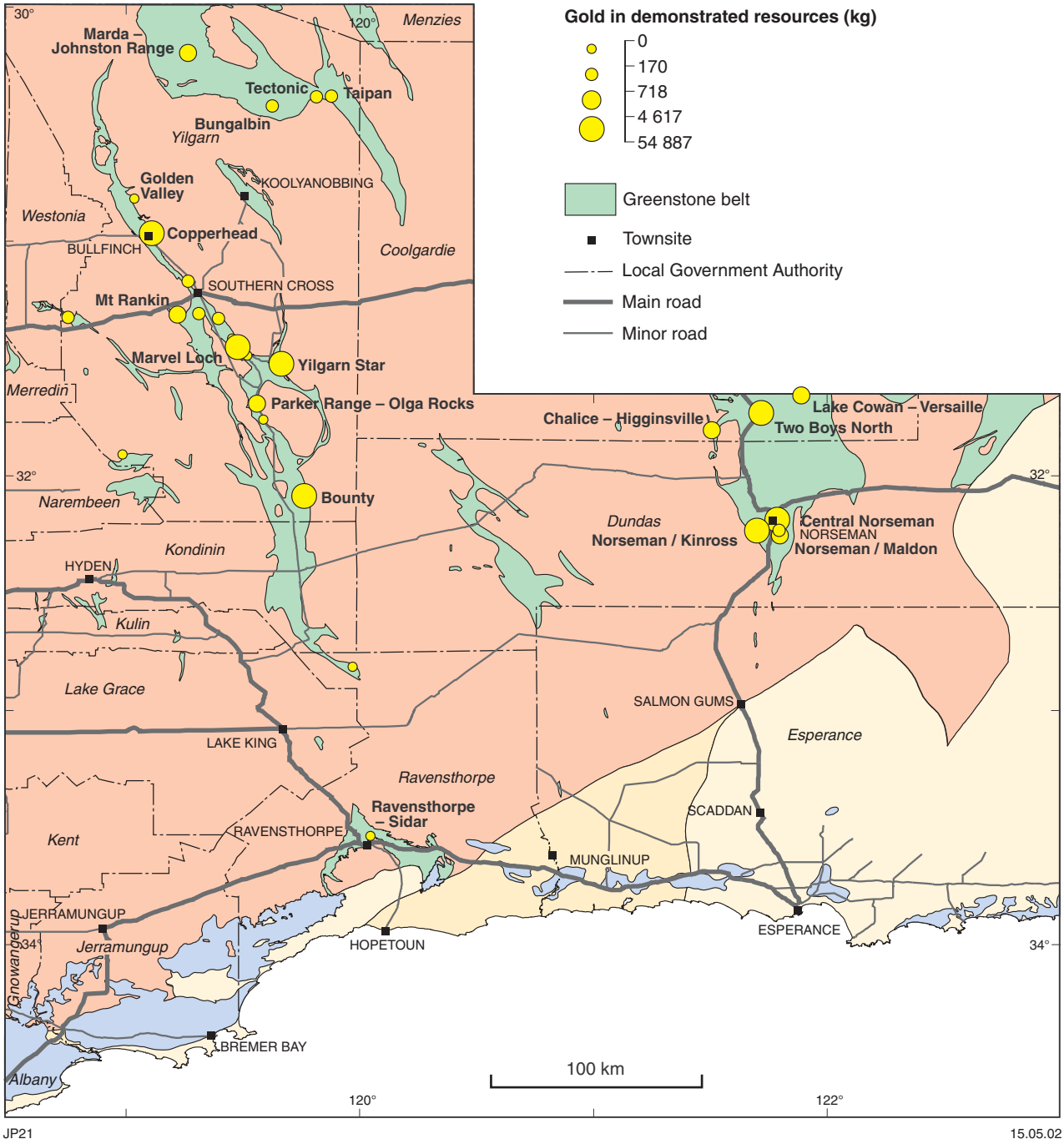

Figure 7. Gold — total contained gold (kg) in measured and indicated resources, by project. See Figure 4 for complete geological legend

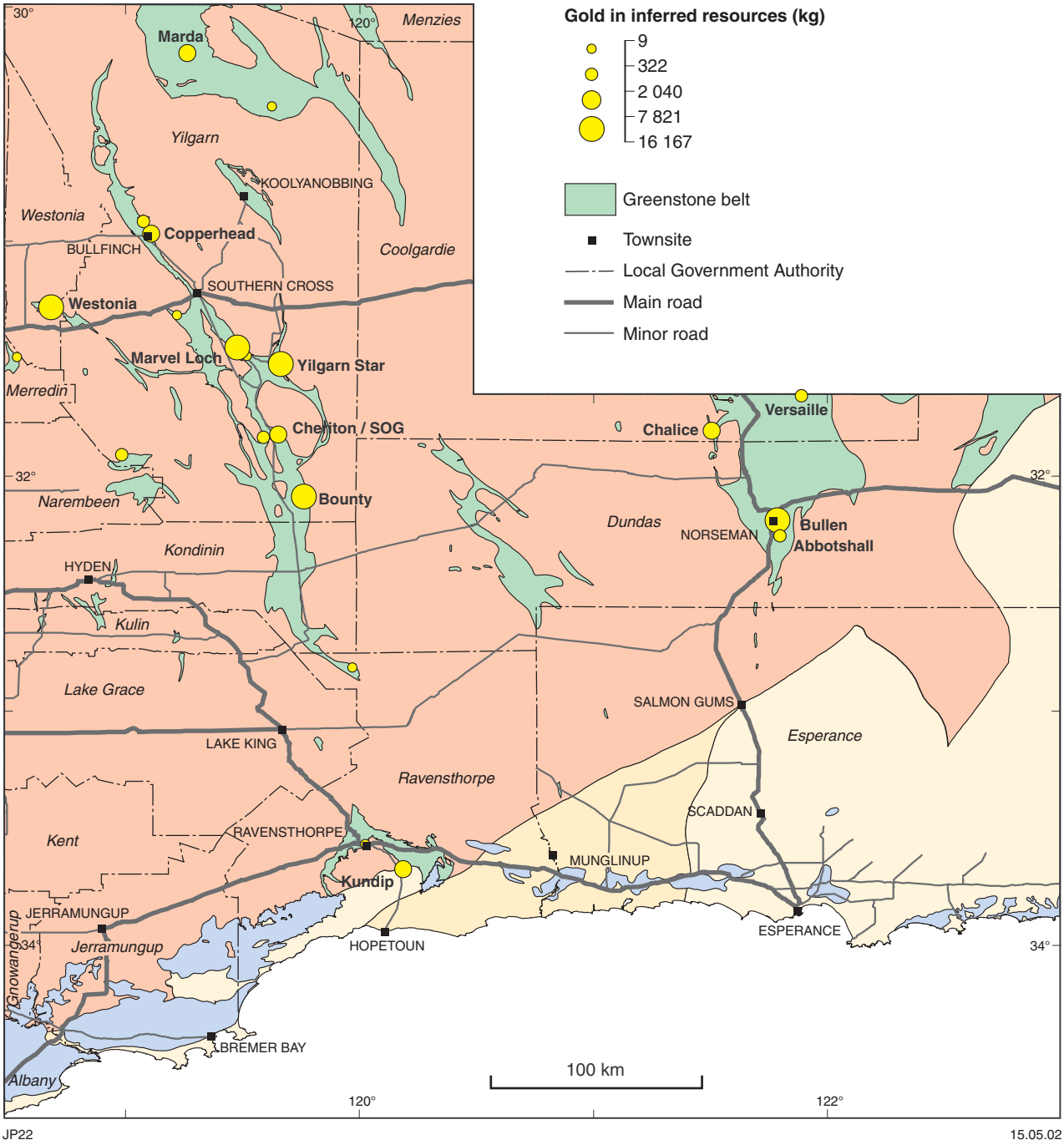

Figure 8. Gold — total contained gold (kg) in inferred resources, by project. See Figure 4 for complete geological legend

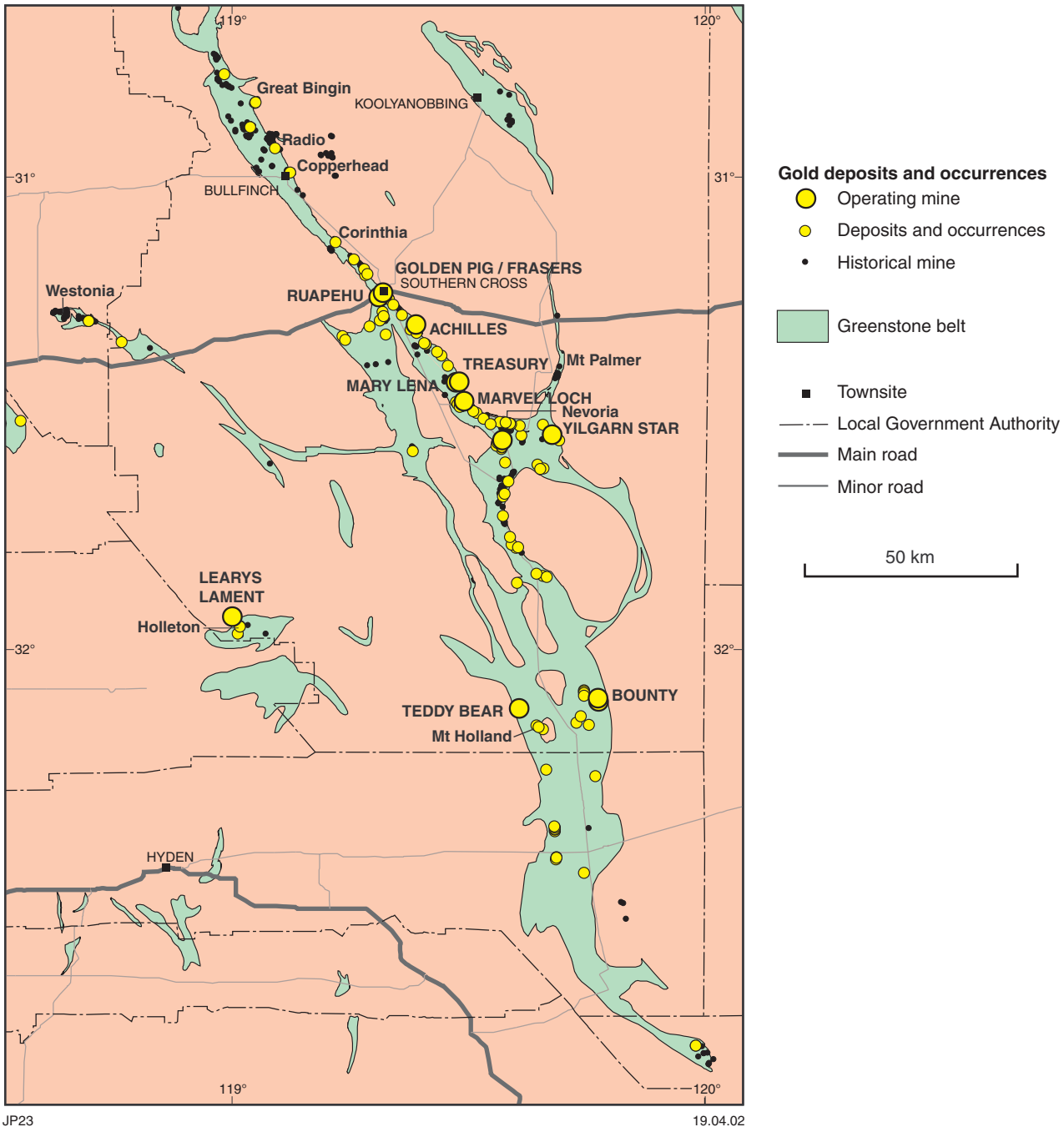

Figure 9. Gold deposits and occurrences in the Southern Cross area. Location and geological legend shown on Figure 4

Distribution and style of gold mineralization

The Yilgarn Goldfield is within the Southern Cross Granite–Greenstone Terrane of the Yilgarn Craton and it includes the Marda greenstone belt, the Southern Cross greenstone belt, and small remnants of greenstone at Westonia and Holleton.

Gee (1995), Dalstra and Ridley (1995), and Davis and Komosinski (1995) have provided descriptions of the geology and gold mineralization within the Yilgarn Goldfield, and Bagas (1994) described the regional geology around Cheritons Find. Following is a summary of these reports:

Regional characteristics

- The majority of deposits are situated within the greenstone belts;
- The primary control on mineralization is lithology.

Local characteristics

- Most deposits are located at contacts between different rock types, or within the sedimentary and jaspilite units that are interbedded with the mafic–ultramafic units;
- An important stratigraphic horizon for gold mineralization is the iron-rich chemogenic unit on top of the

major mafic unit. This horizon hosts deposits at Jaccoletti, Great Victoria, and Mount Holland;

- At the deposit scale, there is normally a structural control on mineralization. However, a consistent structural pattern is not evident, and some deposits appear to be without structural control.

Production and resources

The Yilgarn Goldfield has produced a total of 83.3 Mt of ore for 255 752 kg of gold, with an average recovered grade of 3.07 g/t Au. The Southern Cross greenstone belt has historically produced most of the gold within the Yilgarn Goldfield and it contains most of the significant deposits (Fig. 5). Current mining operations include Marvel Loch, Yilgarn Star, Learys Lament, and Bounty (Fig. 9).

The Marvel Loch operation, which is operated by Sons of Gwalia Ltd, has a central mill that processes ore from a number of satellite deposits in the Southern Cross area. Most ore is currently sourced from the Marvel Loch openpit and the Golden Pig underground mine.

Because of low gold prices in recent years, rationalization of existing operations has been necessary, resulting in a reduction in the number of companies operating mines and exploring in the Yilgarn Goldfield. In the Southern Cross – Marvel Loch area the number of operating mills has been reduced from five to two (Marvel Loch and Yilgarn Star) during the late 1990s.

Total measured and indicated resources for the Yilgarn Goldfield at the end of 1999 were 51.5 Mt of ore for a total of 91 150 kg of gold, with an average grade of 1.77 g/t Au. This represents 37% of the total measured and indicated resources in the Southern Cross – Esperance study area. There is a further 15 Mt of ore containing 38 000 kg of gold in the inferred resource category. Resources for each of the projects within the Yilgarn Goldfield are listed in Table 7.

Exploration potential

Sons of Gwalia Ltd and Viceroy Resource Corporation are the two main operators in the Yilgarn Goldfield. Sons of Gwalia has interests in approximately 2500 km^2 of mining tenements around its gold mines in the Southern Cross region. Viceroy Resource Corporation currently owns the Bounty gold mine and controls over 1000 km^2 of tenements in the southern part of the Southern Cross greenstone belt, but the company's assets have been offered for sale, and new owners may take over in 2002.

Sons of Gwalia Ltd is currently focusing exploration in areas of known mineralization — so-called brownfields areas. The following is a summary of significant developments the company has announced in reports to the Australian Stock Exchange:

- Testing for depth extensions at the Golden Pig underground mine has resulted in the delineation of additional reserves;
- Drilling has commenced at the Nevoria mine to assess the viability of extension of the openpit operation;
- Underground operations at the Great Victoria were re-established in November 2000;
- In the Edwards Find area, 15 km southwest of the Marvel Loch mine, soil sampling and RAB drilling have defined four large zones of gold anomalism;
- At the Southern Cross prospects, 5 km south of Southern Cross, four small deposits (Tamarin, Greenmount, Kelly Star, and Blacksnake) have been delineated, and another promising prospect is being tested (Starfish).

Exploration and resource drilling by Viceroy Resource Corporation around the existing openpits at the Lounge Lizard deposit, has led to indicated resources of 593 000 t of ore grading at 3.94 g/t Au, for 75 000 ounces of contained gold. The company reports that excellent potential remains for increasing this resource, as the main eastern and western shear lodes are open to the north, and a geochemically anomalous area to the northeast had been tested by only a small amount of deep exploratory drilling.

The Marda greenstone belt in the northern part of the Yilgarn Goldfield was explored for gold early in the twentieth century, and there was minor production up until 1947. Gold exploration in the mid-1980s led to the discovery of four deposits, referred to as the Marda Central deposits (Davis and Komosinski, 1995). When compared to other greenstone belts in the Yilgarn Goldfield, the Marda greenstone belt is relatively underexplored.

Higginsville–Norseman area

The historical mining centres of Higginsville and Norseman are located in the southern part of the Eastern Goldfields region. Gold was discovered near Norseman in 1894 and production at Higginsville commenced around 1900. Locations of gold deposits and occurrences in the Higginsville–Norseman area are shown in Figure 10.

Distribution and style of gold mineralization

The Higginsville–Norseman area is located within the Archaean Norseman–Wiluna greenstone belt that is part of the Eastern Goldfields Granite–Greenstone Terrane of the Yilgarn Craton.

Thomas et al. (1990), Bonwick (1995), Archer and Turner (1998), and Shedden (1998) gave descriptions of the various gold deposits within the study area, and Doepel (1973) described the regional geology. The following is a summary of these reports:

Regional characteristics

- Almost all the deposits are situated within the greenstone belts;
- The majority of deposits are structurally controlled.

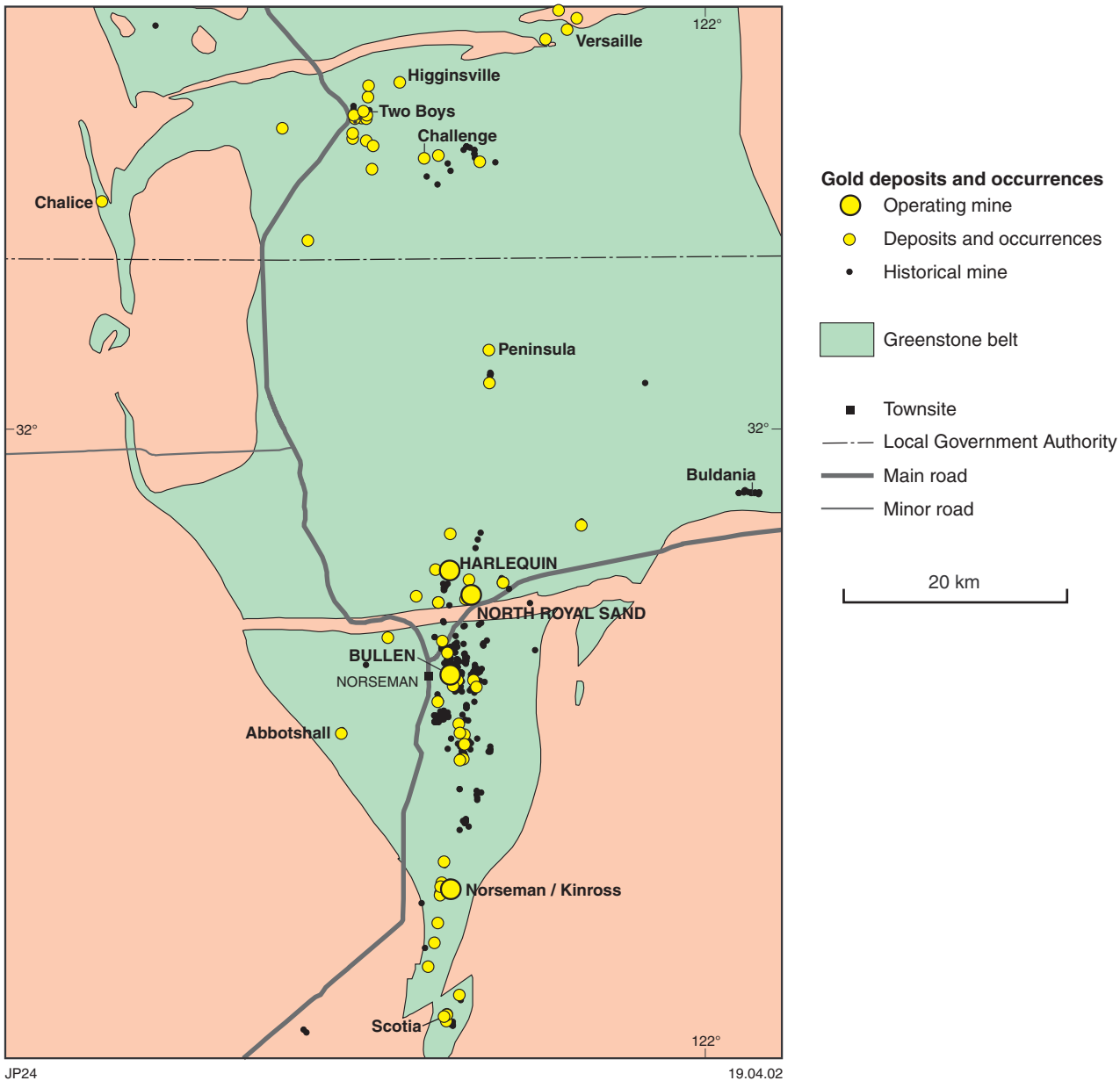

Figure 10. Gold deposits and occurrences in the Norseman area. Location and geological legend shown on Figure 4

Local characteristics

- Most of the mineralization is vein-hosted (reefs);
- Most of the high-grade ore formed where veins intersect gabbro intrusions;
- Most reefs have very narrow alteration selvedges;
- Chalice deposit is shear-hosted (Chalice Shear Zone) within basalts, gabbro, and granitoid.

Production and resources

Total recorded production for the Higginsville–Norseman area to the end of 1985 was 19.1 Mt of ore for 124 863 kg of gold, with an average recovered grade of 6.54 g/t Au. Most of the gold production has come from the Central Norseman deposits and the Chalice gold mine; the latter ceased operation in 1999.

The Central Norseman operation is the only remaining operating gold project in the Higginsville–Norseman area. The operation consists of a centrally located mill surrounded by a number of satellite deposits. Ore is currently being mined from the Bullen and Harlequin deposits.

Total measured and indicated resources for the Higginsville–Norseman area at the end of 1999 were 13 Mt of mineralization containing 45 000 kg of gold, with an average grade of 3.46 g/t Au. There is a further 5.6 Mt of mineralization containing 25 900 kg of gold in the inferred resource category. A breakdown of resources for each project is listed in Table 7.

Exploration potential

During the mid-1980s and the early 1990s, interest in the area was high and exploration using modern techniques discovered a number of deposits including Poseidon South, Challenge, Mitchell Cainozoic deep lead, and Chalice. In addition to these discoveries, known deposits were tested at depth, which resulted in the discovery of additional ore (e.g. Two Boys deposit and the Central Norseman deposits). Recent exploration efforts have focused on testing the greenstone sequences below Lake Cowan and the deep-lead deposits associated with palaeodrainage channels.

Lake Cowan covers a large area of the granite–greenstones between Higginsville and Norseman. Transported and lake sediments obscure the underlying geology and are not amenable to surface geochemical sampling techniques or traditional prospecting. Gold deposits north and south of the lake are associated with a number of regional structures. These structures are interpreted (from aeromagnetic data) to continue under the lake sediments. The discovery of the Harlequin deposit (Archer and Turner, 1998) indicates that the potential for further discoveries is very good.

The high potential for gold mineralization below Lake Cowan is also borne out by comparison with the exploration history in the Lake Lefroy area. Lake Lefroy is a large salt lake approximately 50 km north of Lake Cowan overlying the same greenstone sequence, but outside the Southern Cross – Esperance study area. There are a number of gold deposits north and south of Lake Lefroy, which are aligned along regional structures similar to those interpreted and observed at Lake Cowan. In recent years, WMC Ltd has been exploring under Lake Lefroy with great success and has discovered more than 8.5 Mt of ore at an average grade of 2.56 g/t Au and containing 21 730 kg of gold (Reddell and Dusci, 1997).

Ravensthorpe area

The Ravensthorpe area has a long history of mining and has produced a wide variety of mineral commodities. Mining commenced in 1899, and most of the gold produced came from the lodes that also produced copper and silver. Distribution of gold deposits and occurrences in the Ravensthorpe area is shown in Figure 11.

Distribution and style of gold mineralization

Witt (1998) divided the Ravensthorpe area into three major Precambrian tectonic units: the southern margin of the Archaean Yilgarn Craton, which includes the Ravensthorpe greenstone belt; the Mesoproterozoic Mount Barren Group; and the Archaean Munglinup Gneiss of the Biranup Complex of the Albany–Fraser Orogen.

Witt (1998) described in detail the geology and mineral resources of the Ravensthorpe and Cocanarup areas. In relation to gold mineralization, he noted that:

- Most of the gold has been produced from epigenetic copper–gold(–silver) deposits within the Ravensthorpe greenstone belt;
- Most of the mineralization is hosted by the Annabelle Volcanics, and is within about 2 km of the contact with the Manyutup Tonalite;
- Although the coarse-grained Manyutup Tonalite contains some significant mines (e.g. Elverdton – Mount Desmond), mineralization is largely confined to marginal parts of the pluton;
- There is a spatial association of gold mineralization with small, medium-grained tonalite plutons at Mount Cattlin and Mount McMahon;
- Mineralization is also associated with broad zones of deformation and alteration, including several thrust faults;
- At the deposit scale, mineralization is controlled by narrow, discontinuous shear zones and quartz veins within irregular shears.

Production and resources

Cumulative production from the Ravensthorpe district to the end of 1985 was 111 400 t of ore for a total of 2642 kg of gold, with an average recovered grade of 23.7 g/t Au. Production was from three main centres: Mount Cattlin, Mount McMahon, and Kundip (Fig. 11). Currently there are no operating gold mines in the Ravensthorpe district.

Total measured and indicated resources for the Ravensthorpe district at the end of 1999 were only 50 000 t of mineralization containing 400 kg of gold, with most of the resources at Kundip. There were a further 720 000 t of mineralization containing 4900 kg of gold in inferred resources. Resources for individual projects within the Ravensthorpe project are listed in Table 7.

Exploration potential

Historical production and the known geology of the Ravensthorpe district indicate that potential gold discoveries are most likely to be low tonnage but high grade.

Homestake Gold of Australia Ltd (now Barrick Gold of Australia Ltd) and Tectonic Resources NL have discovered a new style of base metal and precious metal mineralization (Trilogy prospect) in the Palaeoproterozoic Mount Barren Group metasedimentary rocks that were previously considered unprospective (Witt, 1997), but now offer new opportunities for exploration.

Potential for gold mineralization

A number of factors have been examined to assess the gold potential of the Southern Cross – Esperance Region, and the location of areas most likely to be developed in the foreseeable future. These factors include: actual historical production trends and the development of new pre-mining resources, development of new exploration methods and models by the major mining companies exploring in the region, and general world-wide gold-industry trends.

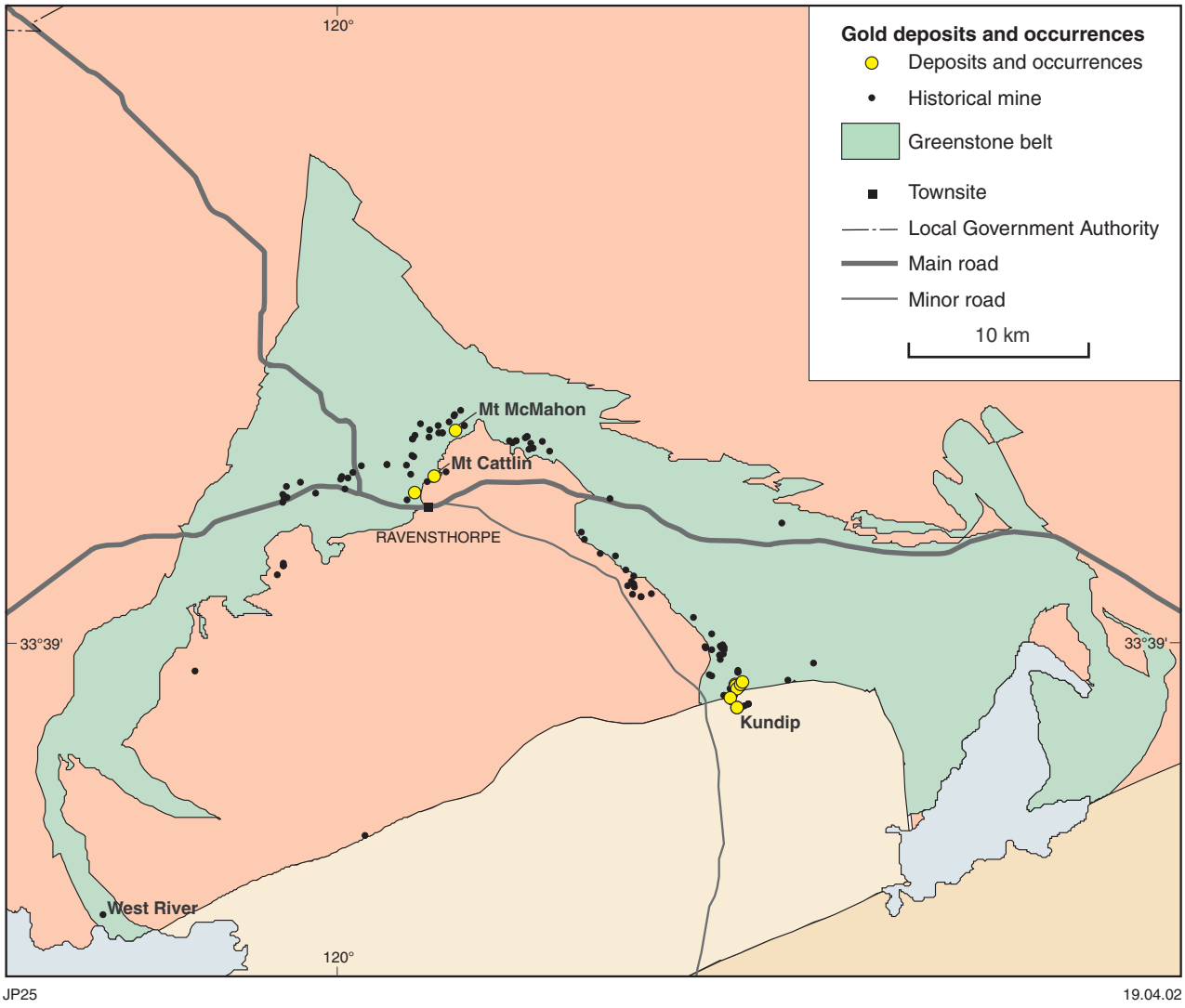

Figure 11. Gold deposits and occurrences in the Ravensthorpe area. Location and geological legend shown on Figure 4

Historical trends in production

Historical production data for greenstone belts of the Southern Cross – Esperance Region show large variations in gold production between the belts and it is useful to examine these to assist in interpreting the remaining potential.

Table 8 shows the total amount of gold produced, the average recovered grade, gold production per km^2, total pre-mining resources, and gold concentration per km^2, for each of the major greenstone belts within the Southern Cross – Esperance Region. A map of the pre-mining resources on a project basis for the whole area is shown on Figure 12. The Southern Cross greenstone belt (which includes Holleton and Westonia) has the highest concentration of gold produced per unit area of greenstone with 119.8 kg/km^2, and the Norseman–Wiluna greenstone belt has the second highest concentration of gold produced at 67.5 kg/km^2. There is a significant decrease in gold concentration to only 14.5 kg/km^2 and 4.3 kg/km^2 for the Ravensthorpe and Marda greenstone belts, respectively. There has been no recorded gold production from the Lake Johnston greenstone belt.

There are no particular geological factors for the large difference between the gold production per unit area of greenstone at Southern Cross and Norseman compared with that at Ravensthorpe, Marda, and Lake Johnston. There may be a combination of other factors, and some of them include:

- The majority of exploration (and expenditure) has been concentrated in the Southern Cross and Norseman regions because this is where most of the historical mining has taken place;
- Most exploration is carried out in areas of good outcrop or near-surface rock, where geochemical sampling is most effective;
- Large areas of greenstone in the region have been subjected to exploration that has targeted other metals (e.g. nickel), and have not been thoroughly explored for gold;

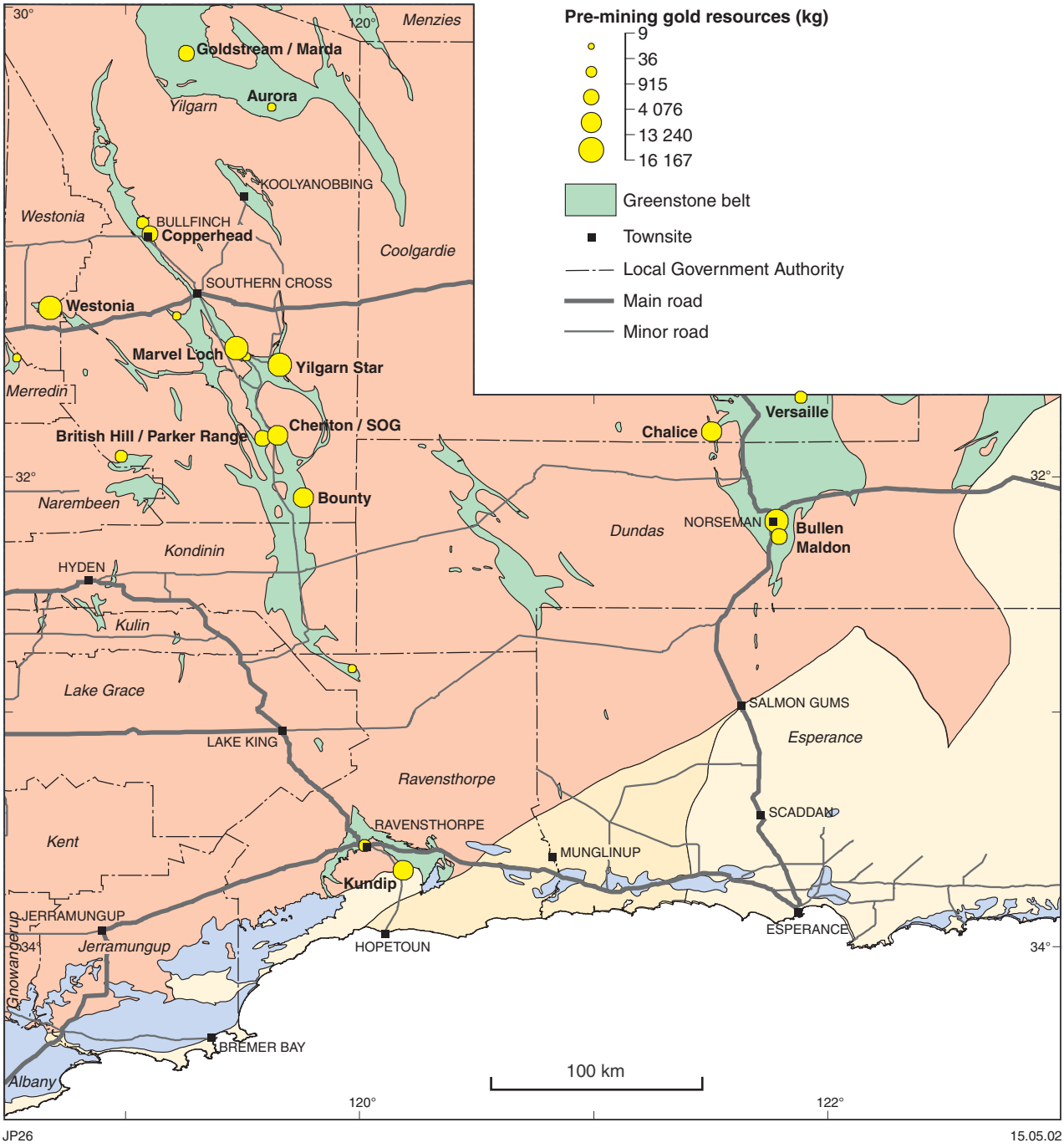

Figure 12. Gold — pre-mining resources (recorded production plus gold remaining in existing resources), by project. See Figure 4 for complete geological legend

Table 8. Gold productivity of greenstone belts in the Southern Cross – Esperance Region

Greenstone belt	*Area*	*Gold production to 1999*			*Total pre-mining resources*	
		Gold produced	*Recovered grade*	*Gold produced per unit area*	*Contained gold*	*Contained gold per unit area*
	(km^2)	*(kg)*	*(g/t)*	*(kg/km^2)*	*(kg)*	*(kg/km^2)*
Southern Cross	3 646	250 693	3.04	68.8	436 819	119.8
Norseman–Wiluna	2 901	124 867	6.53	43	195 934	67.5
Marda	2 869	5 065	5.87	1.8	12 325	4.3
Ravensthorpe	537	2 642	23.72	4.9	7 806	14.5
Lake Johnston	841	0	0	0	0	0.0

NOTE: Total pre-mining resources include measured, indicated, and inferred resources
SOURCE: MINEDEX database

- Any greenfields exploration (i.e. exploration in untested areas) of greenstones that have no historical workings and/or are buried under overburden is expensive and concept driven. Smaller companies may have difficulty in raising funds to explore such areas.

Current trends

Current trends in gold exploration are:

- Sons of Gwalia Ltd concentrating on brownfields exploration (exploring in areas of known mineralization) between Southern Cross and Bullfinch. The company has a number of promising projects and is looking to re-establish production at Corinthia, Nevoria, and Great Victoria;
- Increased interest in the Ravensthorpe area because of encouraging results from recent gold exploration (e.g. Trilogy area) and some promising nickel projects (e.g. RAV8 and Ravensthorpe–Bandalup);
- Exploration of greenstone belts under salt lakes, particularly Lake Cowan.

Exploration expenditure tends to be related to the gold price, and the rate of discovery is related to exploration expenditure. Although the potential for discovering deeply buried deposits is high, so is the cost of exploring for them. Thus, in periods of low gold price, the focus is often towards brownfields exploration.

The value of gold production from an area and the prevailing gold price can be used as a predictive tool to estimate the level of exploration expenditure. Gold exploration expenditure as a percentage of the value of gold production has been declining in Western Australia in recent years from a peak of 15.5% in 1995–96 to 9.3% at the end of 1999 (Flint et al., 1999). This trend is a direct result of the continuing decline in the gold price that has forced companies to a corporate short-term focus on maintaining profitability and an aversion to risk. On this basis, the indications are that the level of gold exploration expenditure in the Southern Cross – Esperance Region during 2000 will be about 9–10% of the value of 1999 production, i.e. about $25 million for 2000.

Another consequence of the declining gold price has been a decrease in gold production in the area. Production in 1999 from the Southern Cross – Esperance Region showed a decrease of 16% (3850 kg Au) compared to the previous year (Table 5). There has been a slight recovery in the gold price during 2000 and early 2001, but this is not of sufficient magnitude to lead to increased exploration and gold production from the region.

Systematic exploration over areas of known mineralization has proved to be successful in discovering new near-surface deposits, and this should remain so, unless there is continued reduction in exploration expenditure. If exploration expenditure is maintained, then the further development and use of ore deposit models, remote sensing technology, and geochemistry to accurately predict the existence of concealed mineralization are likely to result in discoveries and open up new regions that were previously considered unprospective.

The continued development of exploration and mining techniques will result in the discovery and economic extraction of deeper ore, extend the mine life of existing mines, and make marginal resources profitable.

Chapter 5

Iron ore

Mineable iron ore deposits have developed within two stratigraphic horizons in Archaean greenstone belts of the Southern Cross Granite–Greenstone Terrane (Chin and Smith, 1983). The older of these horizons is a single banded iron-formation unit, locally up to 100 m thick, which hosts the Bungalbin and Mount Jackson iron ore deposits. Blockley (1990) suggested that the Koolyanobbing deposits are also in this horizon. The younger horizon consists of several thin banded iron-formation layers containing high-grade hematite that host the Windarling Peak iron ore deposit. Smaller occurrences of iron ore are found at Honman Ridge, Round Top Hill, Mount McMahon, Mayfield, and Southdown. Locations of these are shown on Figure 13.

Within the project area, the only production is from Koolyanobbing by Portman Ltd. Iron ore resources in the Southern Cross – Esperance Region are given in Table 9.

Banded iron-formation

Koolyanobbing

Several banded iron-formation (BIF) units within a sequence of basalts and pelitic units, intruded by minor dykes and sills, form the Koolyanobbing Range. Three types of iron ore deposits are found at Koolyanobbing. The first type has been produced by oxidation of carbonate- or sulfide-rich BIF during supergene enrichment and is dependent on the original mineralogy of the host BIF (Griffin, 1980). The second type of iron ore formed where meteoric and ground waters have penetrated porous zones created by tectonic deformation in the parent oxide-facies BIF. Iron was thus mobilized and redeposited as coarse specular hematite in porous zones (Chin and Smith, 1983). The third type, typified by Koolyanobbing deposit K (Dowds Hill), shows features of the first two deposit types, but also has a core of ore produced by ascending (hypogene) solutions. In this deposit type, iron minerals (specular hematite, goethite, limonite, and minor magnetite) are concentrated in brecciated fold cores in BIF (Griffin, 1980; Chin and Smith, 1983).

Total indicated and inferred resources for the Koolyanobbing deposits (including Mount Jackson and Windarling), as announced to the ASX by the operating company Portman Ltd (10 May, 2001), are estimated at 159.8 Mt at 62.24% Fe, with 0.107% P. Further details on resources at specific sites within the Koolyanobbing project are provided in Table 9.

Portman Ltd expected to achieve production rates of 3 Mt/pa from the established Koolyanobbing operations during 2000–01. In addition, Portman Ltd is undertaking extensive exploration of the Bungalbin, Mount Jackson, and Windarling deposits to the north of Koolyanobbing. Mining from these areas is planned to commence in 2002, and production is planned to increase by 3 to 4 Mt/pa over 3–4 years. This will give the project an overall production capability of 6–7 Mt per year by 2005–06. Planned production figures for the next six years for Portman's deposits in the Koolyanobbing area are given in Table 10 (Portman Ltd, 18 May 2000, written comm.).

In February 2000, Portman entered into an ore-handling agreement with the Esperance Port Authority to accommodate increased production from the proposed expansion of the Koolyanobbing project. The $40 million agreement involves construction of a new storage facility at Esperance and the acquisition of new ore wagons. A major dredging program to deepen the Esperance Port was completed in the second half of 2001. Work on new berth and shiploading facilities at Esperance will be completed in early 2002.

New mining areas at Bungalbin, Mount Jackson, and Windarling will be linked to the Koolyanobbing–Esperance railway by a purpose-built spur line to be constructed in three stages. Continuing development of the Kalgoorlie–Esperance railway over the next five years will ensure it can accommodate developments at the mine and port.

Bungalbin and Mount Jackson

The Bungalbin and Mount Jackson deposits are within a banded iron-formation unit that contains highly contorted alternating bands of jasper and hematite. Bedded or massive limonite and micaceous hematite are concentrated along bedding planes and in fractures. Cainozoic supergene enrichment has contributed to the formation of these deposits, but iron concentrations are also present below the zone of supergene enrichment (Chin and Smith, 1983). Portman is currently exploring these deposits, with mining planned to commence in 2002. Inferred iron ore resources for the eastern and western deposits at Bungalbin are estimated by Portman

Figure 13. Iron ore deposits and occurrences in the Southern Cross – Esperance Region. See Figure 4 for complete geological legend

Table 9. Iron ore resources in the Southern Cross – Esperance Region

Deposit	*Resources (Mt)*	*Fe (%)*	*P (%)*
Bungalbin East	59.0	57.9	0.15
Bungalbin West	6.7	58.1	0.30
Koolyanobbing Deposit A	4.7	62.1	0.06
Koolyanobbing Deposit C	3.9	60.6	0.04
Koolyanobbing Deposit D	2.8	62.0	0.03
Koolyanobbing Deposit K (Dowds Hill)	38.6	62.7	0.12
Mayfield	8.0	60.0	0.10
Mount Jackson J1	28.0	59.0	0.15
Mount Jackson J2	15.0	61.7	0.03
Mount Jackson J3	6.0	63.9	0.05
Mount Jackson J4	6.0	57.0	0.20
Mount McMahon	50.0	<40.0	n.a.
Southdown	54.0	46.8	n.a.
Windarling W1	1.5	62.6	0.19
Windarling W2	4.4	65.3	0.07
Windarling W3	18.3	64.5	0.18

NOTE: n.a. not available
SOURCE: MINEDEX database

to be 59 Mt at 57.9% Fe and 6.7 Mt at 58.1% Fe respectively. Portman has provided inferred resource estimates for four iron ore deposits in the Mount Jackson area on its website (Portman Ltd, 18 May 2000, written comm.). The deposits (J1–J4) have inferred resources estimated at 28.0 Mt at 59% Fe, 15.0 Mt at 61.7% Fe, 6.0 Mt at 63.9% Fe, and 6 Mt at 57% Fe, respectively. They extend for a distance of about 23 km along a series of discontinuous ranges formed over banded iron-formation and metabasalt.

Windarling Peak

Several thin banded iron-formation layers containing high-grade hematite host three iron ore deposits in the Windarling Peak area. The deposits (W1–W3) have a total resource of 24.2 Mt of ore averaging 64.1% Fe (Portman Ltd, 18 May 2000, written comm.). Portman has acquired mining tenements over these deposits and is expected to start mining during 2002.

Honman Ridge – Round Top Hill

Banded iron-formation forms a series of ridges within the Bremer Range near Lake Johnston and Lake Hope. Two jaspilite bands, with true widths of about 25 m, outcrop over a total length of some 7 km at Honman Ridge. These were estimated to contain iron ore resources of 16.26 Mt at an average grade of 38% Fe (Gower and Bunting, 1976), but this is best regarded as pre-resource mineralization under the current JORC* code. There may also be about 0.5 Mt of iron ore at Round Top Hill. A single bulk sample from this area gave 38.2% Fe (Connolly, 1959; Gower and Bunting, 1976).

Mount McMahon

There is an estimated total of 50 Mt (inferred resources category at best) of hematite and goethite in 12 small

* 1999 Australasian Code for Reporting of Mineral Resources and Ore Reserves, prepared by the Joint Ore Reserves Committee (JORC, 1999)

Table 10. Portman Ltd's iron ore production plan for the period 2000–05

Area	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*
Koolyanobbing	2.4	3.0	3.0	2.9	2.0	2.0
Bungalbin	–	–	0.7	0.7	0.7	0.7
Mount Jackson	–	–	–	1.0	2.0	2.0
Windarling Range	–	–	–	–	1.0	2.0
Total	**2.4**	**3.0**	**3.7**	**4.6**	**5.7**	**6.7**

NOTE: Units are million tonnes of iron ore
SOURCE: Portman Ltd, 2000, written comm.

deposits in the Mount McMahon – Mount Short area. Nine holes drilled in the area during 1964 intersected sporadic iron mineralization formed by the supergene enrichment of ferruginous chert and banded iron-formation (Acton and Coleman, 1969). The locations of these deposits are given on Plate 1. The deposits lie within the Ravensthorpe Ranges and have average grades of less than 40% Fe. Little ore-grade material is found below a depth of 25 m (Thom et al., 1977).

Mayfield

An inferred resource totalling 8 Mt of iron ore grading 60% Fe and 0.1% P is estimated for the Mayfield project, 18 km north of Ennuin. The project includes BIF-hosted deposits at Mayfield, Carterton, Sweet William, Newfield East, Newfield Central, Yellowdine, Newington, and Trump.

Southdown

The Southdown magnetite project is situated on the western boundary of the study area, about 25 km west of Cheyne Bay. The deposit is a metamorphosed banded iron-formation hosted by garnet-bearing gneiss and schist. Terrex Resources NL became 100% owners of the project in 1997, when they bought a 75% equity previously held by Portman. Low-key pre-feasibility studies commenced in 1998 and are aimed at reviewing the suitability of the magnetite as heavy media feed for coal-washing applications (Terrex Resources NL, quarterly report of 30 June 1998). A measured resource of 54 Mt with 46.8% Fe is estimated for the magnetite deposit.

Other iron ore deposits

There are also minor BIF-hosted deposits near Mount Rankin, Mount Caudan, Ennuin, Golden Valley, and Days Find. Accurate locations for these occurrences are not available. There are no current resource figures for these deposits but iron contents and estimated resources are given in Connolly (1959). The deposits have average iron contents of 30 to 40% Fe and resources in the order of 1–4 Mt of iron ore. Most exploration in these areas has been for gold mineralization, which is commonly associated with the banded iron-formations.

Chapter 6

Alloying and speciality metals

Nickel

Western Australia's production of nickel (as contained metal in concentrate, matte, or as refined metal) for 1999 was 121 888 t, of which 96.9% was from sulfide nickel deposits. Within the State there are several lateritic nickel projects being commissioned and in the planning or feasibility stages. If these proceed, they would lift output of nickel dramatically over the next decade, and Western Australia could conceivably be providing up to 18% of the world's primary nickel production (compared with about 12% at present) — assuming non-WA production is displaced, but this is by no means assured (Flint, 1999).

The nickel deposits and occurrences within the Southern Cross – Esperance Region are shown on Figure 14. Historical production has come mostly from the Forrestania and Redross deposits. Mining at Redross ceased in 1990, and mining at Forrestania ceased in 1999, leaving the Southern Cross – Esperance Region without an operating nickel mine. This was short-lived, however, as Tectonic Resources NL's nickel sulfide deposit RAV8 started production in April 2000. Another nickel sulfide deposit, LionOre Australia's Emily Ann deposit, commenced production in late 2001.

Geology

Ultramafic igneous rocks, rich in olivine, have high nickel contents in both silicate and sulfide minerals. These nickeliferous minerals are principally found in:

- Massive and disseminated sulfide deposits of Ni–Cu–Fe at depth, or in their weathered equivalents (gossans) at or near the surface;
- Lateritic deposits of silicates and oxides in regolith profiles developed over ultramafic rocks.

Based on the nature of the host rock, Marston (1984) classified nickel sulfide deposits in Western Australia into five types:

- Volcanic peridotite-associated deposits
- Intrusive dunite-associated deposits
- Gabbroid-associated deposits
- Layered sedimentary-associated deposits
- Vein-type deposits with arsenic.

The majority of Western Australia's sulfide nickel deposits are located within the Archaean greenstone belts of the eastern Yilgarn Craton, where there is an abundance of magnesium-rich ultramafic volcanic rocks and laminated sulfidic metasedimentary rocks. Major strike faults probably influenced the nature and distribution of volcanism and sedimentation and controlled nickel mineralization (Marston, 1984).

Initial work carried out on the nickel deposits of the Yilgarn Craton resulted in the majority of the deposits being classified as intrusive dunite-associated deposits or volcanic peridotite-associated (komatiite) deposits (Marston, 1984).

Komatiites are ultramafic volcanic rocks extruded as lavas that often form part of a larger volcanic pile made up of cyclic ultramafic (komatiite lavas) and mafic (basalt lavas) volcanism. This ultramafic volcanism was mainly restricted to the Archaean, when the crust was thinner and crustal temperatures high enough to enable ultramafic magmas to reach the surface before crystallizing. An important property of ultramafic lavas is their low viscosity, allowing them to spread thinly over large areas (sheet flow) or follow the topography (like a river) forming lava channels. Hill and Gole (1990) proposed that komatiite-associated deposits could be divided into two major subdivisions based on the different mechanisms of emplacement:

- those with sulfides in relatively thin (<150 m) flows with massive sulfides as olivine–sulfide cumulates forming the basal parts of the lava flows. Grades of massive sulfide deposits range from 2% to 15% Ni. Most of the sulfide deposits within the Southern Cross – Esperance Region are of this type;
- disseminated sulfides in large layered bodies of olivine cumulate. Nickel grades reach a maximum of 1.5%, but most range between 0.5% and 0.7%. Examples within the Yilgarn Craton include deposits at Mount Keith, Six Mile Well, Beteno, and Honeymoon Well. The only deposit of this type known within the study region is part of the Maggie Hays deposit.

Lateritic nickel deposits have formed by the deep weathering and ferruginization of olivine-rich rocks, and are generally devoid of sulfides. Average nickel contents are between 1.2 and 1.4%, accompanied by variable amounts of cobalt (in some cases this cobalt is commercially important). Discontinuities in bedrock structure

Figure 14. Nickel deposits and occurrences in the Southern Cross – Esperance Region. See Figure 4 for complete geological legend

may result in deeper weathering and/or restricted groundwater flow and thereby produce higher nickel or cobalt contents than the average (Marston, 1984). Examples of large nickel laterite deposits in the Yilgarn Craton are at Murrin Murrin, Cawse, and Bulong. Within the study area, the Halleys nickel laterite deposit, near Bandalup Hill at Ravensthorpe, is under development (Ravensthorpe – Bandalup Hill project).

The four main areas within the Southern Cross – Esperance Region that have significant nickel mineralization are Forrestania, Lake Johnston, Norseman, and Ravensthorpe.

Southern Cross – Forrestania area

Forrestania nickel deposits

The Forrestania nickel deposits are located in the southern part of the Southern Cross greenstone belt, which is also referred to as the Forrestania region or Forrestania greenstone belt (Frost et al., 1998). The deposits are centred on the Forrestania mine, 130 km south of Southern Cross (Fig. 14).

During the nickel boom of the late 1960s to early 1970s, Amax Exploration (Australia) Inc. carried out extensive exploration in the Forrestania region, and this included extensive regional rotary airblast (RAB) drilling programs to test ultramafic rocks at depth under the transported and/or highly weathered overburden. In October 1969, the first nickel gossan was discovered at the New Morning prospect. The Cosmic Boy, Digger Rocks, South Digger Rocks, and Flying Fox deposits, and most of the known nickel sulfide occurrences, were located over a seven year period (Frost et al., 1998).

Outokumpu Australia Pty Ltd commenced mining at Forrestania in September 1992, with the first nickel sulfide ore taken from the Digger Rocks openpit — 20 years after the first drillholes intersected nickel sulfides. The Forrestania nickel deposits include Cosmic Boy, Digger Rocks, Flying Fox, South Digger Rocks, Beautiful Sunday, New Morning, Seagull, and Liquid Acrobat.

The pre-mining nickel sulfide resource for the nickel deposits at Forrestania was 11.5 Mt of ore at an average grade of 2.0% Ni.

Frost et al. (1998) described the regional geology and the distribution of the Forrestania nickel deposits. The following is a summary of their key points:

- Forrestania nickel deposits are komatiite-hosted nickel sulfides;
- Deposits show there is a strong volcanological control over the setting of the ores and their host rocks, with the variation in the style of nickel sulfide mineralization interpreted to reflect the dynamic environment of accumulation of magmatic sulfides in komatiitic lavas;
- Olivine adcumulate to mesocumulate bodies that host the nickel sulfide deposits at Cosmic Boy, Flying Fox, and other deposits at Forrestania, were likely to have formed in preferred lava pathways that facilitated the crystallization of thick cumulate piles from continually replenished lavas;
- Massive sulfide deposits are interpreted to form at an early stage of flow in preferred lava pathways, or at least before significant olivine crystallization, probably through ground melting of the sulfidic sediment substrate over which the lava flowed.

Outokumpu Australia Pty Ltd took up the Forrestania nickel deposits in 1989, and implemented a new cost-effective exploration strategy. The company planned the initial target selection by developing ore-deposit models based on a sound understanding of the controls of nickel sulfide mineralization and the nature of the komatiite sequences in Archaean greenstone belts (Frost et al., 1998). The purpose of this type of exploration strategy was to focus on relatively inexpensive exploration techniques such as geophysical and geochemical surveys, and drilling in areas more prospective for sulfide mineralization.

From an assessment of past exploration activity it appears that the most successful exploration strategy for the Forrestania area has been systematic regional drilling programs. This type of exploration has proven successful in many other areas of Western Australia, and also for other metals (notably gold). The strength of this type of exploration approach is that it does not depend on an interpretation of the underlying geology. However, most companies do not have the resources to carry out extensive regional drilling programs and have to select smaller areas as Outokumpu did at Forrestania.

Trough Well prospect

The Trough Well prospect is located 70 km north-northwest of Southern Cross, on the eastern side of the narrow greenstone belt that extends northwards from Southern Cross. In the Bullfinch to Trough Well area, the belt consists mainly of metabasaltic rocks with minor banded iron-formations, and narrow ultramafic units (Marston, 1984).

In 1970, a gossan was discovered at the southern end of an ultramafic unit in the Trough Well area. The ultramafic unit is 900 m long and between 60 and 250 m wide. The southern and northern ends of the unit are terminated by granitoid rock, and the nickel mineralization is in three areas along the base of the ultramafic unit (Marston, 1984).

This small deposit has not been mined, but there is a resource of 20 000 t of nickel sulfide ore at a grade of 2.5% Ni, containing 5 t of nickel metal.

Lake Johnston area

The Lake Johnston greenstone belt lies approximately 500 km east of Perth, within the Southern Cross Granite–Greenstone Terrane. The greenstone belt is named after a large salt lake that covers the central part of the belt. The two major nickel sulfide resources, Maggie Hays and Emily Ann, are both located in the northern part of the belt (Fig. 14).

Exploration for nickel sulfides in the Lake Johnston area commenced in 1966 and the first evidence of nickel mineralization was found 600 m south of the Maggie Hays deposit in 1971. In 1981, Amoco Minerals Australia Incorporated intersected sulfide mineralization in nine drillholes, and at least one of these intersected the Maggie Hays deposit. In 1991, Forrestania Gold NL purchased the Maggie Hays prospect. In 1993, Forrestania successfully located disseminated sulfide mineralization, some 22 years after the first discovery. In 1995, significant strike extensions of massive sulfides were located to the north of the disseminated zone, and these were referred to as the northern zone. The Emily Ann deposit was discovered 3 km north of and along strike from the Maggie Hays deposit in 1997.

Gower and Bunting (1976) described the regional geology of the Lake Johnston area and Buck et al. (1998) described the Maggie Hays and Emily Ann deposits. The following is based on Buck et al. (1998).

Maggie Hays

The Maggie Hays area extends south for 12 km from the Jimberlana dyke in the north to a granitoid pluton north of Maggie Hays Hill. The bedrock geology is covered by laterite and colluvium.

Maggie Hays is a large, low-grade nickel sulfide deposit. The orebody is tabular and mineralization is distributed over a strike length of about 1400 m. The deposit consists of two zones, the Southern zone and Northern zone, each of which differs in host lithology and style of mineralization.

Southern zone: mineralization lies at the base of the thickest zone of the central ultramafic unit and it appears, in part, to occupy an internal trough-shaped depression. The mineralized zone is up to 40 m thick and consists mainly of disseminated sulfides. There is also a narrow basal massive sulfide zone up to 7 m thick.

Northern zone: mineralization is hosted by the felsic volcanic unit that forms the stratigraphic footwall to the central ultramafic unit. The zone averages 3 m in thickness, with a maximum thickness of up to 9.5 m. The mineralization is in massive sulfide layers up to 3 m thick, with broader zones of massive sulfide stringers that appear to represent a matrix enclosing felsic clasts.

Emily Ann

The Emily Ann deposit, 3 km north of Maggie Hays, is within the central ultramafic sequence that is covered by a thick layer of transported sediments. The central ultramafic unit is not a thick, lenticular, cumulate flow unit (unlike Maggie Hays), but instead is a series of remobilized and layered ultramafic lenses, which are interpreted as being remnants of an original thicker ultramafic assemblage modified by later tectonism.

The deposit has two distinct ore surfaces, the footwall surface and the hangingwall surface, which are separated by 40 m of barren felsic volcanic country rock. The footwall ore surface is the better developed of the two, and is composed predominantly of remobilized massive sulfide mineralization hosted by felsic volcanic rocks, with minor intercalated low-magnesian ultramafic rocks.

Emily Ann is a small high-grade deposit with an estimated indicated and inferred resource of 2.1 Mt of ore grading 3.98% Ni, for 84 000 t of contained nickel.

Ravensthorpe area

Three Archaean fault-bounded tectonic units have been recognized in the Ravensthorpe region: the Carlingup Terrane, the Ravensthorpe Terrane, and the Cocanarup greenstones (Fig. 15). Exploration during the 1960s and 1970s revealed the presence of nickel sulfide mineralization in the Carlingup Terrane (Witt, 1998). Significant discoveries include the nickel sulfide deposit at RAV8 and the nickel laterite deposits at Bandalup Hill.

RAV8

The RAV8 deposit is in serpentinized dunite and peroditite, and consists of minor massive to brecciated sulfide ore within a larger shoot of disseminated sulfides. Disseminated ore contains up to 2% Ni, and massive sulfide ore up to 18% Ni (Witt, 1997).

The project is operated by Tectonic Resources NL, who purchased the RAV8 nickel project from the Ravensthorpe Joint Venture Partners in July 1997. Infill drilling, which was completed in December 1997, increased the known length, width, and thickness of the mineralization. RAV8 has a current total mining reserve of 206 404 t of ore grading 5.49% nickel (Tectonic Resources NL, 2000).

Ravensthorpe–Bandalup

The Ravensthorpe–Bandalup nickel project is about 25 km east of Ravensthorpe and contains three nickel laterite deposits: Halleys, Shoemaker Levy, and Hale Bopp (Fig. 16) The deposits were discovered over 20 years ago, and became known as the Bandalup Hill nickel laterite, but it was only recently that a metallurgical process became available to economically extract nickel (and cobalt) from the laterite.

Norseman area

The Norseman area is located within the Archaean Norseman–Wiluna greenstone belt of the Eastern Goldfields Granite–Greenstone Terrane. The Norseman–Wiluna belt is the largest producer of nickel in Western Australia and contains Western Australia's largest deposits of both sulfide and lateritic nickel. Within the Southern Cross – Esperance study area, nickel sulfide mineralization occurs at Redross and Pioneer, and nickel laterite occurs at Mount Thirsty (Fig. 14) at the southern end of the belt.

Redross

The Redross deposit, 60 km north of Norseman, is the most southerly of the Widgiemooltha group of nickel

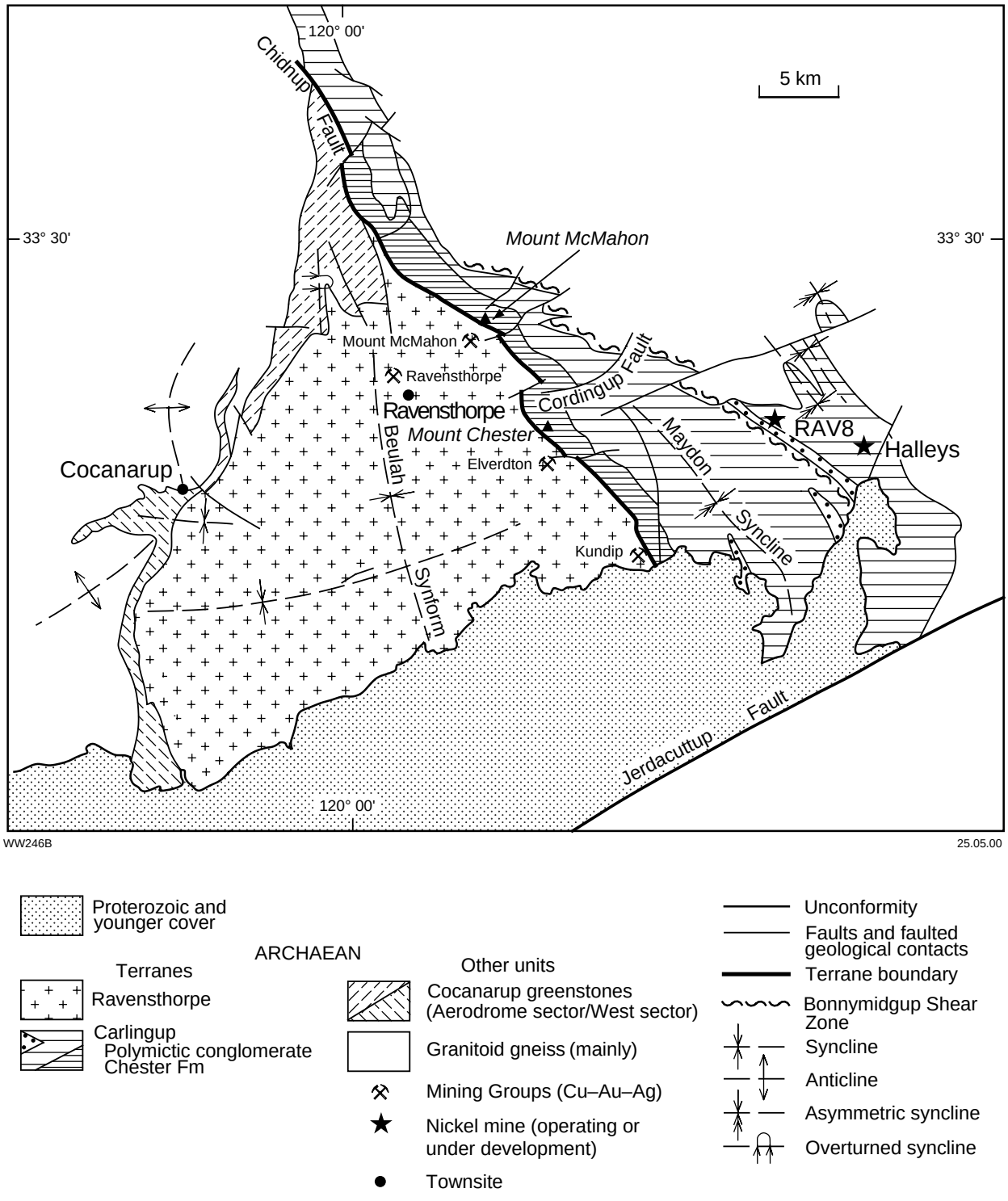

Figure 15. Geological map showing the main tectonostratigraphic subdivisions of the Ravensthorpe greenstone belt (after Witt, 1995)

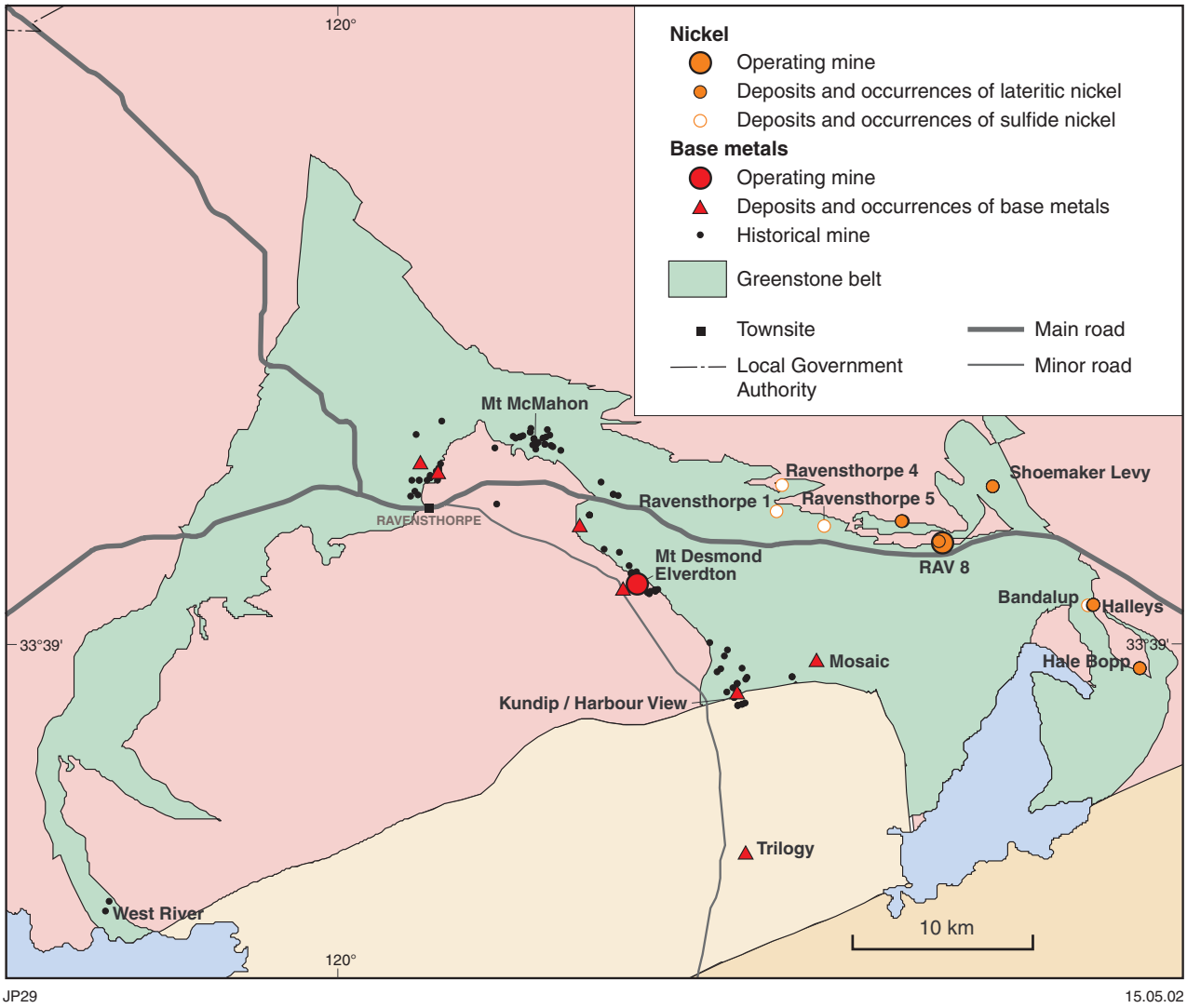

Figure 16. Nickel and base metal deposits and occurrences in the Ravensthorpe area. Location and geological legend shown on Figure 4

deposits. The Widgiemooltha nickel deposits are distributed around the Widgiemooltha dome — a major anticlinal structure with a core of deformed granitoid (Marston, 1984).

Nickel exploration in the region started in 1967, and peaked during the 'nickel boom' between 1968 and 1972. The Redross deposit was discovered by the Anaconda–CRA joint venture partners in 1968. Development commenced in 1970 and the deposit was mined by the joint venture from 1974 to 1978. WMC Ltd purchased Redross and production started again in 1989–90 (when Redross formed part of WMC's Kambalda project).

The Redross deposit lies at the base of an ultramafic (komatiite) unit that is 60–120 m thick. Metabasalt units and sulfidic sedimentary units are in contact along the base of the ultramafic unit (Marston, 1984).

Nickel ore lies within three shoots known as Redross, and the Eastern and Western veins. The bulk of the mineralization is in the Redross vein (80%) with most of the remainder in the Eastern vein (17%). The Redross vein formed within the ultramafic unit along or near the metabasalt–ultramafic rock contact. The vein was then offset into the metabasalt and ultramafic units by a number of faults that crosscut the orebody. The Redross vein is known to extend from the surface to a vertical depth of 450 m (Marston, 1984).

Pioneer prospects

The Pioneer nickel prospects are 27 km north-northwest of Norseman, on the eastern side of the Pioneer dome, a syntectonic structure formed by granitoid and gneiss (Marston, 1984). Exploration in the area was carried out in the period between 1968 and 1971 by the Newmont – Central Norseman Gold Mines joint venture. Gossans were identified at two localities 1.5 km apart and along strike from each other: the northern gossan was called JH and the southern gossan was called BB.

The prospects are situated in a mafic to ultramafic sequence in contact with gneissic rocks of the Pioneer dome (Marston, 1984). The JH prospect consists of two separate mineralized shoots, at or near the basal contact of the ultramafic unit. The northern shoot is 118 m long and 6 m wide, and the southern shoot is 60 m long and 1.6 m wide. The BB prospect consists of one mineralized shoot, 15 m above the basal contact, which is 90 m long and up to 3 m wide.

The Pioneer prospects have not been mined, but there is a measured and indicated resource totalling 33 000 t at a grade of 1.1% Ni (containing 363 t of nickel metal) at the JH prospect.

Mount Thirsty

The Mount Thirsty prospect is located 20 km northwest of Norseman. Australian Gold Resources Ltd announced in its September 1999 Quarterly Report to the ASX that drilling had intersected an area of laterite-hosted nickel–cobalt mineralization over an area of 700 × 500 m. No resource estimate has yet been released.

Production and resources

Total cumulative nickel production to the end of 1999 for the Southern Cross – Esperance Region was 484 869 t of nickel concentrate at an average grade of 13.15% Ni and containing 63 807 t of nickel metal. Production was from the Redross deposit during the periods from 1974 to 1978 and 1989–90, and from the Forrestania deposits from late 1992 to 1999.

During 1999, nickel production for the study area was 64 245 t of nickel concentrate at an average grade of 13.8% Ni containing 8 881 t of nickel metal. All production was from the Forrestania nickel project where operations ceased in August 1999. The cumulative production from Forrestania has been 397 653 t of concentrate containing 50 701 t of nickel metal with a value of around $437 million (Table 11).

The Redross mine has produced a total of 87 216 t of nickel concentrate, averaging 15.03% Ni and containing 13 106 t of nickel metal.

Table 11. Production of nickel concentrate from Forrestania, from 1993 to 1999

Year	*Concentrate (t)*	*Contained metal (t)*	*Value ($M)*
1993	24 801	2 437	15.5
1994	51 889	6 229	45.6
1995	83 607	10 378	104.8
1996	65 959	8 085	74.1
1997	64 628	8 200	73.8
1998	42 524	6 491	48.2
1999	64 245	8 881	75.5
Total	**397 653**	**50 701**	**437.5**

SOURCE: MPR Royalties Branch

Table 12 lists the nickel resources by project for the Southern Cross – Esperance study area. The significant nickel projects are the Maggie Hays – Emily Ann project, the Ravensthorpe–Bandalup project, and the Ravensthorpe 8 (RAV8) project.

Mining at the RAV8 project in Ravensthorpe commenced in April 2000 and the first shipment of nickel sulfide concentrate was delivered to WMC Ltd's Kambalda smelter in August of the same year. The mine is to be both opencut and underground, and is expected to have a two-year mine life. Production is currently planned to total 47 800 t of nickel concentrate containing 8705 t of nickel. Current total mining reserves are 206 404 t of ore at 5.49% Ni (Tectonic Resources NL, 2000).

BHP Billiton has reached agreement with Comet Resources NL to purchase the remaining 50% of the Ravensthorpe–Bandalup nickel laterite project. BHP Billiton already owns 50% of the project through QNI Pty Ltd. QNI Pty Ltd had previously signed an agreement with Comet Resources NL to construct an acid leach plant to produce nickel and cobalt concentrate. The concentrate will be shipped to QNI's Yabulu Refinery in Queensland. The Ravensthorpe–Bandalup nickel project is expected to produce 35 000 t of nickel and 1300 t of cobalt per annum over a 20 year period. Work on the feasibility studies for the development of the mine and acid-leach plant is at an advanced stage.

Development of the Emily Ann deposit started in early 2001, and the first concentrate was produced in late 2001. Agreements were reached by the project owner, LionOre Australia (Nickel), to sell nickel concentrate to Inco Ltd of Canada, and funding has been arranged with Inco for the development of the underground mining operation. On average of 6700 t of nickel will be produced every year over the mine life. Full production is expected in 2002.

Nickel potential

Within the Southern Cross – Esperance study area, exploration targeting both laterite and sulfide nickel mineralization is continuing near Southern Cross, Forrestania, Lake Johnston, Lake Cowan – Norseman, and Ravensthorpe.

Although noted for its nickel sulfide deposits, the Forrestania area has not yet been shown to contain significant nickel laterite. However, geological mapping of HYDEN (Chin et al., 1984a) indicates there is extensive laterite overlying ultramafic sequences known to contain sulfide mineralization. Furthermore, the mapping indicates the possibility of large areas of laterite being buried under the transported colluvium material.

In the Ravensthorpe region, Witt (1998) described several lenses and units of ultramafic rock that do not appear on RAVENSTHORPE (Thom and Lipple, 1974). These units have the potential to host nickel sulfides.

Although the resource at the Maggie Hays sulfide nickel deposit has been known since 1970, development has not proceeded because of depressed nickel prices and

Table 12. Nickel resources for deposits in the Southern Cross – Esperance Region

Project	*Site*	*Site code*	*Site type* [a]	*Stage of development* [b]	*Mineralization type*	*Resource category* [c]	*Tonnage Mt*	*Grade (%)*	*Mineral commodity*	*Contained metal (t)*	*Date*
Emily Ann – Maggie Hays	Emily Ann	S06448	DU		Ni sulfide	IND	1.586	3.95	Ni	62 647	1999
	Emily Ann	S06448	DU		Ni sulfide	INF	0.531	4.04	Ni	21 452	1999
	Maggie Hays	S04369	DU		Ni sulfide	IND	10.839	1.5	Ni	162 585	1998
	Maggie Hays	S04369	DU		Ni sulfide	IND	10.839	0.054	Co	5 853.06	1998
	Maggie Hays	S04369	DU		Ni sulfide	INF	0.97	1.1	Ni	10 670	1998
	Maggie Hays	S04369	DU		Ni sulfide	INF	0.97	0.045	Co	436.5	1998
Forrestania	Forrestania	S01248	MB	S	Ni sulfide	IND	2.7	2.1	Ni	56 700	1998
	Forrestania	S01248	MB	S	Ni sulfide	INF	2.1	1.4	Ni	29 400	1998
Jimberlana	Jimberlana	S16711	DO		Ni laterite	INF	4	1.17	Ni	46 800	1999
	Jimberlana	S16711	DO		Ni laterite	INF	4	0.083	Co	3 320	1999
Miitel–Redross	Redross	S02903	MU	S	Ni sulfide	DEM	0.399	3.38	Ni	13 486	2000
Pioneer	Pioneer JH	S01683	DU		Ni sulfide	DEM	0.033	1.1	Ni	363	1984
	Pioneer JH	S01683	DU		Ni sulfide	DEM	0.033	0.1	Cu	33	1984
Ravensthorpe–Bandalup	Hale Bopp	S05631	DO		Ni laterite	IND	28.9	0.7	Ni	202 300	2000
	Hale Bopp	S05631	DO		Ni laterite	IND	28.9	0.03	Co	8 670	2000
	Halleys	S01174	DO		Ni laterite	MES	50.9	0.9	Ni	458 100	2000
	Halleys	S01174	DO		Ni laterite	MES	50.9	0.04	Co	20 360	2000
	Halleys	S01174	DO		Ni laterite	IND	14.2	0.8	Ni	113 600	2000
	Halleys	S01174	DO		Ni laterite	IND	14.2	0.03	Co	4 260	2000
	Shoemaker Levy	S06685	DO		Ni laterite	IND	71.2	0.7	Ni	498 400	2000
	Shoemaker Levy	S06685	DO		Ni laterite	IND	71.2	0.3	Co	213 600	2000
Ravensthorpe 8 (RAV8)	Ravensthorpe 8	S02612	MB	O	Ni sulfide	DEM	0.205	5.7	Ni	11 685	1999
Ravensthorpe / Greenstone	Nindilbillup	S06586	DO		Ni laterite	IND	17	0.73	Ni	124 100	1997
	Nindilbillup	S06586	DO		Ni laterite	IND	17	0.03	Co	5 100	1997
	Ravensthorpe 1	S02333	DU		Ni sulfide	IND	0.524	1	Ni	5 240	1996
	Ravensthorpe 4	S02334	DU		Ni sulfide	INF	0.92	0.7	Ni	6 440	1999
	Ravensthorpe 5	S05689	DO		Ni sulfide	INF	0.141	1.6	Ni	2 256	1996
Trough Well	Trough Well	S01476	DU		Ni sulfide	INF	0.02	2.7	Ni	540	1975
	Trough Well	S01476	DU		Ni sulfide	INF	0.02	0.15	Cu	30	1975
Young River Nickel	Young River	S02332	DO		Ni laterite	INF	1	1	Ni	10 000	1978

NOTES:

(a) Site type
- DO deposit openpit
- DU deposit underground
- DB deposit both (openpit and underground)
- DT deposit tails (tailings and/or dumps retreatment)
- MO mine openpit
- MU mine underground
- MB mine both (openpit and underground)
- MT mine tails (tailings and/or dumps retreatment)

(b) Stage of development
- C care and maintenance
- O operating
- S shut down

(c) Resource category
- MES measured
- IND indicated
- INF inferred
- DEM demonstrated (sum of measured and indicated where undifferentiated)

SOURCE: MINEDEX database

a number of technical problems. However, the discovery of the Emily Ann deposit has significantly improved the prospect of production from Maggie Hays, although no final decision on this has been made. Cash flow from mining the Emily Ann deposit would allow the operator to sustain a systematic exploration strategy for discovering new resources of nickel in the region.

Bullion Minerals Ltd has two promising nickel sulfide prospects: Mount Day about 6 km north along strike from Emily Ann, and Round Top Hill about 10 km to the east from Emily Ann. Drilling results at Round Top Hill included 4 m at 1.56% Ni within an intercept of 18 m grading 0.57% Ni (Bullion Minerals Ltd, 2000). At Mount Day, the company has committed to a drilling program to test a strong nickel sulfide target (Bullion Minerals Ltd, 2001).

Tectonic Resources NL, operator of the RAV8 nickel mine, announced to the ASX on 3 May 2000 that grade-control drilling had intersected high-grade nickel sulfide mineralization outside the current pit outline. This mineralization has the potential to add a further 50% to the current resource.

Greenstone Resources NL holds a number of tenements in the Ravensthorpe area and the company has estimated an inferred resource at the Nindilbillup deposit of 17 Mt of lateritic nickel mineralization averaging 0.73% Ni and 0.03% Co (Table 12). Greenstone Resources has joint venture agreements with Homestake Australia Pty Ltd to explore the ultramafic units in the northern region of the Carlingup Terrane near Mount Short.

Tungsten

Most exploration for tungsten minerals (scheelite and wolframite) in the Yilgarn Craton was carried out during World War I. The Higginsville deposits were discovered at this time and were the first to produce scheelite ore in the Southern Cross – Esperance Region. Other mines for tungsten are Dallisons Reward and Hopes Hill. A scheelite occurrence is known at Lake Seabrook. Locations of the tungsten occurrences are shown on Plate 1.

Higginsville

Scheelite mineralization is associated with gold in most of the Higginsville gold mines, typically found within quartz veins that intrude mafic–ultramafic rocks. Much of the scheelite mined from the area was produced as a byproduct of gold mining. Most of the ore was mined from the Milesis scheelite mine, which opened in the 1930s and between 1940 and 1944 produced 14 959 kg of concentrate containing 9603.28 kg of WO_3 (Baxter, 1978).

Dallisons Reward

Historical Au–W–Cu workings are located at Dallisons Reward, 16 km southwest of Kundip. In 1907, a parcel of ore yielded 943.4 kg of concentrate assaying 75% WO_3 and 1.2 kg of gold was also produced from the workings (Baxter, 1978).

Gold and scheelite mineralization at Dallisons Reward is developed within a quartz-veined, garnet-rich skarn (Greenstone Resources NL, 1996; Thom et al., 1977).

Hopes Hill

A parcel of 12.7 t of tungsten ore, containing 25.17 kg of WO_3, was mined from Hopes Hill in 1953. However, the exact location of the shaft from which the ore was produced is unknown. Country rock in the vicinity is chlorite schist, intruded by quartz veins and felsic porphyry (Baxter, 1978).

Lake Seabrook

Scheelite–fluorite mineralization is developed in chloritic schist and amphibolite near a contact with granitic gneiss, 12 km southeast of Koolyanobbing. Scheelite is localized in quartz–epidote skarn-like veins that are parallel to the foliation of the host rock (Baxter, 1978).

Vanadium

Concentrations of vanadium- and titanium-bearing magnetite are found in greenstone belts of the Yilgarn Craton, and in the northeastern parts of the Albany–Fraser Orogen (outside the study area). Vanadium minerals are found in the Southern Cross – Esperance Region in gold mines at Holleton (vanadinite and pucherite), Westonia (pucherite and clinobisvanite), Ennuin, Nevoria, and Parker Range (vanadinite) (Baxter, 1978). The only occurrence for which vanadium resources have been estimated is the Medcalf deposit in the Lake Johnston greenstone belt. The locations of these are shown on Plate 1.

Medcalf – Vesuvius Hill

Vanadiferous magnetite is found in a pyroxenite–leucogabbro layered mafic intrusion in the Maggie Hays Formation, with mineralization concentrated at the base of a pyroxenite layer (Baxter, 1978). In 1982, inferred resources were estimated at 16 Mt grading 0.8% V_2O_5 and 11.8% TiO_2 (Harris, 1982).

Tin

Tin was produced from tin-bearing lithium pegmatite dykes at several localities near Norseman between 1966 and 1968. These dykes are irregularly shaped and commonly exhibit complex zoning (Doepel, 1973). Cassiterite, by far the most important tin ore, is present in pegmatite dykes at Mount Deans, Mount Thirsty, Holleton, and Cattlin Creek. Locations of these occurrences are shown on Plate 1.

Mount Deans

Tin-bearing pegmatite dykes are found in mafic lavas and associated intrusive rocks at Mount Deans. Recorded

production, between 1965 and 1967, was 7.18 t of tin concentrate containing 4.57 t of tin. Most of this production came from an irregular pegmatite vein (striking north-northwest and dipping 20–50° west) containing zinnwaldite, muscovite, and lepidolite. Cassiterite is found in the upper part of the vein associated with an albite and zinnwaldite-enriched zone (Blockley, 1980).

Mount Thirsty

In the Mount Thirsty area, tremolite–actinolite rock, felsic volcanic rocks, and amphibolite have been intruded by stocks and veins of granitoid and pegmatite. Tin deposits are located in pegmatite dykes hosted by tremolite–actinolite schist. The host schist is altered to a biotite–tremolite–actinolite rock close to dykes. Two dykes were mined in the area. These dykes contain lepidolite, zinnwaldite, muscovite, tourmaline, and minor amounts of cassiterite and beryl. Two parcels of ore were crushed at the Norseman State Battery in 1966 and 1967, for an average grade of 0.26% Sn, but no further production data are available (Blockley, 1980). Recent exploration at Mount Thirsty has been mainly for Ni–Co mineralization.

Holleton

The tin deposit at Holleton lies on the northwestern edge of the Holleton greenstone belt. Rock types exposed in the vicinity of the deposit are pyroxenite, metabasalt, and ultramafic rocks. Cassiterite is found in a swarm of pegmatite dykes that trend 030° and dip easterly. Tourmaline, ilmenite, and beryl are also present in the pegmatite. During 1930, a total of 0.61 t of tin concentrate was produced from 32.6 t of ore (Blockley, 1980).

Cattlin Creek

Small quantities of cassiterite have been found in a lithium pegmatite at Cattlin Creek, about 2 km north of Ravensthorpe. Spodumene, lepidolite, amblygonite, and beryl are also present in potentially economic amounts (Blockley, 1980).

Tantalum–lithium–beryllium

The global demand for tantalum has recently increased, due to its use in the expanding electronics industry: in the production of capacitors, and with particular applications in the computer, communications, and instrumentation industries. At a few localities in the Southern Cross – Esperance Region, pegmatites contain tantalite, beryl, feldspar, and lithium minerals (spodumene, lepidolite, zinnwaldite, and amblygonite), with some of these pegmatites currently being explored for their tantalite potential. The following is a summary of the main occurrences known in the region — Cattlin Creek, Mount Thirsty, Mount Day, Cocanarup, and Mount Deans. Locations of occurrences are shown on Plate 1. The most promising prospect is Cattlin Creek, held in 1999 by Sons of Gwalia Ltd. Cattlin Creek and Cocanarup have both produced tantalite, but production of spodumene has only been recorded from Cattlin Creek. Australasian Gold Mines NL recently reported the discovery of a major pegmatite-hosted tantalum deposit at Mount Deans.

Cattlin Creek

A large, tabular pegmatite intrudes the lower Archaean metamorphosed volcanic rocks at Cattlin Creek, 2 km northwest of Ravensthorpe. The pegmatite contains a large number of minerals, including the lithium minerals spodumene and lepidolite, plus tantalite, beryl, orthoclase, and quartz. Recorded production is 108.3 t of spodumene containing about 6670 kg of Li_2O, and 1.1 t of tantalite containing 16 kg of $TaNbO_5$. Hill (1976) reported that this pegmatite has a resource of 1.3 Mt of spodumene. The inferred resource of tantalite in the pegmatite is estimated at 206 000 t at 644 ppm Ta_2O_5 (Register of Australian Mining, 1999). The tantalite resource is open-ended to the north and northeast, and is found within the lepidolite zone in a thick flat-lying pegmatite about 12 m thick. A large portion of the high-grade resource is covered with very little overburden.

In January 2001, Sons of Gwalia Ltd (SOG) reached agreement with Haddington International Resources Ltd to develop both Cattlin Creek and Bald Hill (outside the project area). All tantalite produced would be delivered to SOG under a licence agreement. Haddington International Resources Ltd has commenced a feasibility study on Cattlin Creek (Haddington International Resources Ltd, 2001).

Mount Thirsty

Exploration by Iron Ore Corporation from 1974 to 1982 in the Mount Thirsty area, approximately 14 km north of Norseman, indicated that the pegmatites in this area may be prospective for tantalum and tin. However, exploration was primarily aimed at cobalt, manganese, and nickel. The rock types distinguished in the area are gabbro, pyroxenite, serpentinized peridotite, ferruginous chert, felsic volcanic rocks, and black shale of the Archaean Mount Kirk Formation. This sequence has been intruded by granitoid and pegmatite, as well as the Widgiemooltha dyke suite (Menzies, 1981).

Mount Day

A number of pegmatite dykes intrude pillowed and massive metabasalts and metadolerite–gabbro at Mount Day, 10 km north of Emily Ann. Small concentrations of tantalite–columbite mineralization are associated with lepidolite and quartz-rich phases within the dykes. The best result from a grab sample from a quartz-rich zone was 390 ppm Ta and 1250 ppm Nb (Armstrong, 1981). A small pegmatite on the southern slope of Mount Day contains beryl. The occurrence was regarded as uneconomic (Gower and Bunting, 1976).

Cocanarup

Pegmatites in an area 1 km southwest of Cocanarup contain beryl, columbite, and the lithium-bearing minerals amblygonite, lepidolite, and zinnwaldite. Pegmatite dykes are common in the local greenstone sequences, and are thought to be late-stage differentiates of the Ravensthorpe quartz diorite pluton (Thom et al., 1984b). Mineralization at Cocanarup is very locally developed. Recorded production is 680.25 kg of tantalite from 1360.5 t of pegmatite ore. These pegmatites are much smaller than those at Cattlin Creek, discussed above (Thom et al., 1984b).

Mount Deans

Tin-bearing pegmatite veins are found at Mount Deans, about 10 km south of Norseman. The pegmatite veins are associated with small granitoid intrusions into Archaean metabasalts and metasedimentary rocks (Blockley, 1980). Minor tin production has been reported (see section on **Tin**).

Recent exploration by Australasian Gold Mines NL has identified tantalum mineralization in the pegmatite veins. Based on an RC drilling program, indicated and inferred resources of 9.1 Mt at 216 g/t Ta_2O_5 have been identified within 60 m of the surface. The company has announced a feasibility study on the establishment of a 500 000 tpa integrated operation at Norseman sourcing ore from Mount Deans and Binneringie, which is outside the study area (Australasian Gold Mines NL, 2002).

Titanium–zirconium (heavy mineral sands)

The coastal areas of the Southern Cross – Esperance Region have been explored for heavy minerals since 1940. The main exploration targets have been beach sands and dune sands of the current shoreline, particularly at the outlet of present-day rivers. Palaeoshorelines and palaeo-river channels have also been examined. There is no reported production of heavy minerals from the region at present, but there was minor historical production from localities such as Cheyne Bay.

The main deposits and localities of significance are found at Cheyne Bay, Gordon Inlet, Wray Bay, Condingup – Cape Arid National Park, Hurst, Southern Hills, Dillon Bay, Oldfield Inlet, Margaret Cove, Stokes Inlet, Alexander River, Barker Inlet, and Kundip (Fig. 17). There are no operating mines and none of the prospects is considered to be economic. Brief descriptions of the known deposits are given below.

Cheyne Bay

Deposits of heavy minerals lie at the base of cliffs near Cheyne Bay. The Cheyne Bay deposits (also known as the Cape Riche deposits) have been investigated by companies and GSWA at various times since 1940. During 1949–50, Rare Metals Pty Ltd produced 158.5 t of heavy mineral concentrate from these deposits. Between 1992 and 1995, exploration for heavy mineral sands was carried out in the Cheyne Bay area by Dr J. Locsei (Locsei, 1995)

Cheyne Bay is underlain by Archaean granitoid and gneiss, with occasional dolerite sills and cross-cutting pegmatite dykes. Inland from Cheyne Bay, Archaean rocks are overlain by sandstone, siltstone, and conglomerate of the Eocene Plantagenet Group. These sedimentary rocks are commonly lateritized or overlain by pisolitic scree. Colluvial and alluvial formations are found in low-lying areas. Eolian sand dunes have been deposited along the numerous inlets. The eroded coastal limestone cliffs along the foreshore, carrying possibly up to 25% heavy mineral content, are considered to be a secondary source of heavy minerals that are concentrated on the beach. Hand augering confirmed beach sand extending to depths of more than 4.3 m. Sand on the beach is thicker adjacent to the mouths of the creeks, where the heavy minerals are concentrated. Heavy mineral grades of the sand ranged from 1% to as high as 80%. The northern portion, away from the beach, was found to have negligible potential (Locsei, 1995). The main minerals in the deposits are ilmenite and zircon, with minor garnet, rutile, and monazite. The published resource in the deposit is about 300 000 t of heavy minerals (Baxter, 1977).

Gordon Inlet

The Gordon Inlet prospect, 15 km northeast of Bremer Bay, extends along the coast from Fishery Cove to Point Anne. The main heavy mineral concentrations are found around Gordon Inlet, the estuary of the Gairdner River. The Gordon Inlet prospect has also been known as the Bremer Bay, Doubtful Island Bay, and Gairdner River deposit. Since 1948 the deposit has been periodically examined by GSWA, New Consolidated Goldfields (Aust.) Pty Ltd, Laporte Titanium (Aust.) Pty Ltd, Day Dawn Minerals NL (a company owned by Mr F. Pinchin), and Eucla Mining NL. Heavy mineral concentrations are reported from the beach, foredune, and a buried beach. The richest concentration is found in the beach, whereas the heavy minerals in the other two environments are minor. The main deposit extends 12 km south of Gordon Inlet, with a rich pocket 3 km south of the inlet. The deposit is up to 6 m thick, and contains up to 25% heavy minerals. The heavy minerals present are ilmenite, leucoxene, zircon, and minor rutile. The inferred resource in the deposit is estimated to have an average grade of 11.8% and to contain 372 000 t of heavy minerals, but the deposit is not considered to be economic (Baxter, 1977).

Wray Bay

Between 1987 and 1991 Eucla Mining NL and Placer Exploration Ltd carried out exploration for heavy mineral sands in palaeoshoreline deposits of Eocene and younger age in the inland area north of Wray Bay. Heavy mineral sands in this area overlie terrestrial sedimentary rocks of the Eocene Werillup Formation, and were probably developed during a major Eocene or younger marine transgression. The sand formations lie between 5 and 20 m

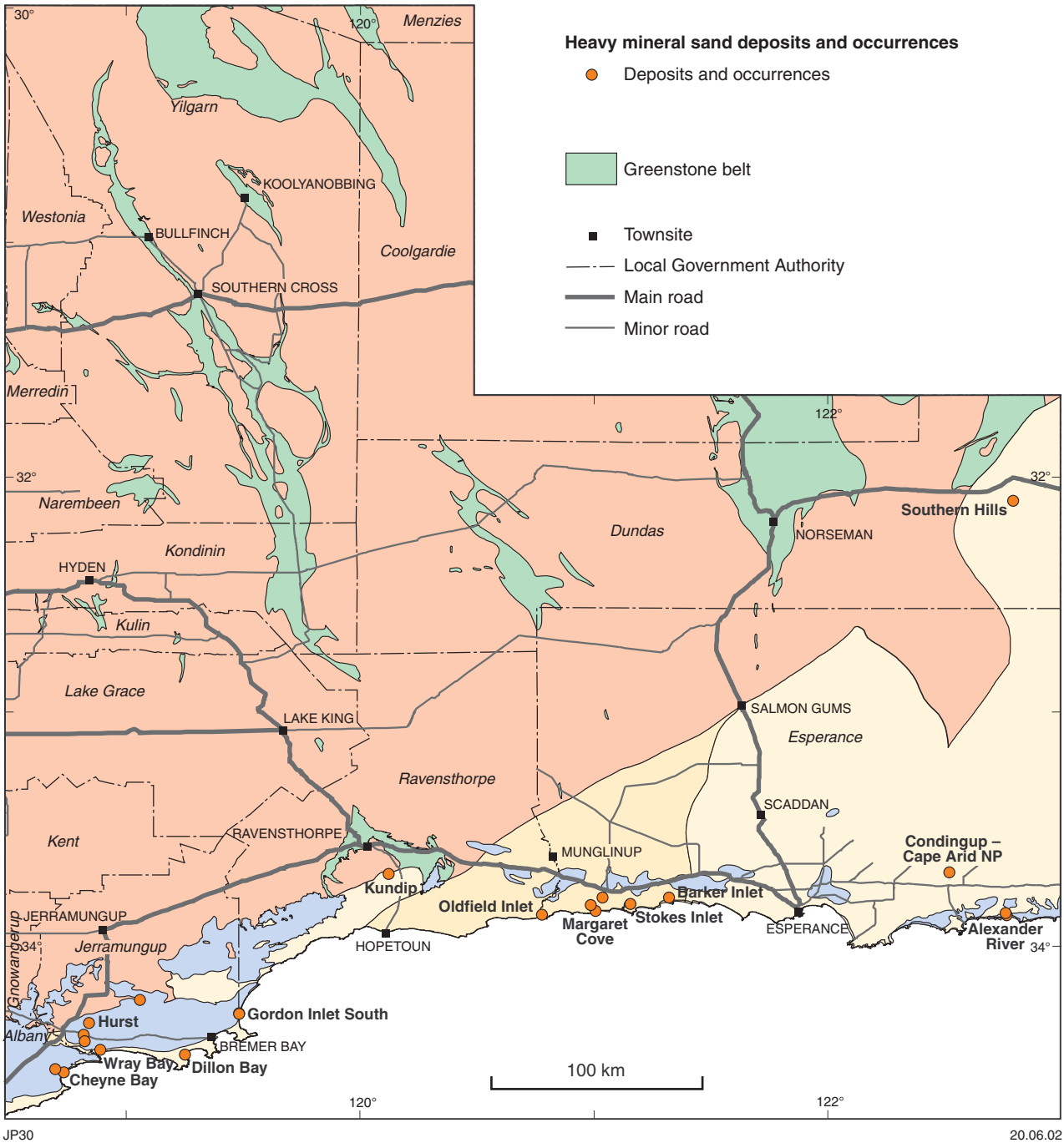

Figure 17. Heavy mineral sand deposits and occurrences in the Southern Cross – Esperance Region. See Figure 4 for complete geological legend

below the present surface. The deposits contain up to 5% heavy minerals, of which 75–90% is ilmenite, 5–20% leucoxene, 1–3% zircon, with trace rutile and monazite. The inferred resource in the area was estimated at 40 Mt at 2.6% heavy minerals (at a 2% cutoff), which was considered to be subeconomic.

Exploration was also conducted by Eucla Mining NL and Placer Exploration Ltd in post-Eocene sediments closer to Wray Bay, but located no significant mineralization (Eucla Mining NL, 1991a,b).

Condingup – Cape Arid National Park

Between 1988 and 1996 Eucla Mining NL, Placer Exploration Ltd, and RGC Exploration Pty Ltd carried out exploration for heavy minerals in Cainozoic marine sands in the area west of Cape Arid National Park and extending to around Condingup, approximately 60 km east-northeast of Esperance.

Exploration was focused on Eocene Plantagenet Group sedimentary rocks of the Bremer Basin. The rocks, which

unconformably overlie Proterozoic rocks of the Albany–Fraser Orogen, comprise the basal Eocene Werillup Formation (consisting of sand, carbonaceous sand, and clay) and Pallinup Siltstone. Reverse circulation drilling by RGC in the areas just west of Cape Arid National Park revealed the sand in the Werillup Formation to be poorly developed, and no significant heavy mineral assemblages were intersected. However, drilling by Eucla Mining NL and Placer Exploration Ltd found some high zircon concentrations at the eastern end of Exploration Licence 69/275. The companies considered the area unprospective for beach placer concentrations (Hall, 1989; Eucla Mining NL, 1990a,b).

Southern Hills

During 1994–95 Gold Partners NL carried out exploration for mineral sands and rare earth elements at the Southern Hills prospect, 110 km east of Norseman (Fig. 17). Exploration was primarily aimed at locating significant tonnages of ilmenite within sand amenable to beneficiation by wet gravity processes. A field inspection, involving visual evaluation of auger samples, revealed that the ilmenite accumulations were evenly distributed in clay-rich alluvium. Although the presence of a large resource of ilmenite was not totally ruled out, the clay-rich nature of the deposit was considered an impediment to economic extraction (Gold Partners NL, 1995).

Dillon Bay

Between 1989 and 1991 Eucla Mining NL explored for heavy mineral sands in the Dillon Bay area (Fig. 17). Two programs of RC drilling in Quaternary sands failed to detect significant concentrations of heavy minerals, and the highest grades intersected were 3% heavy minerals. A ground magnetic survey returned inconclusive results (Eucla Mining NL, 1991b).

Oldfield Inlet

These deposits are adjacent to the inlet at the mouth of the Oldfield River (Fig. 17). Most sand dunes along the shore of the inlet are weakly mineralized, with heavy minerals concentrated between the high- and low-water marks. The most common heavy minerals are ilmenite, zircon, and garnet (Baxter, 1977). Between 1992 and 1994 the surrounding area was explored by Cable Sands WA Pty Ltd, but results were not encouraging (Forsyth, 1993; Harewood, 1994).

Margaret Cove

Margaret Cove is a southeast-facing bay at the mouth of Torradup River, which drains migmatite and sedimentary rocks. At the mouth of the river, on both sides of the inlet, small concentrations of heavy minerals are restricted to the beach and dunes. The most common heavy mineral is ilmenite (Baxter, 1977).

Stokes Inlet

Stokes Inlet is at the estuary of the Lort and Young Rivers (Fig. 17). The inland dunes contain disseminated mineralization for 3 km west and 1.5 km east of the Stokes Inlet. The most abundant heavy mineral is ilmenite, with small amounts of garnet, zircon, and monazite. Very few heavy minerals are concentrated on the beach below the Tamala Limestone cliffs (Baxter, 1977). Between 1992 and 1994, the surrounding area was explored by Cable Sands WA Pty Ltd, but results were not encouraging (Forsyth, 1993; Harewood,1994).

Alexander River

Heavy mineral sand samples from the beach at the mouth of the Alexander River, on the shores of Alexander Bay, indicate predominantly ilmenite, zircon, and garnet, with small amounts of staurolite and monazite. The material contains minor spinel, leucoxene, and rutile (Baxter, 1977).

In 1990–91 Westralian Sands Ltd explored for heavy mineral sands in coastal sediments in the Alexander River area. Their tenements covered large areas of Eocene Plantagenet Group sedimentary rocks containing the Werillup Formation, which is known to contain minor (<1%) heavy mineral sands. The present beach accumulations were recognized as being derived from the upper 10–15 m of the Eocene Werillup Formation, which is being actively eroded by the river systems. However, 72 boreholes drilled in the area did not intersect heavy minerals above 1% concentration (Gifford, 1992).

Barker Inlet

Heavy mineral concentrations are found on the shores of Barker Inlet (Baxter, 1977).

Kundip

During the early 1990s, Marymia Exploration NL explored primarily for talc at Kundip. However, as part of the exploration program, possible heavy mineral sands in the Cainozoic sedimentary rocks were also investigated. Aircore drilling to test for the existence of strandlines was unsuccessful (Parks, 1991).

Heavy mineral sands potential

The Archaean and Proterozoic granitoid, gneiss, and metamorphic rocks in the Yilgarn and Albany–Fraser Orogen, which constitute much of the Southern Cross – Esperance Region, are good sources of heavy minerals. Although a large deposit of heavy mineral sand has yet to be discovered in the Southern Cross – Esperance Region, the area is underexplored and may have significant potential.

Manganese

Deposits of stratiform massive to bedded manganese oxide mineralization are found in both Archaean and Proterozoic metasedimentary rocks in the Southern Cross – Esperance Region. There is no reported production of manganese from the region, but the Mount Chester deposit, and perhaps Elverdton as well, was mined for agricultural purposes in about 1950. The following are brief descriptions of five known deposits in the region — Mount Chester, Elverdton, Kundip, Hamersley Gorge, and Coppermine Creek (Plate 1).

Mount Chester

Mount Chester deposit is situated about 10 km east-southeast of Ravensthorpe. Manganese mineralization is interbedded with Archaean shale, jaspilite, and schist, which have undergone lateritization and kaolinization. The deposit outcrops discontinuously over a length of 145 m with occasional outcrops farther southeast along strike. The surface mineralization is higher grade than that intersected by an adit 135 m long and up to 30 m below the surface. The deposit was mined some time about 1950 and the manganese used in the manufacture of superphosphate, but there is no reported production. The deposit is regarded as too small and too low grade (approximately 33% Mn) to be economic (de la Hunty, 1963; Thom et al., 1977; Witt, 1997).

Elverdton

The Elverdton deposit is approximately 10 km south of Ravensthorpe. It is similar to that at Mount Chester, with some surface enrichment. Workings consisted of two shafts (2 m and 11 m deep) located approximately 30 m apart along strike. Selected dump material assayed 24.76% Mn and a sample from the outcrop assayed 34.1% Mn (de la Hunty, 1963). There is no reported production.

Kundip

A surficial occurrence of manganiferous boulders, 3.6 km northeast of Kundip, contains 49% manganese. A similar occurrence, 2.4 km east-southeast of Desmond, consists of manganiferous boulders (30% Mn) amongst laterite developed over ferruginized quartzite and schist. Resources of these deposits are considered to be insignificant (Thom et al., 1977).

Manganese is also found 8 km east of Kundip as a small cap over an Archaean metasedimentary sequence containing shale. The outcrop is thin and about 10 m long. A sample assayed 36.7% Mn (de la Hunty, 1963).

Hamersley Gorge

The Hamersley Gorge manganese deposit is located approximately 35 km south-southwest of Ravensthorpe. The deposit is in three outcrops, of which the most easterly, largest outcrop, has been tested by a 10 m-deep shaft. The manganese is found in a steeply dipping manganiferous horizon in Proterozoic Kybulup Schist, with some surface enrichment. The average grade of ten surface samples was 31.4% Mn. The deposit is estimated to contain approximately 135 000 t of manganese (de la Hunty, 1963).

Coppermine Creek (Naendip)

The Coppermine Creek deposit is located on the western side of Coppermine Creek, about 75 km southwest of Ravensthorpe. The main zone of mineralization is found in the Proterozoic Kybulup Schist. A composite of eight surface samples assayed 44% Mn, whereas a composite of six samples from underground workings averaged 33.67% Mn. The deposit is estimated to contain inferred resources of 30 000–40 000 t averaging 40% Mn, or about 150 000 t averaging 35% Mn (de la Hunty, 1963; Thom and Chin, 1984b). At Naendip, 3 km northeast of Coppermine Creek, a resource of 70 000 t averaging 35% Mn has been estimated (de la Hunty, 1963).

Manganese potential

The Proterozoic metasedimentary rocks, particularly the Kybulup Schist, are considered prospective for manganese mineralization.

Molybdenite

Three occurrences of molybdenite are known in the Southern Cross – Esperance Region — at Needilup, Buldania, and Kumarl Siding. All three have low potential for development.

Needilup

Flakes of molybdenite, up to 20 mm across, were noted in a fine-grained pegmatite intruding Archaean gneiss of possible metasedimentary origin some 3 km west of Needilup (Thom et al., 1984b).

Buldania

A single foliated mass of molybdenite was reported from Buldania (Simpson, 1952; Doepel, 1973).

Kumarl Siding

Coarse flakes of molybdenite are known in granitoid about 10 km northeast of Kumarl Siding (Simpson, 1952; Doepel, 1973).

Chapter 7

Base metals

Numerous mines, deposits, and occurrences of base metals are distributed throughout the study area, both in rocks of the Yilgarn Craton and the Albany–Fraser Orogen. Most of these deposits are vein type, with primary copper ore containing quartz, gold, and chalcopyrite (Davies and Blockley, 1990). Exploration for base metals in the Southern Cross – Esperance Region has experienced a recent revival, prompted by the discovery of the poly-metallic Trilogy deposit in 1977. Base metal mines and deposits of the region are shown on Plate 1 and Figure 16. However, these maps do not show some of the new prospects and anomalies that have recently been identified during exploration, for example Grass Patch. About 90 base metal sites (mostly historical mine sites) were obtained from MINEDEX and about 20 base metal occurrences were obtained from WAMIN. The locations of these are shown on Plate 1. Many of the historical copper sites discussed were primarily mined for gold, manganese, or iron, and are shown as precious metal or iron sites on Plate 1.

Available historical production data for the region are presented in Table 13. Most of the recorded production has come from the Ravensthorpe area, with small amounts from the Jerramungup and Marda areas. The last operating base metal mine in the Ravensthorpe area was Elverdton, which closed in 1971. However, Elverdton is still classed as an operating mine because the mine tailings are currently being mined to produce fertilizer.

Yilgarn Craton

Most known base metal occurrences in this part of the Yilgarn Craton are found in the Ravensthorpe area. The period of greatest production at Ravensthorpe was between 1958 and 1971, when the area produced about 30% of Western Australia's cumulative total copper, all from the Elverdton mine (Thom et al., 1977). Production has also been recorded from isolated base metal deposits at Jerramungup, Carterton, and Marda. There are also minor occurrences of copper and lead at Beete, Mount Thirsty, Koolyanobbing, and Hatters Hill.

Ravensthorpe area

Copper was first mined in the area in 1899, and nearly half of Western Australia's total recorded production of copper ore and concentrates has come from the Ravensthorpe area. Copper mines at Ravensthorpe have yielded a total of about 19 000 t of copper (Thom et al., 1977). Mining essentially ceased in 1971, when the Elverdton mine closed down, but small amounts of gold and copper continue to be produced from the tailings dumps.

Mineralization is hosted mainly by the Annabelle Volcanics, and the lodes are within 2 km of the contact with the Manyutup Tonalite. Copper mineralization is divided into three styles (Marston, 1979; Ferguson, 1999):

- Sulfide veins with or without hydrothermal quartz, with veins parallel to or transecting the foliation of the host rock;
- Brecciated ore consisting of fragmented country rock enclosed by foliated sulfides;
- Foliated disseminated sulfides aligned with the host rock foliation.

Mineralization is mostly quartz–gold or quartz–gold–chalcopyrite with minor pyrite–pyrrhotite; oxidation extends to a depth of 65 m and mineralization is localized in suitable structures (Thom et al., 1977).

The Ravensthorpe mines are divided geographically into five groups — Mount Desmond, Mount Cattlin, Mount McMahon, Kundip, and West River, and these are discussed in more detail below. The Mount Desmond group has the largest recorded production. There are also isolated deposits, such as the Mosaic mine.

Recent exploration has been aimed at establishing remaining resources in previously mined deposits, particularly at Mount Cattlin and Kundip.

Mount Desmond

The Mount Desmond group of workings contains the Elverdton, Flag, British Flag, Welcome Stranger, Fairlie and Desmond mines. The Mount Desmond group of mines produced a total of 102 786.68 t of copper ore and concentrate, with an average grade of 15.17% Cu, and containing 15 592.57 t of copper metal (Marston, 1979). In addition, a total of 2232.62 kg of silver was produced from the base metal mines in the area.

The Elverdton mine was the biggest producer of copper in the Ravensthorpe area, and was worked mainly between 1958 and 1971. Elverdton has been used as a

Table 13. Copper production from the Southern Cross – Esperance Region

Mining area	*Mine*	*From*	*To*	*Copper ore (t)*	*Grade (%)*	*Contained Cu (t)*
Bullfinch	Day Dawn	1907	1907	25.61	9.92	2.54
Cocanarup	Pick and Shovel	1907	1907	4.54	15.20	0.69
Jerramungup	Cardinenup	1946	1951	169.51	2.20	3.73
	Jerramungup	1962	1962	6.50	4.40	0.29
	Netty	1907	1907	3.13	40.89	1.28
Kundip	Afric	1905	1905	6.12	12.91	0.79
	Alice Mary	1906	1910	33.59	12.09	4.06
	Ard Patrick	1921	1921	2.53	10.67	0.27
	Blue Ribbon	1904	1904	11.53	15.61	1.80
	Fair Play	1909	1920			133.41
	Flag	1914	1918	362.01	11.05	40.00
	Gem	1916	1923	92.44	24.82	22.94
	Gem Consolidated	1913	1919			77.98
	Harbour View	1900	1905	614.06	12.71	78.05
		1907	1912	516.43	12.72	65.69
	Harbour View North	1906	1907	2.97	10.10	0.29
		1914	1914	6.65	6.62	0.44
	Hecla	1906	1907	25.34	11.88	3.01
	Hillsborough	1907	1923	703.96	8.32	58.57
	Kundip	1909	1909	5.16	18.22	0.94
		1941	1942	9.35	22.03	2.06
		1942	1944	4.58	27.51	1.26
		1952	1952	5.08	9.25	0.47
	Lady Nina	1917	1918	9.44	13.24	1.25
	May Day	1914	1914	0.36	100.00	0.36
	Mount Pleasant	1904	1904	3.98	15.08	0.60
	North Harbour View	1917	1922	15.97	6.32	1.01
	New Maori Queen	1907	1907	13.95	1.29	0.18
	Nil Desperandum	1903	1903	4.33	8.08	0.35
	Omaha	1903	1903	9.30	14.95	1.39
	Ravensthorpe	1940	1940	14.02	19.54	2.74
	Red White and Blue	1901	1909	489.35	11.41	55.83
	South Gift	1914	1914			0.40
	Two Boys	1916	1919			28.75
	Who Can Tell	1906	1906	1.47	10.88	0.16
Marda	Marda	1942	1942	16.26	5.04	0.82
Mount Desmond	Addie	1906	1906	5.21	19.77	1.03
	British Flag	1904	1904	27.21	18.63	5.07
		1913	1913	20.22	18.30	3.70
	Comstock	1910	1911	41.32	17.40	7.19
	Desmond	1915	1920	1 415.20	11.83	167.42
	Desmond Central	1907	1907	3.06	15.03	0.46
	Elverdton	1915	1920	7 537.61	9.11	686.68
	Elverdton South	1901	1901	19.00	25.42	4.83
		1903	1904	18.78	12.94	2.43
	Fairlie	1906	1907	8.95	13.30	1.19
	Ironclad	1914	1914	70.32	15.81	11.12
	Marnoo	1904	1904	4.32	20.60	0.89
	Mountain View	1901	1901	9.65	31.61	3.05
Mount Desmond	Mount Desmond	1901	1905	202.06	15.47	31.26
		1951	1958	248.11	9.79	24.29
	PLP	1904	1910	212.01	16.15	34.24
	Ravensthorpe	1953	1955	66.04	8.31	5.49
	Resurrection	1906	1906	1.12	8.93	0.10
	Welcome Stranger	1901	1901	4.06	21.92	0.89
		1903	1904	12.97	14.34	1.86
		1903	1903	5.39	15.96	0.86

Table 13 (continued)

Mining area	*Mine*	*From*	*To*	*Copper ore (t)*	*Grade (%)*	*Contained Cu (t)*
Mount McMahon	Ballarat	1920	1920	9.87	14.49	1.43
	Beryl	1942	1942	3.05	39.02	1.19
	Bickerton	1920	1920	2.49	12.05	0.30
	Big Surprise	1956	1957	36.18	31.67	11.46
	Birthday	1905	1906	6.38	13.32	0.85
	Blue Spec	1906	1906	12.02	12.48	1.50
	Contest	1905	1907	15.94	11.61	1.85
	Duke of York	1904	1904	1.84	6.52	0.12
	Emily Hale	1903	1906	134.39	16.20	21.77
	Federal	1904	1904	8.81	12.26	1.08
	Kington	1900	1900	11.18	28.62	3.20
	Last Chance	1901	1918	1 451.71	15.63	226.90
		1901	1904	35.43	12.98	4.60
		1905	1907	241.89	11.54	27.91
	Last Chance Extended	1906	1906	2.59	13.51	0.35
	Mary	1901	1910	898.82	13.53	121.61
	Mount Benson	1915	1915	28.40	11.27	3.20
		1916	1918	382.37	5.43	20.77
	Mount Benson Extended	1910	1912	61.42	19.33	11.87
	Mount Garrity	1902	1902	12.70	25.98	3.30
		1904	1904	15.25	21.97	3.35
		1907	1908	9.52	17.33	1.65
	Mount McMahon	1904	1904	5.10	14.90	0.76
	Our Selection	1907	1907	11.06	9.04	1.00
	Ravensthorpe	1954	1955	15.57	10.56	1.64
	Ravensthorpe	1962	1963	51.56	12.94	6.67
	Ravensthorpe	1962	1971	38.25	8.30	3.17
Mount Cattlin	Copper Horseshoe	1904	1905	13.77	14.67	2.02
		1907	1907	1.45	2.76	0.04
	Floater	1901	1901	49.98	1.02	0.51
	Grimsby	1901	1903	5.94	9.60	0.57
	Mount Cattlin	1902	1905	286.08	11.13	31.84
	Mount Cattlin West	1905	1910	140.36	14.53	20.39
	Pick and Shovel	1902	1902	4.06	37.44	1.52
	Ravensthorpe	1955	1955	3.05	11.34	0.35
	Ravensthorpe	1957	1971	52 004.05	22.24	11 565.70
	Ruggle	1904	1904	33.47	14.31	4.79
	Sunset	1903	1908	562.59	11.78	66.27
	Surprise	1901	1909	479.19	12.24	58.65
	Turn of the Tide	1904	1904	4.28	5.84	0.25
	Zealandia	1901	1903	59.80	22.54	13.48
	Grafter	1906	1907	69.45	2.91	2.02
West River	Ravensthorpe	1944	1944			0.98
	West River	1962	1963	7.11	6.86	0.49

SOURCE: MINEDEX database

source of copper fertilizer in recent years, with re-mining of copper-rich tailings from the dump. The mine originally exploited the principal mineralized shear zone of the area, which strikes north-northwest and dips steeply east. Mineralized zones at Elverton also contain minor cobaltiferous galena. At the Desmond mine, there is low-grade chalcopyrite stringer mineralization, and drilling has yielded assay widths ranging from 7 m of 0.76% Cu, to 33 m of 0.16% Cu (Amoco Minerals Australia Company, 1979; Brathwaite and Harley, 1977).

Mount Cattlin

The Mount Cattlin group of workings includes the Marion Martin, Mount Cattlin, and Surprise mines. A total of 34 785.05 t of copper ore and concentrate averaging 7.38% Cu, and containing 2567.2 t of copper metal, was produced from the Mount Cattlin group of mines (Marston, 1979). The mines are hosted by east-northeasterly trending amphibolite, quartz–feldspar–biotite–amphibole schist, and metavolcanic rocks. At the Mount Cattlin mine, the orebody is reported to be between 1.5 and 3.0 m thick, developed in a shear zone. Supergene enrichment is not important at this mine, and primary sulfides are found below 16.5 m. Typical ore consists of massive pyrrhotite–pyrite–chalcopyrite breccia. The Marion Martin mine is hosted by foliated, garnetiferous amphibolite and has been exploited to a depth of 95 m over a strike length of 170 m. Ore consists of massive pyrite–chalcopyrite(–tetrahedrite) with minor disseminated

magnetite (Marston, 1979). Disseminated pyrite and chalcopyrite are found in a zone about 2.4 m thick in amphibolite at the Surprise mine. The Marion Martin mine was last worked in 1920 (Marston, 1979). Some silver was also produced from mines in the Mount Cattlin area, with a total recorded production of 2137.59 kg Ag.

Mount McMahon

The Mount McMahon group of workings contains the Last Chance, Mount Garrity, Mary, Big Surprise, and Mount Benson mines. All these mines are close to granitoid contacts. A mineralized shear at the Last Chance mine is 0.6–2.4 m wide, steeply dipping toward the south, and striking west-northwesterly. Most production from this mine came from supergene ore from the oxidized zone. The Mount Benson mine exploited mineralized shears with average widths of about 1 m. A total of 5404.22 t of copper ore and concentrates was produced from the Mount McMahon group of mines, with an average grade of 11.88% Cu and containing 642.15 t of copper metal (Marston, 1979). A total of 16.33 kg of silver was also produced from the Mount McMahon area.

Kundip

This group of workings contains the Harbour View, Beryl, Flag, May Day, and Hillsborough–Fairplay mines. The Kundip mines were primarily gold producing, but 51 990.59 t of copper ore and concentrate with an average grade of 1.83% Cu and containing 956.57 t of copper metal have also been produced. A total recorded production of 85.03 kg of silver has also come from gold mines in the area, with nearly half of this from the Flag mine. Mineralization is confined to shears within metavolcanic country rocks. Shears strike north-northeast and dip steeply west at Harbour View, and strike east to east-northeast and dip moderately south at Flag, Hillsborough, May Day, and Beryl (Marston, 1979).

West River

There are two small copper–zinc mines (Last Venture and West River), and numerous minor workings found in a north-northwest striking zone about 3 km long at West River, 15 km south of Cocanarup Homestead (Marston, 1979). Exploration over volcano-sedimentary successions in the Ravensthorpe greenstone belt identified stratiform sulfide mineralization in metavolcanic rocks near felsic–mafic contacts and in quartz veins (Ferguson, 1999). The Last Venture mine contains stratiform massive sphalerite in thin lenses and pyrite–chalcopyrite in quartz veins. About 1 kg of silver was produced from Last Venture in 1909. The West River (Copper King) mine has sphalerite aggregates and disseminated pyrite–chalcopyrite in quartz veins (Ferguson, 1999). About 1000 t of copper ore containing 100 t of copper metal has been produced from the area (Thom et al., 1984b).

Mosaic

At the Mosaic mine, sulfide mineralization in two perpendicular veins consists of massive tetrahedrite–tennantite. Analyses of ore yielded up to 35% copper, 440 g/t silver, 60 g/t gold, and 17.6% antimony (Hodges, 1983; Metana Minerals NL, 1988). A total of 54.941 kg of silver was produced from this mine during the period from 1904 to 1908.

Other base metal deposits and occurrences

Other base metal deposits and occurrences, with a variety of mineralization styles, are widespread and include Jerramungup, Carterton, Marda, Beete, Mount Thirsty, Koolyanobbing, and Hatters Hill. Some of these are shown as precious metal occurrences and deposits on Plate 1, because they were mined primarily for gold.

Jerramungup

Old copper workings, including the Netty mine near Jerramungup, are located on the southern margin of an easterly trending mafic dyke (gabbro and dolerite) in foliated, biotite-rich adamellite. A cupriferous limonite vein has formed at the contact between the dyke and the granitoid. Copper staining in fractures is formed by supergene redistribution, and malachite has been noted in veins in porphyritic granitoid and fine-grained dolomite. Production from the Netty mine ceased in 1969 and totalled about 3.13 t of copper metal. Total recorded production from the area was 179.14 t of copper ore containing about 5.30 t of copper metal. Samples collected in 1978 contained 1.0–1.6% Cu and small amounts of lead, zinc, nickel, and manganese (Marston, 1979; Thom et al., 1984b).

Carterton

Small amounts of copper and gold are found in quartz veins in a north-trending amphibolite at Carterton, 30 km north of Ennuin. Production in the 1950s totalled 66 t of cupreous ore with an average grade of 5.13% Cu (Marston, 1979).

Marda

At the Marda (Eleven Mile) mine, near Mount Jackson, copper mineralization is found in a quartz vein in metadolerite and metagabbro. A total of 16.26 t of carbonate–oxide copper ore was produced in 1942 with an average grade of 5% Cu and containing 0.81 t of copper metal (Marston, 1979).

Beete

The Beete deposit is at the southern end of the Norseman greenstone belt, east of Lake Gilmore. Clastic-hosted lead–zinc mineralization is contained mainly in banded quartzite. Drilling by Newmont between 1965 and 1972 enabled an inferred resource of 43 000 t at 1.2% Zn and 0.2% Pb to be estimated (Ferguson, 1999).

Mount Thirsty

Copper gossans are developed over the weathered base of a metamorphosed layered mafic–ultramafic sill at Mount Thirsty (Marston, 1979).

Koolyanobbing

Galena and sphalerite are found in a body of quartz up to 6 m wide and about 150 m long within greenstone schist (Ferguson, 1999; Blockley, 1971).

Hatters Hill

Malachite and azurite staining is found in auriferous reefs at gold prospects at Hatters Hill (Chin et al., 1984b)

Albany–Fraser Orogen

A few base metal prospects and occurrences are known from the Albany–Fraser Orogen — Trilogy, Grass Patch, Hamersley Gorge, Naendip, Bremer Bay, Yardilla, Sixty Mile, Gnama South, and Talbot. Further details on some of these are provided below. Mining occurred at Hamersley Gorge and Naendip, but production data are available only for the Hamersley Gorge prospect.

Trilogy

Significant mineralization at Trilogy, 8 km southeast of Kundip (Fig. 16), was discovered in 1997 by joint venture partners Tectonic Resources NL and Homestake Ltd. Trilogy contains sediment-hosted massive sulfide mineralization with copper–gold and silver–lead–zinc zones. Massive sulfide zones, up to 1.5 m thick, were found near the surface with minor stringers and disseminations. Host rocks are part of the Proterozoic Mount Barren Group, and lie on the southern flank of an overturned syncline. The mineralized zone is about 400 m along strike, 50 m thick, and it dips southeast at 30°. Data on the Trilogy prospect are scarce and preliminary, and it is not certain if the mineralization is syngenetic or epigenetic, stratabound or shear controlled (Ferguson, 1999). One current theory is that the mineralization could be of sedimentary exhalative style (SEDEX) within the thrusted Proterozoic sedimentary rocks.

Tectonic Resources NL has announced an indicated resource of 4.3 Mt containing 52 500 t of copper metal, 149 000 oz of gold, 7.76 M oz of silver, 75 400 t of lead metal, and 51 500 t of zinc metal. Of the total resource, about 95% is less than 150 m from surface. Work on a pre-feasibility study, which includes metallurgical work on the gold and silver oxide resource, has begun (Tectonic Resources NL, 2001).

The discovery of Trilogy has sparked renewed interest in base metal exploration in the Southern Cross – Esperance Region, particularly within Proterozoic sedimentary rocks. These rocks unconformably overlie, or are thrusted over, mineralized Archaean rocks, and were previously regarded as unprospective. With a younger (Proterozoic) age than the predominantly Archaean mineralization in the region, the Albany–Fraser Orogen becomes a much more prospective target for base metals, including Broken Hill-style and Mount Isa-style mineralization.

Grass Patch

Pan Australian Resources NL has proposed that the Grass Patch project, 80 km south of Norseman, has the potential to host Proterozoic stratabound base metal mineralization similar to that found at Broken Hill and Mount Isa. A lead–zinc exploration model has been established using interpretation of detailed regional aeromagnetic data, regional age dating of the rocks, and regional drilling data from the 1980s. In mid-1999 Pan Australian Resources and BHP Minerals entered into a joint venture to conduct exploration over the Grass Patch project area (Pan Australian Resources NL, 1999).

Preliminary compilation and interpretation of reconnaissance data have shown that the southeastern part of the project area has potential to host lead–zinc mineralization. The lithologies in this area include garnet-rich quartzofeldspathic metasedimentary rocks, metamorphic volcanic rocks, and pelitic rocks. Drilling data support the presence of 'sag' and 'rift' geological domains, and carbonate lithologies have been located within the contact zone between the domains. These characteristics are regarded as indicative of a 'Broken Hill-style' geological setting with associated mineralization and alteration (Pan Australian Resources NL, 1998). Exploration by BHP will focus on an RC drilling program to test specific targets defined by aeromagnetic data and supported by recent geochemical and petrographical results (Pan Australian Resources NL, 1999).

Hamersley Gorge

The Hamersley Gorge (McCulloch) prospect, 37 km south-southwest of Ravensthorpe, contains malachite–atacamite veinlets and azurite nodules and lenses (up to 5 mm wide) within micaceous schist and psammite. Marston (1979) suggested that the copper had been redeposited and was supergene in origin. In 1915 a parcel of 2.06 t of ore at 13.58% Cu was mined from the prospect. Galena is also reported from this area, with lead minerals occurring in thin quartz veins (Thom and Chin, 1984b). Three selected lead samples obtained from this prospect gave assay results of 50.8%, 1.5%, and 5.3% Pb (Blockley, 1971). Most of the recent exploration in the area has targeted manganese.

Naendip

Small copper workings (Coppermine Creek) are found about 3.2 km east-northeast of Naendip. There are no data available on the mineralization style or recorded production (Marston, 1979; Thom and Chin, 1984b). Some galena has been reported in veins at the Naendip prospect. A sample assumed to be from this prospect assayed 12.2% Pb (Blockley, 1971).

Bremer Bay

Lead minerals (cerussite and anglesite) are found in a quartz vein within the Kybulup Schist, 8 km north of Bremer Bay (Blockley, 1971; Ferguson, 1999).

Fraser Range area

Sparsely disseminated chalcopyrite is found in the Fraser Range area at Yardilla and Sixty Mile. At these sites mineralization is within migmatite and amphibolite in the vicinity of the Fraser fault zone. Pyrrhotite–chalcopyrite–pentlandite mineralization is found as stringers, veinlets, and disseminations at Gnama South and Talbot in the Fraser Complex. This mineralization is developed close to norite–peridotite contacts (Marston, 1979).

Chapter 8

Energy minerals

Lignite

There are lignitic coal deposits of Eocene age in the study region — in the Bremer and Eucla Basins, and in palaeodrainage channels on the southern Yilgarn Craton. The lignitic coal is present in the Rollos Bore Formation in palaeodrainages and in the Plantagenet Group of the Bremer Basin (Le Blanc Smith, 1990). The Plantagenet Group was deposited in depressions in the Precambrian surface, and comprises an upper unit, the Pallinup Siltstone, and a lower unit, the Werillup Formation. The Werillup Formation consists of carbonaceous clays, sand, and lignite (Western Collieries Ltd, 1983).

The two main deposits with economic potential are O'Sullivan and Scaddan, with small accumulations at Fitzgerald River and Lort. Locations of the deposits are shown on Plate 1.

O'Sullivan

A lignite deposit, 30 km long and 5 km wide, is located near Salmon Gums, halfway between Norseman and Esperance. Lignitic coal beds within the Rollos Bore Formation are confined to palaeodrainage channels. The lignite zone extends from about 20 m beneath the surface, and it is about 20 m thick. The hydrocarbon potential, i.e. the oil yield per dry tonne of lignite, is of particular interest. The oil is in the form of kerogen derived from the breakdown of algae, and it is insoluble in organic solvents. Kerogen is concentrated within the lignite in a zone that averages 9.3 m in thickness. The oil yield in this zone ranges from 41 to 236 litres per tonne. Using a cutoff of 40 litres per tonne, the oil yield averaged 94 litres per tonne over the total lignite resource of 760 Mt. These figures equate to 272 million barrels of oil in the total resource and 226 million barrels within the kerogen-enriched zone (Hillcrest Resources NL, announcement to ASX, 31 August 1999).

Original delineation of the project in the early 1980s was carried out by BHP (Exploration Permit EP-147) and included drilling of 70 holes. A syndicate of private investors resumed exploration in the area in 1992. Hillcrest Resources NL and the unlisted Australian Power and Energy Corp (APEC) farmed into the project in 1998, and Texaco farmed in during 1999. Texaco withdrew investment support for the Esperance power project in February 2000, but is continuing work on a pre-feasibility study and process-design package. The proposal is for a three-stage process of recovering kerogen and naturally occurring hydrocarbons to produce oil, burning of the lignite in situ to produce steam for power generation, and bacterial oxidation of the remaining lignite in situ to produce methane and humic acid.

Portman Ltd has entered into an agreement to test the lignite's suitability as a reductant in iron metal production. The aim would be to produce iron metal from the out-of-sales specification high-phosphorus iron from Koolyanobbing (Portman Ltd, announcement to ASX, 7 December 2001).

Any future development will be affected if there is an extension of the natural gas pipeline from either Bunbury to Esperance, or from Kalgoorlie to Esperance.

Scaddan

In the early 1980s Western Collieries Ltd announced that it had located a substantial lignite deposit within the Eocene Werillup Formation near Scaddan, 50 km north of Esperance. Subsequent exploration showed that initial reports of the quality and quantity of the lignite had been optimistic, and the deposit was downgraded to a total measured resource of 614 Mt lignite by 1987 (Kristensen and Wilson, 1986; Western Collieries Ltd, 1987). An updated measured resource of 1375 Mt lignite is reported in the Australian Mines Handbook (Louthean, 1997). The lignite is found in a northerly trending shallow deposit, about 35 km long and with a variable width of up to 7 km. The seam has an average thickness of 10 m and is covered by about 30 m of sedimentary rocks. The lignite has an average specific energy of about 7.6 MJ/kg, and an ash content of about 12%; but salt contents are high at about 6.4% (Western Collieries Ltd, 1987). The lignite may be used for on-site power generation, possibly with gasification or liquefaction. Wesfarmers Coal Ltd is currently monitoring developments in gasification and use of high-salt lignite coals with the aim of developing a pilot plant or small-scale generating station at Esperance (Louthean, 1997).

Fitzgerald River

Lignite occurs as a single bed or lens in the Werillup Formation within the Eocene Plantagenet Group at Fitzgerald River, 45 km north of Bremer Bay. Drilling

carried out before 1973 by GSWA led to an estimated inferred resource of 1.1 Mt of lignite with 2.3% extractable montan wax and 0.3 barrels/t of extractable crude oil (Cockbain and van de Graaff, 1973). The lignite has a calorific value of 5.6 to 10.6 MJ/kg (Thom and Chin, 1984b).

Lort

At Lort, near the northern margin of the Cainozoic Bremer Basin, thin seams of lignite and brown coal are interbedded with brown carbonaceous clay, and were intersected during a small program of reverse circulation drilling by Conex Australia NL during 1981. This coal has specific energy values comparable with those of Victorian brown coal, but it has higher ash and lower water contents (Earth Energy Resources Consultants, 1981).

Neridup

CRA Exploration Ltd drilled 11 rotary holes at Neridup, 60 km northeast of Esperance, during 1980–81. Minor lignite fragments in carbonaceous siltstone were found in the Werillup Formation of the Eocene Plantagenet Group. The carbonaceous siltstone contains 5% carbon and 15 litres/t oil by distillation. The lignite is not in identifiable seams and drilling has failed to delineate a lignite deposit (Muggeridge, 1981, 1982).

Chapter 9

Industrial minerals

The Southern Cross – Esperance Region of Western Australia contains a variety of industrial minerals and many of these are yet to be fully exploited. From around the late 1920s to 1999 there has been intermittent production of a number of industrial minerals from this region, but the production reported to the Department in 1999 was limited to salt (129 744 t valued at $5.3 million), gypsum (86 774 t valued at $620 710), and sand (3406 t valued at $17 033), which together had a total value of $5.96 million.

The potential for further development of industrial mineral projects in the Southern Cross – Esperance Region can be considered to be high, although the current production in the region in comparison with the rest of the State is extremely small (less than 0.5% of the State's value of production of industrial minerals). Some of the industrial minerals that appear to have a promising future are magnesite, graphite, kaolin, and spongolite.

The locations of all the industrial mineral deposits and occurrences in the Southern Cross – Esperance Region are given in Appendix 1, and brief descriptions of these deposits and occurrences follow.

Salt

The State's major salt operations are found in the northern and western coastal regions of the State at Dampier, Lake MacLeod, Port Hedland, and Shark Bay. Western Australia produces around 95% of the national output, and Australia ranks sixth in world salt production.

The biggest salt-producing operation in the Southern Cross – Esperance Region is at Lake Deborah East, about 18 km north of Koolyanobbing (Plate 1). Relatively small quantities of salt are also produced from Pink Lake near Esperance (Plate 1). The historical production of salt from the Southern Cross – Esperance Region to 1999 amounts to 804 959 t valued at $33.3 million. In 1999, production was 129 744 t valued at $5.3 million (Table 1). However, this production is only around 1.4% (by quantity) of Western Australia's total salt production of 8.86 Mt, which is valued at $186 million.

Lake Deborah East

Lake Deborah East mine, 400 km east of Perth and 70 km north of Southern Cross, is the largest salt-producing centre in the Southern Cross – Esperance Region. Salt is extracted by the evaporation of water collected in the lake during winter rains. The site has resources of approximately 70 Mt. The operation has a production capacity of approximately 250 000 tpa, and is owned by WA Salt Supply Pty Ltd. The operation, which includes a refinery at Hamilton Hill, south of Perth, supplies most of the local salt market and currently exports 22% of its refined product to Singapore, Fiji, Mauritius, Brunei, and the United Kingdom. A wide range of salt types is produced, including bath salt, butchers' salt, casing salt, cheese salt, coarse salt, fine salt, hide salt, sheepskin salt, swimming pool salt, table salt, and water-softening salt (Bracken et al., 1998).

Pink Lake

WA Salt Supply Pty Ltd also produces relatively small amounts of salt, around 10 000 tpa, from Pink Lake near Esperance. The salt is used for applications such as swimming-pool salt and butchers' salt.

Lake Biddy

Between 1985 and 1996 a total of 1612 t (valued at $76 690) of salt was produced by A. L., K. L., and P. M. Green from Lake Biddy. Since then, there has been no reported production.

Salt potential

The most prospective areas for salt in the Southern Cross – Esperance Region are the salt lakes. However, the size of these deposits is small compared with deposits elsewhere in the State at Dampier, Lake MacLeod, and Port Hedland; and so large-scale development is unlikely.

Gypsum

The earliest reported production of gypsum from the Southern Cross – Esperance Region was in 1926, from the Lake Seabrook deposit, and reported production since then (from 1926 to 2000) from the Southern Cross – Esperance Region has totalled approximately 2 Mt (Table 14).

The gypsum deposits in the study area contain seed and kopi forms of natural gypsum. Kopi is a fine-grained

Table 14. Gypsum production in the Southern Cross – Esperance Region between 1926 and 2000

Locality	*Period*	*Tonnes*
Lake Camm	1988 to 2000	64 547
Lake Cobham	1984 to 2000	133 986
Lake Cowan	1935 to 2000	631 225
Lake Gulson	1985 to 2000	107 257
Lake Seabrook	1926 to 1992	855 635
Lake Tay	1990 to 2000	86 195
Lake Lockhart	1992 to 2000	12 960
Moorine Rock	1992 to 1999	20 799
Mount Walker	1987 to 1988	4 974
Scaddan	1992 to 1999	75 893
Stennetts Lake	1992 to 1999	2 300
Total		**1 995 771**

SOURCE: MPR Royalties Branch

(<0.06 mm), loose, powdery or earthy variety found on the surface of dry saline lakes, and in adjacent dune deposits. It may become cemented to form a moderately hard crust. Seed gypsum consists of rounded to subangular crystals found together with kopi on the surface of dry lakes and in dunes.

Gypsum production from the region during 1999 totalled 86 774 t with a value of $620 710 (Table 1). However, in 2000 reported production was 46 204 t valued at $339 459, a much reduced figure. Most of the production from the Southern Cross – Esperance Region consists of lower value agricultural-grade gypsum.

A number of deposits in the region have resources in excess of 1 Mt. The mines in the region with reported production are Lake Cobham, Lake Cowan, Scaddan, Lake Tay, Moorine Rock, Lake Gulson, Lake Camm, Lake Lockhart, Lake Seabrook, Mount Walker, and Stennetts Lake (Fig.18). However, mining of many of these deposits is on an ad hoc basis. In addition to these deposits, many other small gypsum deposits are known in the salt lakes of the Southern Cross – Esperance Region. These are summarized in Table 15.

Descriptions of currently producing and other significant deposits are given below.

Lake Cobham

Seed gypsum is up to one metre thick on the lake bed, underlain by grey sand and overlain by one metre of kopi and soil. A thin horizon containing coxiella shells is located in about the middle of the gypsum layer. During the period from 1984 to 2000 there was production of 133 986 t for agricultural uses, but no resource estimates have been reported for the deposit (Jones, 1994).

Lake Cowan

Medium to coarse seed gypsum at Lake Cowan is found on the lake flats, and in dunes along the lake margins. Lake-flat deposits are laterally extensive, although thin (0.3–0.5 m), and are close to the watertable. Dune deposits are less extensive and are composed of seed gypsum from 0.6 to 4.5 m thick (average 2 m) beneath kopi gypsum from 0.2 to 0.6 m thick. Jones (1994) estimated the resources in the deposit and these are shown in Table 16. For the period between 1935 and 2000 a total of 631 225 t is recorded as having been produced from the deposit for use in the plaster and cement industries, as well as some low-grade applications.

Scaddan

Approximately 8 km north of Scaddan townsite, and adjacent to the Coolgardie–Esperance railway tracks, gypsum is found on a dry lake bed with between 0 and 1.5 m of sand–soil–kopi gypsum overlying between 0.5 and 2 m of clean medium to coarse seed gypsum. The watertable is about 3 m below the lake bed. Reported production from the deposit during the period from 1992 to 1999 was 75 893 t.

Lake Tay

Seed and kopi gypsum are found as lacustrine sediments and eolian sheets, hummocks, and dunes along the southeast shore of Lake Tay, about 80 km west of Salmon Gums. The inferred resources were estimated at 1.54 Mt of seed gypsum of 95.5% purity, 373 000 t of seed gypsum of 98.5% purity, and 1.7 Mt of seed–kopi gypsum of unknown purity (Jones, 1994). During the period from 1990 to 2000 a total of 86 195 t of gypsum from the deposit was produced for export.

Moorine Rock

At Moorine Rock, approximately 25 km southwest of Southern Cross, kopi gypsum is found overlying both the lake bed and dunes. From 1992 to 1999 a total of 20 799 t of gypsum was produced from the deposit.

Moorine Rock South gypsum deposit, 9.6 km south of Moorine Rock, is on a dry lake flat and contains medium to large crystals in the southern part and seed in the northern part. The deposit reaches a thickness of 1.5 m in the centre of the flat and is overlain by 15 cm of dirty kopi. A kopi dune on the eastern edge of the flat rises to 3 m in elevation, but is covered by only 0.6 m of kopi. There is no reported production and the deposit is estimated to contain an inferred resource of 298 000 t of seed–kopi of 77% purity and 7500 t of kopi–seed of 83% purity (Jones, 1994).

Lake Seabrook

Seed gypsum dunes are developed over an area 5 km long and of variable width on the western edge of a peninsula that extends northwards into Lake Seabrook, about 40 km northeast of Southern Cross. The height of each dune ranges from 0.3 to 6 m and the width ranges from 100 to 500 m. A layer, up to 30 cm deep, of 'thumbnail-size' crystals on the lake covers an area of more than 8 km^2.

Figure 18. Gypsum deposits and occurrences in the Southern Cross – Esperance Region. See Figure 4 for complete geological legend

Table 15. Minor gypsum deposits and occurrences in the Southern Cross – Esperance Region

Locality	*Comments*
Bodallin	Kopi patches are on a low ridge at the southeast edge of an old claypan
Boodarockin	Gypsum is in a dune along the southern edge of small salt lake. The dune is 2 m high, 15–20 m wide, and 2 km long, and consists of seed gypsum with a covering of kopi. The floor of the deposit is nearly flat and about 1 m above the high-water level of the salt lake. The resource in the deposit is estimated at 36 000 t of 88% purity
Boondi	A gypsum bed up to 20 cm thick is in an unnamed lake, 12 km south of former Boondi rail siding
Eva Lake	Poorly documented gypsum, 21 km north of Mount Clara
Geordie Rock	Poorly documented gypsum, 7 km north of Geordie Rock
Grass Patch	Poorly documented gypsum, 9.5 km east of Grass Patch Siding
Hamersley Lakes	Poorly documented gypsum just north of Woongaring Hills
Lake Baladjie	A layer of gypsum crystals 5 cm thick lies under a salt crust on a lake. No reported production
Lake Biddy	Poorly documented gypsum on the lake bed
Lake Burkett	Gypsum found on a lake bed
Lake Chidnup	Minor occurrence of seed and clayey kopi gypsum
Lake Cowan North	Gypsum 20–40 cm thick is in lake sediments. No reported production and the resource is unknown
Lake Dundas	A deposit of unknown quality and resource. No reported production. However, the southern half of the lake appears to have good potential for gypsum deposits
Lake Gilmore	A layer of gypsum, 50 cm thick, has been reported in the lake and kopi dunes
Lake Gilmore West	Poorly documented gypsum, 5 km west of Lake Gilmore
Lake Lockhart	Between 1992 and 2000, 12 960 t of gypsum was produced from a deposit 2 km east-northeast of Lake Lockhart and approximately 10 km south of Lake Buchan gypsum deposit (see text). There is no information on the geology of this deposit
Lake Magenta	Kopi and possibly seed gypsum lies on the lake bed. Several kopi-capped fine seed gypsum dunes, which rise 4–5 m above the lake bed, lie at the north end of the lake. No reported production and resource is unknown
Lake Mends	Poorly documented gypsum, 9 km northeast of Pyramid Lake
Lake Tay East	This deposit is thought to be similar to that at Lake Tay and has a pre-resource estimate of 160 000 t
Mount Palmer	Thin seed dune, average thickness 0.5 m, overlying dirty seed gypsum and clay on the east shore of a salt lake. The dune is approximately 2 000 m long and 320 m wide. Other possible deposits lie 1 km east and 3.5 km southeast of this location. The resource estimates are 310 000 t of >90% purity of seed, and 100 000 t of about 50% purity of kopi/seed gypsum, respectively
Mount Walker	Kopi-capped seed dune on the south shore of a small lake north of the Narembeen – Mount Walker road. The dune appears to include: a clean, medium-sized seed gypsum layer underlain by a thin recrystallized gypsum layer; both overlain by reddish seed gypsum/kopi; and capped by soil and/or a thin reddish kopi. The total thickness for the recrystallized layer plus the clean reddish seed gypsum appears to be about 2–3 m. During 1987–88, there was production of 4 974 t for local agricultural uses. The deposit appears to be mined out
Narembeen	Kopi samples from this location, 8 km east of Narembeen, have been submitted to GSWA, but the nature of the deposit is unknown
Norseman East	Poorly documented gypsum, 7 km east of Norseman
Parker Range	Kopi gypsum, 30–45 cm thick, on lake bed and some low kopi/seed dunes on and near the eastern shore. One dune was described as being about 800 m long, 90 m wide, and 4–6 m high. Dunes are 1–4 m thick and generally comprise 0.5–1.5 m of kopi, capping 1–2 m of seed gypsum. No production reported and the resource is unknown
Southern Cross	A small patch of dirty crystals, varying from 15 to 75 cm thick, lies on the west side of a small lake flat. On the southeast corner of this flat is a small seed dune averaging 1.2 m high and 27 m wide. No reported production. The deposit is estimated to contain 10 000 t of 80% purity gypsum crystals, and 9 000 t of 75% purity seed gypsum. Possible agricultural uses
Stennetts Lake	A kopi gypsum dune is up to 10 m high, 60 m wide, 240 m long, and trends at 030º. The kopi is clean and white, and the dune runs through an old sand-covered lake bed. The deposit is estimated to contain 19 000 t of 93% puritykopi gypsum. Production of 2 300 t was recorded between 1992 and 1999, possibly for agricultural uses
Three Stars Lake	The nature of the deposit is unknown but is presumed to be similar to Lake Tay
Yellowdine	Poorly documented gypsum, 4.5 km east of Yellowdine

SOURCE: Jones (1994)

Table 16. Resources of gypsum at the Lake Cowan deposit

Gypsum type	*Inferred resource (Mt)*	*Grade (purity %)*
Seed	5.46	95–98
Seed	1.3	>95
Seed	5.7	>90
Granular, kopi	0.9	>90

SOURCE: Jones (1994)

The inferred resources of the deposit are estimated at 1.02 Mt of seed of 95% purity, and 3.1 Mt of crystals of >80% purity (Jones, 1994). Between 1926 and 1992 there was production of 855 635 t from the deposit, mainly for use in the plasterboard industry.

Lake Gulson

Gypsum is found in low dunes and ridges on the southeast shore of a small lake southeast of Lake Gulson. A typical dune comprises between 0 and 0.3 m of sand–silt overlying between 0.2 and 0.5 m of kopi and fine seed gypsum, which is underlain by between 0.3 and 1.0 m of fine to medium seed gypsum (down to the watertable). During the period from 1985 to 2000 there was production of 107 257 t, probably for agricultural uses, but no resource estimate is available (Jones, 1994).

Lake Camm

On the southern end of Lake Camm gypsum is found as several low dunes, between 1 and 1.5 m high. The dunes are composed of between 0 and 0.5 m of sand or soil overlying from 1 to 1.5 m of fine to coarse seed gypsum. During the period from 1988 to 2000 there was production of 64 547 t for agricultural uses. A sample indicated 82% gypsum, 0.3% salt, and more than 10% quartz (Jones, 1994).

Lake Kathleen

A seed gypsum layer about 35 cm thick under some 30 cm of kopi–clay is found in the southeastern part of Lake Kathleen, 14.5 km north of Lake King townsite. Seed dunes on the nearby bank contain up to 2.5 m of seed gypsum, overlain by 60 cm of kopi. Other dunes in the belt farthest from the lake contain seed gypsum under kopi, or are composed of kopi and granular gypsum. There is no reported production from the deposit, but selective mining may be possible for plaster, cement, or agricultural uses. The inferred resources in the deposit are estimated at 660 000 t of seed of 84% purity, 200 000 t of seed of 77% purity, 190 000 t of seed of 73% purity, and 90 000 t of kopi–seed of 50% purity (Jones, 1994).

Beete

Kopi and seed gypsum dunes lie on the east and southeast shores of a salt lake system near Beete. The dunes are from 1 to 4 m high, and composed of up to 1 m thick kopi gypsum, underlain by between 1 and 4 m of seed gypsum. Seed and kopi gypsum layers more than 2 m thick are also found in parts of the lake. Jones (1994) estimated the resources in the deposit and these are outlined in Table 17. There is no reported production from the deposit.

Lake Julia

At Lake Julia, 24 km north of Southern Cross townsite, clean flat lenses of pale brown, saccharoidal gypsum are overlain by a surface layer of dirty gypsum. Clayey gypsum underlies saccharoidal gypsum and grades rapidly into lake mud. The average thickness of saccharoidal gypsum is about 0.6 m, but may be up to 3 m in dunes on the eastern side of the lake. There has been no reported production, but the deposit is estimated to contain an inferred resource of 1.1 Mt of 90% purity, possibly suitable for plaster and agricultural uses (Jones, 1994).

Pyramid Lake

A lake deposit of gypsum containing an estimated inferred resource of 1.7 Mt is at Pyramid Lake, about 65 km west-southwest of Salmon Gums. Details of the deposit are not available, and there is no reported production (Jones, 1994).

Lake King

During the period from 1985 to 1987, exploration was carried out for gypsum in the salt lakes of the Cainozoic palaeodrainage system overlying Archaean granitoid and gneiss, near Lake King, about 7.5 km west of Lake King townsite. Sampling by hand auger established potential for a mineable gypsum deposit in Lake King, with two areas (i.e. areas 1 and 5 of Purkait, 1987) identified as containing inferred resources of high-grade gypsum. Area 5 was estimated to contain a resource of 500 000 t with an average of 96.6% $CaSO_4.2H_2O$ and less than 1% SiO_2, whereas the resource in area 1 was estimated at 60 000 t with an average of 93% $CaSO_4.2H_2O$ and 2.4% SiO_2.

Table 17. Resources of gypsum at the Beete deposit

Gypsum type	*Resource*		
	Category [(a)]	*tonnes*	*Grade (purity %)*
Seed	MES, IND	435 000	93
	(incl MES	272 000	96)
Seed	MES	100 000	93
Seed, kopi	IND	600 000	approx. 95
Seed, kopi	INF	4 250 000	approx. 90

NOTE: (a) MES–measured; IND–indicated; INF–inferred
SOURCE: Jones (1994)

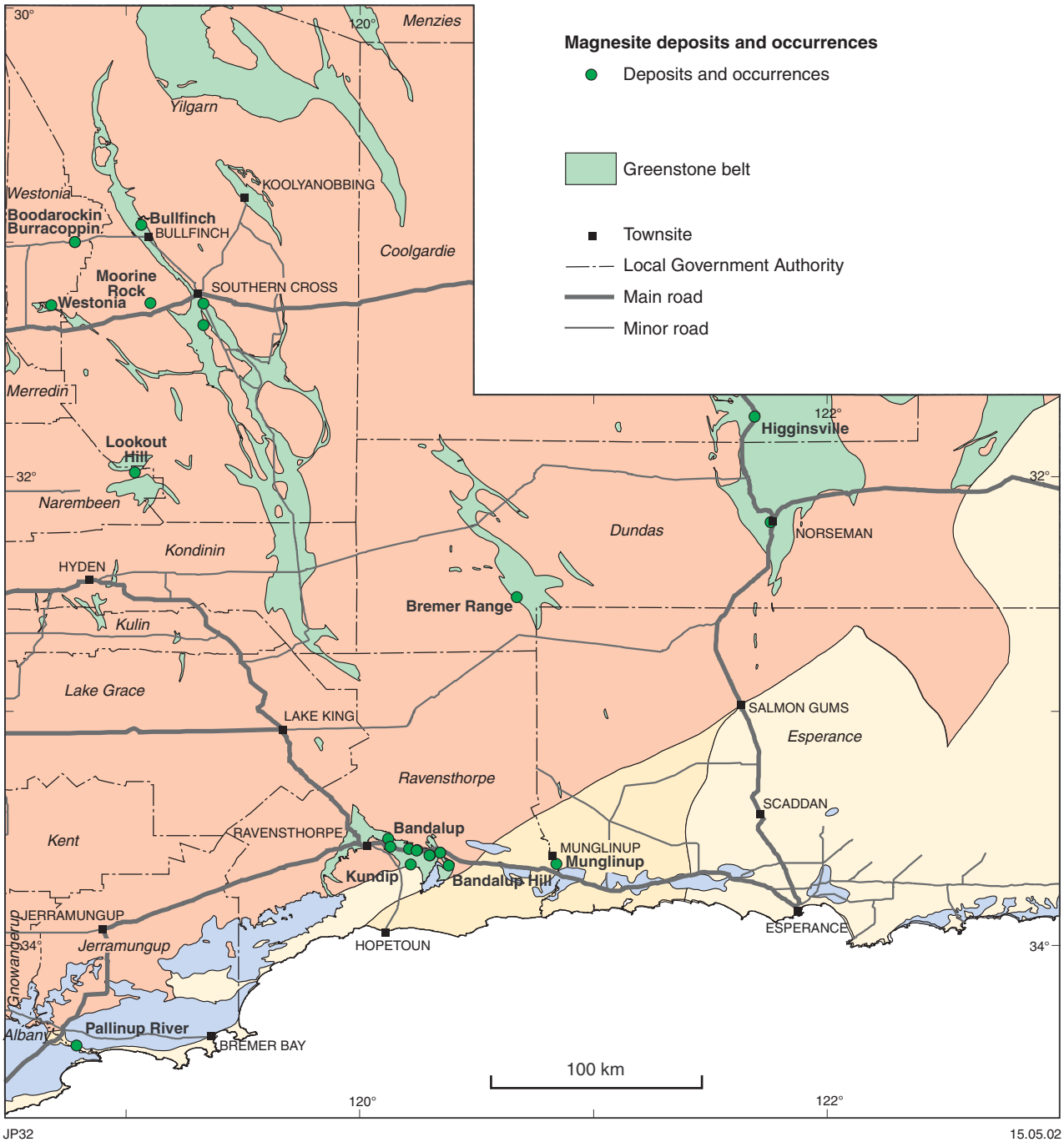

Figure 19. Magnesite deposits and occurrences in the Southern Cross – Esperance Region. See Figure 4 for complete geological legend

Lake Buchan

On the southeast shore of Lake Buchan, about 5 km south-southeast of Newdegate townsite, are dunes and samphire flats containing gypsum. A belt of seed dunes along the edge of the lake reaches 2.7 km in length, 100 m in width, and averages 1.5 m in height. Immediately southeast of the dunes is a flat area with 5 cm of kopi overlying 45 cm of seed. A second flat, farther southeast, has 45 cm of kopi overlying 1.2 m of seed gypsum. A third, smaller flat to the north contains 75 cm of seed overlain by 45 cm of kopi. The inferred resources of the deposit are estimated at 129 000 t of seed of 82% purity, 310 000 t of seed of 78% purity, and 210 000 t of seed–kopi of 60% purity. There is no reported production from Lake Buchan.

Gypsum potential

The salt lakes (playas) in the Southern Cross – Esperance Region remain areas with the most potential for discovery of large gypsum deposits.

Magnesite

The last recorded mining of magnesite in Western Australia was in 1985 from the Bandalup deposit, which is approximately 30 km east of Ravensthorpe. During the period from 1959 to 1985, the Bandalup deposit produced 67 945 t of magnesite (valued at $1.2 million). Numerous other magnesite deposits and occurrences are also known in the Ravensthorpe area, as well as in other localities of the Southern Cross – Esperance Region (Fig. 19).

Below are brief descriptions of the more significant magnesite deposits in the Southern Cross – Esperance Region, based principally on Abeysinghe (1996). Minor magnesite occurrences in the region are described briefly in Table 18.

Ravensthorpe area

Magnesite deposits in the Ravensthorpe area occur as massive structureless bodies overlying many rock types, and can be broadly assigned to two groups, based on their lithological associations: those associated with Archaean ultramafic and mafic rocks, and those associated with the Eocene Pallinup Siltstone of the Plantagenet Group (Abeysinghe, 1996).

Archaean ultramafic and mafic association

Residual magnesite deposits are developed over Archaean serpentinite, amphibolite, quartzite, and schist. Two varieties of deposits identified are: a 'lean' surficial type, and a dense accumulate type. The lean type is usually 1.0–2.5 m thick, and overlain by a soil horizon generally 0.5–1.0 m thick. The dense accumulate type forms as lenticular, lumpy bodies with well-defined margins at low-lying to intermediate physiographic levels, adjacent to creeks. The thickness varies from 0.5 to 10.0 m. The lump magnesite varies from hard, flinty (occasionally dolomitic) to soft, porous and chalky material, and locally lies directly on siliceous metasedimentary rocks. Basement rocks are commonly present as either isolated boulders or as small remnants.

The following magnesite deposits are associated with Archaean ultramafic and mafic rocks in the area around

Table 18. Minor occurrences of magnesite in the Southern Cross – Esperance Region

Locality	*Comments*
Boodarockin	Specimens of hard, dense, fine-grained, cream-coloured magnesite have been collected, which have an appearance similar to marble
Bremer Range	A small amount of hard and flinty magnesite is known from this locality
Bullfinch	White magnesite in significant quantities is associated with serpentinous rocks between Bullfinch and Golden Valley. Hard, soft, and pure varieties are present. Some contain chalcedony. The exact location is not given
Burracoppin	Hard, pure magnesite, which contains 2.5% SiO_2, lies approximately 9.6 km northwest of Burracoppin. A more siliceous and friable variety present at the surface contains 16% SiO_2
Higginsville (Hopbush Soak)	Cream and white magnesite is known from a location 3.2 km north of Hopbush Soak, east of Higginsville. A typical sample from this location contained 46.50% MgO
Lookout Hill	Creamy white, cryptocrystalline boulders of magnesite are known at Lookout Hill, a few kilometres southeast of Holleton, and are associated with mafic rocks. Magnesite boulders are also found just south of Holleton
Moorine Rock	Boulders of dirty, off-white, cryptocrystalline magnesite are found northwest of the siding at Moorine Rock
Norseman	Nodular magnesite was found in a small shear zone in an adit at the Hardy Norseman GML 21. White cryptocrystalline magnesite is found in the surface soil near the Nellie May GML 873, 14.5 km northeast of Norseman, and a sample contained 96.5% $MgCO_3$ and 3.5% $CaCO_3$. The rocks in the area include widespread peridotite, pyroxenite, and norite
	Magnesite is also a deep weathering product over ultramafic rocks associated with the Jimberlana intrusion, which extends from northeast of Norseman to Round Top Hill on Lake Johnston. Magnesite is more abundantly developed over the ultramafic portions of the intrusion
Pallinup River	'Coralloidal' and fossil-like concretions of white microgranular magnesite are found 9.6 km inland from the mouth of the Pallinup River. A vein of magnesite was also noted in weathered serpentinite near a graphite vein in the same area
Southern Cross	Many isolated magnesite occurrences are found within the Southern Cross district. A location approximately 3.2 km south of the town could yield large tonnages of commercial quality, and contains 45.02% MgO (=94.1% $MgCO_3$), whereas samples taken 15.2 km south of the town are slightly porous and chalky
Westonia	Large nodules and boulders of pure magnesite have been collected from a lease known as Edna May Deeps, where small bands of Archaean peridotite and serpentinite are known. Production of 22 t was recorded in 1963 (valued at $177) from MC 60. Concretions of impure magnesite are also known in soil near Bodallin Soak

SOURCE: Abeysinghe (1996)

Ravensthorpe — Bandalup Creek (B1, B2, B5), Kundip (B3), Ravensthorpe (B4), Ravensthorpe (B6), Ravensthorpe (B7), Ravensthorpe (B8), Bandalup Hill (L1). Locations are shown on Figure 19; more detailed information on these locations is available in Abeysinghe (1996, fig. 27).

Bandalup Creek

Magnesite is associated with small exposures of hornblende-bearing mafic rocks in an area covering more than 37 ha, south of the South Coast Highway, near Bandalup Creek. Exploration pits show that magnesite is well developed as boulders (concretions) between 2.5 and 5 m in diameter. Most boulders are massive, although some are relatively soft and readily break down into finer material. Inferred resources for this area are estimated at about 176 500 t of lump magnesite (Abeysinghe, 1996).

Kundip

South of the Jerdacuttup River, and approximately 6 km northeast of Kundip, magnesite is mainly associated with serpentine-bearing schist. The inferred resource is estimated at more than 100 000 t. However, the deposit is considered to be uneconomic because of its small size and the problems anticipated with selective mining (Abeysinghe, 1996).

Ravensthorpe

Four magnesite occurrences in the Ravensthorpe area were referred to as B4 and B6–B8 by Abeysinghe (1996, fig. 27).

At B4, three distinct magnesite bodies, mostly in the form of dense surface accumulations, are found along and parallel to a creek, north of the South Coast Highway. Exploration pits indicated that the depth of magnesite does not exceed 3 m. A sample studied by XRD indicated less than 5% halite. The westerly exposures are associated with a heavy mantle of chalcedonic–jasperoidal silica. The resource available from this area is inferred to be about 20 000 t (Abeysinghe, 1996).

At B6, outcrops of magnesite, restricted to the crests and upper slopes of prominent ridges, are found at the eastern slopes of Ravensthorpe Range and south of Jerdacuttup River. Magnesite is generally associated with mafic outcrops and rubble. Minor outcrops of jaspilite, amphibolite, and quartzite are also in the vicinity of B6. The thickness of the magnesite ranges from 1.5 to 2.5 m. The resource available from this area is considered to be insignificant.

At B7, approximately 8 km east of Ravensthorpe, magnesite outcrops associated with serpentinites are found along northerly trending ridges. Some magnesite outcrops contain surficial travertine. Small tonnages of magnesite were obtained from this area in the early 1900s by surface picking and from shallow veins, and were used in the Ravensthorpe copper smelter, but there is insufficient lump magnesite available for this deposit to be commercially significant (Abeysinghe, 1996).

At B8, 14–17.5 km east of Ravensthorpe, scattered exposures of magnesite are found on the east and west side of Jerdacuttup River. Some outcrops have well-developed exteriors with a 'cauliflower'-like appearance, and a thin travertine layer is commonly developed on the surface nodules. The exposures are associated with metamorphosed mafic rocks and minor metasedimentary rocks. The depth of magnesite is shallow, with no indication of significant resources.

Bandalup Hill

Magnesite overlies serpentinite on a laterite-capped hill, approximately 3 km southeast of Bandalup Hill. It is a hard, white material with karst-like surfaces, though some outcrops contain a brown dolomitic coating. In places the magnesite extends laterally under the laterite. Exploration drilling for nickel in the area intersected magnesite at depths of between 15 and 46 m in three holes, drilled at 100 m intervals (Locsei, 1986). The Bandalup Hill deposit is estimated to contain more than 5 Mt of magnesite. However, this figure is based on information from only three drillholes and should be treated with caution (Abeysinghe, 1996).

Quality

A summary of the chemical variations of magnesite associated with ultramafic and mafic rocks is given in Table 19. In general, the samples contain higher amounts of Cr and Ni than those from the Pallinup Siltstone magnesites, indicating their derivation from ultramafic rock (see tables 32 and 33 of Abeysinghe, 1996).

Most of the magnesite deposits in the Archaean rocks in the region are subeconomic because of their grade variations and small size. However, deposits B1, B2, and possibly B5, adjacent to the Bandalup Creek, are of high quality and contain mineable magnesite of high grade.

Origin

Field relationships suggest that residual weathering of high-magnesium basalts and ultramafic rocks during the Cainozoic gave rise to most of the magnesite deposits in

Table 19. Partial chemical analyses of magnesite associated with ultramafic–mafic rocks and the Pallinup Siltstone

Compound	*Magnesite with ultramafic–mafic rocks (%)*	*Magnesite with Pallinup Siltstone (%)*
MgO	5.53 – 48.60	46.20 – 48.30
CaO	0.42 – 38.40	<0.43 – 1.82
SiO_2	<0.05 – 41.30	<0.05 – 1.91
Fe_2O_3	<0.05 – 4.61	<0.05
Al_2O_3	<0.05 – 6.35	<0.05
CO_2	9.40 – 49.55	–
TiO_2	–	<0.05

SOURCE: Abeysinghe (1996)

these rocks. This is strongly supported by the high chromium and nickel content of these deposits.

Eocene Pallinup Siltstone association

Bandalup

Approximately 3 km northeast of Bandalup Hill, adjacent to the South Coast Highway, extensive replacement deposits of magnesite are developed in sandy sediments of the Late Eocene Pallinup Siltstone (Fig. 19). The Pallinup Siltstone unconformably overlies deeply weathered Archaean quartz–mica schist, metamorphosed sandstone, and volcanic rock, and magnesite is found at several levels, separated by layers of Cainozoic sand. The deposits are composed largely of nodules of magnesite up to 0.75 m in diameter, but also include soft, earthy or clayey, structureless or incoherent material. They have a maximum thickness of approximately 7 m, with an average mineable thickness of 4 m.

The Bandalup deposits are scattered, and the indicated resources are estimated at 1.1 Mt, based on exploratory percussion drilling (Abeysinghe, 1996).

Quality

These samples are of higher quality than those associated with Archaean mafic rocks, and Table 19 shows chemical variations in 11 samples analysed. Trace element analyses indicate that the Cr content of these samples is low (<4 ppm) compared with those associated with the Archaean ultramafic–mafic rocks, and Ni values are also generally lower and more uniform (table 33, Abeysinghe, 1996).

Silica occurs mostly as free silica and not as silicate, whereas most of the deleterious lime is in the form of calcite. The quality of Pallinup magnesite is affected by the presence of significant amounts of montmorillonitic clay and chalky magnesite. The montmorillonite is extremely difficult to remove by washing, owing to its hydrophyllic nature, and the handling of chalky material causes continuous attrition and the creation of fines.

Origin

Butler (1961) suggested that magnesite within the Pallinup Siltstone was due to deposition of magnesite from solutions containing magnesium and carbonate extracted from the serpentinites. He considered the presence of nodular bodies throughout the deposit to support such a mechanism. He also suggested that the restriction of the deposits to shallow depths favoured supergene enrichment; the depletion of chromium and nickel in these samples is in agreement with such a hypothesis. It is possible that alkaline groundwater, rich in magnesium derived from weathered serpentinites, percolated through sandy sediments of the Late Eocene Pallinup Siltstone following their post-Eocene uplift above sea level. The magnesite probably replaced poorly lithified green sands of the Plantagenet Group, and is separated by layers of unreplaced sands. Various stages of replacement are locally preserved, up to the development of coarse nodular magnesite.

Other magnesite occurrences in the Ravensthorpe area

Impure, light-brown to grey, medium-grained, friable magnesite and dolomite are commonly exposed along a track heading west from Kundip. Chemical analyses of five samples show MgO values ranging from 8.81 to 39.0%. High percentages of nickel in some of these samples indicate derivation from ultramafic rocks in the region.

Many other small occurrences of magnesite with no commercial significance are associated with sheared and altered ultramafic rocks in the Ravensthorpe area.

Munglinup

Magnesite is evident in a shaft sunk for graphite at a location approximately 75 km east of Ravensthorpe (Fig. 19), on a tributary of the Oldfield River (Blatchford, 1917; Simpson, 1952). Magnesite is developed between foliae of graphite and seems to be a weathering product of carbonated peridotite within the gneissic host rocks. The continuity of the peridotite may be traced by surface magnesite boulders commonly containing opaline silica.

Magnesite is also widely associated with graphite veins in a number of trenches in 'Halberts main zone' of graphite workings at Young River. Two analyses of magnesite from this locality indicate that the magnesite is of high quality, containing 47.2 and 48.0% MgO (Abeysinghe, 1996).

Magnesite potential

Modern exploration for magnesite within the Southern Cross – Esperance Region has been limited. Ultramafic rocks are common in the region; hence the area is prospective for large magnesite deposits. The recent discovery of magnesite at Lawlers (near Leinster), and at Murrin Murrin (near Leonora), in areas of comparable ultramafic lithologies, indicates that commercial deposits may exist within the region. Other possible targets may be Cainozoic palaeochannel or lacustrine environments near serpentinized or other ultramafic rocks, where redeposition of magnesite could occur from magnesium-bearing solutions. Such deposits would be similar in age to those found in sediments at the Bandalup deposits in the Ravensthorpe area. Although the indicated resource of the Bandalup deposit is 1.1 Mt, there is the possibility for the discovery of much larger Cainozoic lacustrine replacement deposits in this region.

Clays

There is no reported production of speciality or common clays from the Southern Cross – Esperance Region. However, some kaolin deposits in the region appear to have potential for commercial development, and some of

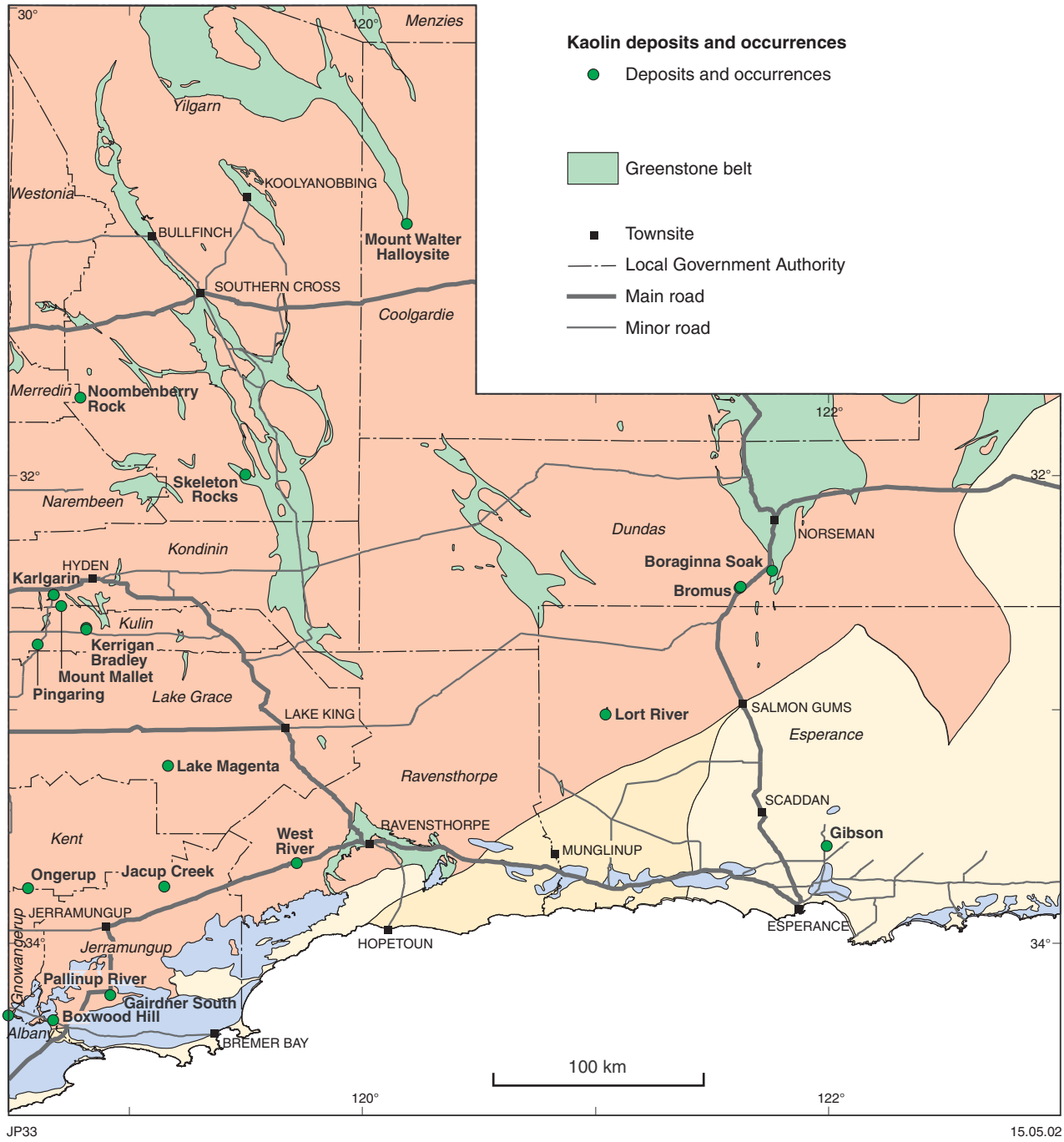

Figure 20. Kaolin deposits and occurrences in the Southern Cross – Esperance Region. See Figure 4 for complete geological legend

these deposits are currently being assessed. The Kerrigan deposit, including Bradley, has been evaluated in the most detail and has the most potential. In addition, other occurrences of kaolin are known and warrant further exploration. Following are descriptions of the kaolin deposits and occurrences in the region; their locations are shown on Figure 20.

Kerrigan and Bradley

The Kerrigan kaolin deposit is located 350 km east of Perth and approximately 25 km southeast of Karlgarin (Fig. 20). In 1992 the area was drilled by Graphite Holdings Pty Ltd — intersecting large lenses of exceptionally bright clay in an area designated as 'Bradley'. Clay intersections similar to those found at the Bradley deposit were also encountered in nearby areas during CRA's extensive regional exploration program for kaolin during the period from 1993 to 1996.

Weathering of Archaean porphyritic granitoid and adamellite, and leucocratic granofels of granitoid–adamellite composition has given rise to this kaolin deposit. Over much of the area, the rocks are deeply weathered, forming a well-leached kaolinized zone under

Table 20. Characteristics of kaolin from the Bradley deposit

Characteristic/ parameter	*Result*
Yield	-10 µm product averages 45%
Brightness	Unbeneficiated ISO brightness is in the range between 85.4 and 89.1%
Quartz	Less than 1%
Fines	-2 µm content of the product ranges from 42 to 83%, with an average of 74%. The variability is considered to be due to sample size and interval

SOURCE: Abeysinghe and Fetherston (1999)

a lateritic duricrust. Locally, however, laterite lies directly above relatively fresh granitoid. Exposures of leached zones are common in breakaways around the edges of the lateritic uplands. Aeromagnetic features and drillhole intersections show that mafic dykes intrude the Archaean rocks.

The kaolin forms a matrix between quartz crystals, and is derived from the breakdown of potash and soda feldspar. Preserved textures in outcrops show that the kaolin is definitely of residual origin.

The overburden of nodular lateritic duricrust grading into ferruginous mottled clays averages about 4 m thick. At the top of the pallid zone, which comprises well-leached kaolin and off-white and slightly discoloured kaolin, is an irregular layer of well-cemented, siliceous kaolin up to 2 m thick. The pallid zone is up to 30 m thick, averaging 16 m, and contains lenses of highly leached kaolin referred to as 'high white' (Kristensen, 1994; Williams, 1996; Williams and Bisset, 1996).

Preliminary analytical results indicate that the kaolin is of exceptionally high quality requiring little or no beneficiation other than size separation (Kristensen, 1994). The Bradley deposit contains abundant good-quality kaolin with potential for use in paper manufacture. The characteristics of the kaolin from the Bradley deposit are summarized in Table 20.

Based on the 115 holes drilled in the area between 1993 and 1994 (mostly in the Bradley deposit), CRA Exploration Ltd estimated inferred resources in the Bradley deposit to be about 80 Mt, over an area of some 3 km^2. The resource estimate is based on drill spacings of between 200 and 400 m. Kaolin in the deposit is up to 27 m thick, averaging 16 m, with an average overburden thickness of 4 m. The average thickness of 'high white' lenses within the pallid zone is about 8 m.

Some samples from the area west of the Kerrigan deposit indicate high-grade kaolin suitable for paper-coating applications. These samples are from localities more than 5 km apart, and therefore suggest the possibility of an extensive resource of high-grade kaolin within the general area in addition to the Kerrigan deposit (Abeysinghe and Fetherston, 1999).

Bromus

The Bromus kaolin deposit is located near the Norseman–Esperance railway, 5 km south-southwest of Bromus siding (Fig. 20). The port at Esperance is 165 km south of the deposit, and Norseman is 40 km by road to the northeast.

In 1970 Petromin NL discovered the kaolin deposit whilst exploring for base metals in areas of magnetic anomalies (Petromin NL, 1974; Lipple, 1977). The area consists of sporadic outcrops of migmatite and fine-grained, equigranular adamellite. Coarse irregular pegmatite and medium- to coarse-grained foliated adamellite intrude the migmatite. Kaolin lies beneath various surficial deposits including residual and reworked silcrete, ferricrete, yellow to buff sand, limonitic nodules, and ferruginous sandstone. The area also contains partly reworked Quaternary eolian deposits of clay, silt, and sand with locally derived calcareous nodules. There are also extensive alluvial and colluvial deposits derived by sheetwash. Drilling indicates that white and coloured clays, consisting of kaolinite with up to 40% quartz grit, have developed mainly due to weathering in situ of fine-grained adamellite.

Drilling and sampling indicate that material close to coating grade could be produced if the problem of viscosity could be overcome (Abeysinghe and Fetherston, 1999).

Odom Holdings (1998) estimated a tonnage of 21 Mt of kaolinitic clay, excluding the material sterilized by the railway line. Of this tonnage, the resources of the -20 µm fraction of kaolin have been estimated at 9 Mt (inferred category).

Lort River

The Lort River kaolin prospect (Fig. 20) is approximately 5 km northeast of Lake Mends, about 130 km northwest of Esperance, and adjoins the southern boundary of the Peak Charles National Park. Kaolin was identified during drilling in 1988–89 by Summit Gold (Aust) Pty Ltd during an exploration program for base and precious metals associated with rocks of ultramafic and/or alkaline affinity in an area northeast of Lake Mends (Eggers, 1989). The area is underlain by Archaean monzogranite, banded and migmatitic granitic rocks, and intrusive quartz–amphibole syenite and pyroxene-bearing syenitic rocks of Proterozoic age.

Since the main exploration focus was for base and precious metals, sampling and testing of kaolin was limited. Overall, test results indicate that more work is required to test the suitability of this clay for paper-grade material. The lack of sufficient chemical analytical data makes it difficult to comment on the suitability of the material for other uses (Abeysinghe and Fetherston, 1999).

Gibson

This prospect is about 17.5 km west-northwest of Gibson and 30 km north-northeast of Esperance (Fig. 20). Kaolin mineralization covers an area of 10 km^2 and overlies a basement of granitic gneiss.

In 1990 WMC Ltd, on behalf of Simmons Holdings Pty Ltd, drilled 47 aircore holes with the aim of identifying kaolin for use in high-quality paper coating or filling applications. The holes revealed that the depth of the weathering profile ranged from around 2 to 26 m, and drilling intersected foliated gneiss, unfoliated granitoid, and occasional mafic dykes. Kaolin is restricted mainly to zones of weathered granitoid and gneiss, and has formed as residual material in situ. Testing of the drill samples showed that brightness values were well within paper-coating grade, but viscosity was variable and below the required quality (Bonwick, 1991a,b).

Other occurrences

The most significant minor occurrences of kaolin are at Boxwood Hill, Lake Magenta, Noombenberry Rock, Skeleton Rocks, Karlgarin, Mount Mallet, Pingaring, Ongerup, Pallinup River, Gairdner South, Jacup Creek, West River, Boraginna Soak, and Ryans Find (Mount Walter). The following provides further information on each, and their locations are shown on Figure 20.

Boxwood Hill

Numerous road cuttings, approximately 8 km west of Boxwood Hill along Borden Road, contain kaolin developed within laterite. Such kaolin occurrences appear to be widespread in the area and are generally sub-horizontal to horizontal below laterite. Rocks associated with laterite and the kaolin horizons are dominantly yellow to grey siltstone, silty sandstone, and spongolite of the Late Eocene Pallinup Siltstone. Granitic and gneissic rocks are also found adjacent to some of these kaolin occurrences, and it is possible that kaolin has formed as transported deposits from the material derived from these granitoids, but there is no firm evidence to confirm this view.

Chemical analyses of the -10 µm fraction indicate typical kaolinite compositions, but suggest unsuitability for paper-grade material because of low Al_2O_3 (19.9–28.3%) and high SiO_2 (48.1–49.3%) as well as unacceptably high percentages of Na_2O (2.38–6.73%), Fe_2O_3 (1.37–1.96%), and TiO_2 (1.06–3.15%). Further testing of the material is required to check the suitability of the material for other industrial applications (Abeysinghe and Fetherston, 1999).

Lake Magenta

A sample, collected from Location 2293, 15 km north of Lake Magenta, contained over 60% kaolinite, less than 10% quartz, and less than 5% halite, when studied using XRD, suggesting that kaolin is in situ and derived from granitoid or granitic gneiss. Chemical composition of the sample indicates that TiO_2 (0.37%), Fe_2O_3 (0.44%), CaO (<0.05%) and K_2O (0.12%) are within acceptable levels for paper-coating grades, but Al_2O_3 (33.80%) is slightly low, and Na_2O (2.84%) and MgO (0.53%) levels appear to be high for such uses. Brightness is within the specifications for some paper-filler applications (Abeysinghe and Fetherston, 1999).

Noombenberry Rock

Chemical analyses of three raw samples of kaolin from a deeply weathered granitoid profile, 2 km northeast of Noombenberry Rock and approximately 25 km northeast of Muntadgin, indicate more abundant SiO_2 (62.10–70.80%) than in typical kaolinite, because of the presence of abundant quartz (25–45%) in raw samples. The Al_2O_3 of raw samples ranged from 20.90 to 27.60%, and could possibly be increased by separating mica and microcline. More physical testing of samples involving particle-size fractionation, viscosity, and brightness measurements are necessary for further evaluation of the quality of this kaolin (Abeysinghe and Fetherston, 1999).

Skeleton Rocks

The kaolin at Skeleton Rocks is approximately 80 km south-southeast of Southern Cross and 80 km northeast of Hyden (Fig. 20). Intervals of up to 15 m of kaolinitic clay were intersected during exploration drilling for gold.

Stallman (1996) reported that a composite sample of kaolin from aircore spoils was tested to determine the amount of material of less than 10 µm, the total silicate analysis of the -45 µm fraction, and the fired brightness (at 457 mµ). The sample was found to be coarse grained, with only 30% less than 10 µm. Total silicate analysis of the -45 µm fraction (degritted) indicated a clay suitable for sanitary ware applications.

Karlgarin

A quartz-rich kaolin sample has been found in a farm dam 3 km south of Karlgarin townsite (15 km west-southwest of Hyden). Kaolinite is the dominant (more than 50%) mineral, with traces (less than 2%) of quartz and feldspar, and less than 5% halite in the -10 µm fraction. The chemical composition indicates that kaolin has 34.00% Al_2O_3, 47.40% SiO_2, but moderately high Fe_2O_3 (2.83%), making the material unsuitable for high-grade uses such as paper and ceramic applications. However, the material may be suitable for the brick, tile, and clay pipe or pottery industries.

Mount Mallet

A quartz-rich kaolin sample has been found at Mount Mallet, about 20 km southwest of Hyden. Kaolinite is the dominant mineral (greater than 50%), with traces of quartz (less than 2%), feldspar, and halite in the -10 µm fraction. The chemical composition indicates that it has marginally low Al_2O_3 (31.60%) for high-grade uses such as ceramics and paper, but would be suitable for the brick, tile, clay pipe or pottery industries.

Pingaring

Quartz-rich kaolin is found on a small outcrop of kaolin near the railway line, about 40 km southwest of Hyden. Kaolinite is the dominant mineral with between 2 and 10% quartz, less than 2% mica, and less than 2% halite in the -10 µm fraction. The chemical composition indicated 33.5% Al_2O_3 and 48.10% SiO_2, which is suitable for the brick, tile, and clay pipe or pottery industries.

Ongerup

XRD studies of two samples from pits in Kent Location 1083, 25 km north-northeast of Ongerup, indicated over 60% kaolinite with some halloysite, 10–30% quartz, and less than 5% each of mica–illite, undifferentiated clay, and halite (in one sample). Chemical composition indicated that the Al_2O_3 (27.90–34.60%) content of these clays is low for paper-grade applications, although TiO_2 (0.30–1.25%) and Fe_2O_3 (0.70–0.76%) are within acceptable ranges for such applications. Na_2O (0.59–1.70%) and MgO (0.07–0.42%) are also high for paper-grade kaolin.

Pallinup River

There has been some exploration for kaolin at Plantagenet Location 2634, close to Pallinup River, and the work involved drilling and laboratory testing (Lipple, 1977). At this location, clay overlies coarse sandstone and conglomerate that, in turn, overlie granitoid and dolerite dykes.

Gairdner South

Lipple (1977) reported that a kaolin sample from this location had a brightness of 88% (at 467 mμ) and size fractions as follows: 35% less than 2 μm, 30% from 2 to 20 μm, and 35% greater than 20 μm.

Jacup Creek

At Location 1609 (within expired MC 3942), approximately 35 km northeast of Jerramungup, Hawkstone Minerals Ltd drilled and demonstrated the presence of kaolin to a depth of between 12 and 18 m over a large area. The average yield in the -2μm fraction was 11–16%, and the brightness was 85–86% at 457 mμ (Lipple, 1977).

West River

White, fine-grained kaolin with significant quartz and associated with lateritic material is exposed in a road cutting at West River. A sample of quartz-rich kaolin indicated more than 50% kaolinite, 2–10% quartz, less than 2% mica, and less than 5% halite in the -10 μm fraction. This sample has an ISO brightness of 82.2%, which is within the specifications for some high-grade uses such as paper filler. The chemical composition indicates relatively high-grade kaolin having 34.50% Al_2O_3 and 46.40% SiO_2, but there is relatively high Na_2O (1.51%).

Boraginna Soak

Kaolin overlies granitoid, and Doepel (1973) reported that random grab samples contained impurities of quartz (5%), hematite (less than 1%), and goethite (less than 1%).

Ryans Find (Mount Walter)

White clay containing halloysite (a variety of kaolin) horizons is found in lakes 32 km north-northwest of Boorabbin and east of Mount Walter at a locality known as Ryans Find. The halloysite forms a layer up to 2.1 m thick, which is exposed along the west side of a lake. A thin veneer of saline alluvium partly conceals the clay (Sofoulis, 1963; Fetherston and Brown, 1990).

Potential for kaolin and construction-industry clay

Large areas of granitoid and gneiss with deep weathering profiles in the Southern Cross – Esperance Region remain targets for the discovery of large kaolin deposits. Palaeochannels and palaeodrainage systems are other possible target areas.

The alluvial and colluvial formations found in the Southern Cross – Esperance Region have potential for the discovery of common clays suitable for the brick, tile, and other ceramic industries. The test results of common clay samples from Ravensthorpe, Salmon Gums, and Lake Cowan have indicated that the material is suitable for brick manufacture (Abeysinghe, 2002).

Spongolite

Spongolite is a sedimentary rock of the Eocene Plantagenet Group and consists of abundant siliceous sponge spicules (needle-like rods). Its low density and moderate strength make it an attractive building stone, and it can easily be quarried by sawing into blocks. Spongolite can also be used as pet litter, as an abrasive material, and possibly for high-temperature insulating bricks.

In October 1997, a spongolite mine and a 30 000 tpa processing plant were opened by Supersorb Minerals NL (now fully owned by Talon Resources NL) at Woogenellup, 17 km northeast of Mount Barker. The material is for use in the absorbent, fire-retardant, and pet-litter industries. Production in 1999 was 9292 t. Although this operation is outside the Southern Cross – Esperance Region, there is a high potential for similar spongolite developments within the region because there are extensive outcrops of the Eocene Pallinup Siltstone along the coast between Albany and Cape Arid (east of Esperance).

Spongolite is found in many localities in the south of the Southern Cross – Esperance Region, especially in the southern portion of Ravensthorpe and in some parts of Bremer Bay (Thom and Lipple, 1974; Thom and Chin, 1984a). Production of spongolite for use as a building stone is reported from Ravensthorpe and Twertup Creek.

Limestone

Limestone is found in a number of localities in the Southern Cross – Esperance Region but, in terms of purity, most of these localities appear to have low to moderate grade limestone. For the period from 1961 to 1999, the reported production from this region totalled 10 126 t of limestone and limesand. Limestone was used as a flux for copper smelting at Cordingup, and may have been used locally for road aggregate. Limesand appears to have been

used in agriculture as a soil conditioner, but the amounts are not recorded, because production has been from private land and is not required to be reported to MPR. As limestone is used as a neutralizing agent in the PAL (pressure acid leach) process, the planned development of lateritic nickel deposits in the region is likely to create a market for this commodity. Below are descriptions of the three main known deposits in the region. Locations are shown on Plate 1. Limestone is also known from a number of other localities in the Southern Cross – Esperance Region, and a summary of these occurrences is given in Table 21.

Lake Cowan – Buldania Rocks

The Norseman Limestone of Eocene age is exposed at the southern end of the Lake Cowan causeway. The outcrop consists of sandy fossiliferous limestone, fine-grained fossiliferous sandstone, and fossiliferous mudstone. The formation also outcrops approximately 11 km east of Buldania Rocks. Fauna in the formation includes molluscs, bryozoans, foraminifers, echinoids, corals, and a crinoid columnal (Doepel, 1973).

In the 1970s, WMC Ltd explored the Lake Cowan area for limestone for use as a flux in nickel smelting. Investigations revealed that limestone occurs together with clays and ferruginous silcrete in the first 6 to 10 m below surface, overlying coquina with a muddy matrix. Material in the first 20 m below the surface averaged 27% CaO (Fletcher and Hughes, 1976) and was not suitable as a flux.

Hopetoun

The Tamala Limestone and derived sand regolith are widespread along the coastal belt in the Hopetoun area. One sample of limestone (collected by GSWA) contained 88.6% $CaCO_3$ and 3.4% $MgCO_3$ (Abeysinghe, 1998). Several quarries near Hopetoun have produced aggregate for road building. Limestone from the area was used as a flux for the copper smelter at Cordingup (Thom et al., 1977). However, no production from the area has been reported to MPR (Abeysinghe, 1998).

Boyadup Swamp (Esperance)

The only limestone production reported to MPR from the Esperance area is from about 35 km east of Esperance and 7 km south-southwest of Boyadup Swamp. Total production was 7538 t during the period between 1961 and 1982. The material mined was probably limesand that was used as a source of agricultural lime.

Carbonate-rich eolianite of Pleistocene age, possibly equivalent to the Tamala Limestone, is found between coastal hills around Esperance (Morgan and Peers, 1973).

Limestone and limesand potential

The coastal areas of the Southern Cross – Esperance Region are the most prospective areas for limestone and limesand.

Graphite

There are a number of graphite deposits and occurrences in the Southern Cross – Esperance Region. Locations of these are shown on Plate 1.

Munglinup River

The Munglinup River deposit is situated 50 km west of Esperance. Graphite forms units of coarse flake material up to 7 m thick that lie within zones of graphitic schist. Host rocks form part of a Precambrian metamorphic suite of jaspilite, quartz–mica schist, and hornblende and biotite gneiss. The rocks are weathered to depths of 17 m or more. The deposit was mined intermittently between 1953 and 1956 to produce 138 t of graphite (Carter, 1976).

The deposit has measured and indicated resources totalling 1.4 Mt and averaging 18.25% fixed carbon to a depth of 55 m. The resource is open at depth and along strike, and numerous showings of graphite at other prospects within the mining lease suggest substantial potential for increased resources. The actual grades that could be produced are anticipated to contain 98% C, in flake sizes of +300 µm, -300 µm, +180 µm, and +100 µm.

Table 21. Limestone in the Southern Cross – Esperance Region

Locality	*Comments*	*Reference*
Lake Magenta	Calcrete in this region is found as layers and nodules adjacent to playa lakes	Abeysinghe, 1998
Mount Holland	Calcrete deposits are found adjacent to playa lakes, approximately 15 km northeast of Mount Holland. Calcrete is also found approximately 7 km north of Forrestania	Abeysinghe, 1998
Marvel Loch	Approximately 6 km west of Marvel Loch is a large deposit of 'travertine' overlying a dolerite. A typical sample contained 80.5 $CaCO_3$ and 0.22 MgO	Simpson, 1948
Southern Cross	An extensive deposit of impure limestone, mostly in the form of concretionary gravel and partly in layers, lies approximately 2 km south-southeast of Southern Cross	Simpson, 1948

SOURCE: Abeysinghe (1998)

Young River

The Young River deposit is 19 km to the northeast of the Munglinup River deposit. This deposit contains flake graphite in ?Archaean graphitic schist interbedded with biotite and hornblende gneiss (Carter, 1976).

Hyden

Chin et al. (1984b) reported graphite 19 km southeast of Hyden, where it forms as disseminated flakes constituting up to 10% of the Archaean graphite–muscovite schist.

Dolomite

Agricultural-grade dolomite is sporadically produced from small deposits at Lake Magenta, Lake Cobham, and Boodalin Soak (Plate 1). This material contains between 10 and 12% $MgCO_3$ and is not dolomite sensu stricto (which requires >19% $MgCO_3$), but is actually a form of magnesium-enriched limestone.

Vermiculite

Vermiculite is a hydrous micaceous silicate mineral that is formed by the alteration of biotite and iron-bearing phlogopite. The mineral has significant thermal insulation, heat resistance, and acoustic insulation properties, and is used in the construction industry. The mineral also has uses as a filler, as refractory material, and in horticulture.

The total reported production of vermiculite from the Southern Cross – Esperance Region is 3632 t. The two main deposits are at Young River and Heany Find (Plate 1).

Young River

The last reported production of vermiculite in Western Australia was 308 t mined in 1992 from the Young River deposit, approximately 23 km northeast of Munglinup. The deposit, with a total reported production of 1237 t, is hosted in actinolite–anthophyllite schist. The vermiculite, which developed as a result of metasomatic alteration of actinolite, is in thick, impersistent seams (Thom et al., 1977; Fetherston and Brown, 1990; Minerals Gazette, 1991).

Heany Find

Approximately 2395 t of vermiculite have been extracted from a small pit on the shore of a salt lake that is 2 km south of Heany Find, 7 km south-southeast of Yellowdine (Gee, 1982).

Silica

There has been no reported production of silica sand or other silica resources from the Southern Cross – Esperance Region, although a large deposit of silica sand is known within the Albany Shire. The deposit is at Mindijup, 40 km northeast of Albany, outside the study area, and is estimated to contain more than 20 Mt of silica sand. Cainozoic sand formations found in the Albany region extend onto Bremer Bay within the study area, and the potential for discoveries of large deposits within the region is considered high.

Other main occurrences of silica sand known in the Southern Cross – Esperance Region are at Marbellup Hill and Lake Seabrook (Plate 1). A quartz vein 10 km north of Yellowdine is considered to be of adequate quality for use as silica raw material (Abeysinghe, in prep.).

Marbellup Hill (Esperance)

During 1991–92 an area near Marbellup Hill, about 25 km southeast of Esperance, was investigated as a possible source of glass-grade silica sand. Silica sands in this locality form part of the coastal eolianites. Auger drilling, heavy mineral investigation, and chemical analysis of the sands established that some of the sands had commercial viability as silica sand of export quality (Menzel, 1993).

Lake Seabrook

In 1971, Barrier Exploration NL surveyed the silica resources at a quartz blow known as 'Quartz Hill' near Lake Seabrook. The pre-resource mineralization was estimated at about 16.3 Mt (Morton, 1972). A planned drilling program to determine the overall size of the quartz deposit and a follow-up feasibility study were not carried out. The main exploration program was for ultramafic-hosted nickel–copper sulfides and gold in an Archaean sequence of serpentinized ultramafic rocks, metabasalt, and metasedimentary units.

Talc

The main talc occurrence in the Southern Cross – Esperance Region is at Kundip, but minor localities are also at Bullfinch, Southern Cross, and Bremer Bay (Abeysinghe, 1996). Locations are shown on Plate 1. None of the occurrences has been mined.

Kundip

A number of drillholes in Proterozoic rocks in the Kundip area intersected talc at varying depths to 45 m below the surface. Talc layers are present within kaolinitic and sericitic sedimentary rocks, and metasedimentary rocks, including phyllites. The talc is locally associated with thin dolomitic horizons. In this area, the phyllites are deformed and altered to white and pale green kaolin–sericite–quartz assemblages that contain talc-rich horizons.

Talc at Kundip is white to pale brown with a trace of very fine grained quartz, tourmaline, and opaque minerals. Chemical analyses and XRD studies indicate that some samples are close to typical talc composition with quartz, kaolin, and oxides of iron as impurities. Preliminary tests indicate that Kundip talc meets the requirements of the ceramic, paper filling, and plastics industries (Abeysinghe, 1996).

Fluorite

The main fluorite occurrence in the Southern Cross – Esperance Region is at Lake Seabrook, where fluorite and scheelite are associated with quartz veining in a shear zone. Minor occurrences of fluorite related to granitoid intrusion are found at Mount Norcott and Mount Ridley. Locations are shown on Plate 1. None of the occurrences has been mined.

Lake Seabrook

Scheelite and fluorite mineralization in sheared ultramafic rocks is known at the Lake Seabrook prospect, 58 km north-northeast of Southern Cross and 10 km southeast of Koolyanobbing. The prospect was initially pegged by the Morton family in 1967, under a prospecting agreement with Metals Exploration NL. Subsequent exploration work was concentrated in areas considered to be favourable for base metals and gold. Geophysical work and geological mapping on the prospect indicated some fluorite and copper mineralization, which was considered to be typical of a late-stage pneumatolytic origin (Abeysinghe and Fetherston, 1997).

The explored area is adjacent to a northwest-trending 'crushed zone' between Archaean granitoid and gneiss to the west and a sequence of Archaean amphibolites, intermediate to felsic volcanic rocks and tuff, and banded-iron formation to the east (Morton, 1975). The sequence has an easterly dip of 50 to 70°. There is widespread development of talc schist at the contact zone with the alteration of tremolite–actinolite rocks (Morton, 1976). A quartz vein about 1.6 km long and 100 m wide occupies the 'crushed zone', and at the southern end of this zone is a wedge of sheared and chloritic, mineralized ultramafic rock having a width of approximately 25 m. Scheelite mineralization is evident in costeans spreading over a distance of more than 3 km in this 'crushed zone', and is hosted mainly in biotite schist. The fluorite is a fine powder. Some samples collected from the costeans contain more than 6% CaF_2 and are associated with anomalous scheelite (average 0.18% WO_3). Quartz veins along the southern contact of the crushed zone are of variable length up to 150 m, and width up to 15 m, and contain malachite, azurite, chalcocite, an earthy bismuth mineral, beryl, topaz, and powellite.

Exploration work did not reveal any economically viable fluorite or tungsten mineralization (Abeysinghe and Fetherston, 1997).

Mount Norcott

Pink granitoid collected from an outcrop approximately 23 km north-northeast of Norseman and close to Mount Norcott contains 0.13% fluorine. The constituent minerals of the rock are albite, quartz, and microcline, with minor hornblende, epidote, biotite, apatite, magnetite, calcite, sphene, fluorite, limonite, and kaolin. In thin section the fluorite is seen as small colourless interstitial grains (Abeysinghe and Fetherston, 1997).

Mount Ridley

Granitoid at Mount Ridley, about 70 km north-northeast of Esperance, contains fluorite as an accessory mineral. The locality has low development potential (Abeysinghe and Fetherston, 1997).

Kyanite

Kyanite is found in impure quartzite and alumina-rich Proterozoic sedimentary rocks at East Mount Barren, about 40 km south-southwest of Ravensthorpe (Thom et al., 1977). Kyanite is also found, in bands up to 5 cm wide, in metamorphosed aluminium-rich Proterozoic sedimentary rocks at West Beach, 8 km west of East Mount Barren. Both occurrences are named Fitzgerald River National Park on Plate 1 and are considered too small to have potential for commercial development.

Pyrite and pyrrhotite

During the period from 1942 to 1968 Norseman Gold Mines NL produced pyrite at Iron King mine, about 5 km south-southeast of Norseman. Pyrite is hosted by the Holstein Jaspilite and Iron King Members of the Archaean Noganyer Formation. Pyrite was used as a source of sulfur, and total production was 2.3 Mt of ore that yielded 481 507 t of sulfur (Doepel, 1973).

Massive pyrrhotite at Mount Caudan has, in the past, been seen as a possible source of sulfur (Gee, 1982), but there has been no production.

Jarosite

In 1947 a small quantity (9.7 t) of jarosite (hydrous sulfate of potassium and iron) was produced from Cordingup Creek, 4 km southeast of Ravensthorpe (Thom et al., 1977). This was used as a source of potash for fertilizer. Simpson (1951) stated that the jarosite is found as ill-defined veins and impregnations in kaolinized metasedimentary rocks on the south slope of the Cordingup Gap.

Chapter 10

Construction materials and dimension stone

Construction materials

A variety of rock types and alluvial and colluvial material throughout the Southern Cross – Esperance Region are suitable for use as construction material. However, the only reported production of construction material during 1999 within this region is 3406 t of sand reported from the Yilgarn LGA. Most production of these materials is on private land, and is exempt from the reporting requirements of the Mining Act.

Most of the known construction material operations in the Southern Cross – Esperance Region are found close to the population centres. Below is a summary of the availability of construction material, grouped by 1:250 000 geological series maps. Spongolite, on the basis of end-use, may be classified both as an industrial mineral and as a construction material.

Ravensthorpe

Crushed dolerite and granodiorite from a number of localities has been used for road surfacing, railway and bridge embankments, and concrete. Unknown quantities of gravel, sand, limestone, clay, and earthfill have been used for road foundations and surfacing from localities close to centres such as Ravensthorpe. Proterozoic quartzite in the Mount Barren Ranges may be suitable for aggregate material.

Newdegate

Spongolite from many localities in the southern portion of the sheet has been quarried for use as construction material. For example, it has been quarried 4 km northwest of Red Park, near Twertup Creek, for building and local use, and also from 22 km southwest of Ravensthorpe, near the eastern border of Newdegate (Thom et al., 1984b).

Jackson

Construction material, presumably aggregate, is obtained from fine- to medium-grained, even-grained granitoid in the areas south of Koolyanobbing. Current production details are not available.

Sand is quarried from Quaternary eolian sand formations in the area around Lake Deborah East. Sand has also been extracted in the past from Quaternary sand formations south of Lake Baladjie, but there is no reported production (Chin and Smith, 1983).

Hyden

Sand is extracted from the sandplains east of Hyden. Production data are not available.

Norseman

Sand is found in the area around Lake Cowan, approximately 5 km north of Norseman town. Construction material has also been extracted from Cainozoic sand and gravel beds in the area east of Salmon Gums (Doepel, 1973).

Esperance

Unweathered granitic rocks, which are exposed close to Esperance and the railway line, could become a source of rock for concrete, road metal, railway ballast, and armourstone (Morgan and Peers, 1973). Sand and construction material is currently extracted from leases about 3 km north of Esperance. Production data are not available. Also, quarry operations are conducted on private land by the Esperance Port Authority (1 km southeast of Esperance) and Readymix (6 km north of Esperance).

Dimension stone

Many varieties of granite, gneiss, and mafic rocks in the Southern Cross – Esperance Region are suitable for the production of dimension stone. At present, dimension stone is quarried at Fraser Range, Esperance, and Karlgarin (Plate 1). The total historical reported production of dimension stone from the region amounts to 5729 t valued at $1.5 million. In 1999, the reported production from the region was 3886 t of granite valued at $784 280, representing about 85% of the value of the granite dimension stone produced in Western Australia (Table 1).

Fraser Range

Fraser Range Holdings Ltd* produces 'Verde Austral' from an epidote–pyroxene–magnetite augen gneiss at Mount Malcolm in the Fraser Range, approximately 100 km east of Norseman. Production began in mid-1992 and 'Verde Austral' has been transported to Sydney for use in buildings such as the Governor Phillip Tower and Governor Macquarie Tower (Winter, 1994). The 'Verde Austral' is deep olive green, and its quarrying is easier than for the other rock types, such as dolerite, in the area. Another product is 'Garnet Ice', from gneissic granite approximately 85 km east of Norseman. Polished 'Garnet Ice' is predominantly white, with spots of black biotite and red garnet. Another potential product is known as 'Gold Leaf Black', from gabbro found approximately 120 km east of Norseman. 'Gold Leaf Black' is a black micro-gabbro, which, when polished, displays gold-coloured reflections. This rock is considered to be relatively difficult to quarry (Minerals Gazette, 1993).

The augen gneiss 'Verde Austral' was specified by the Sydney City Council as one of the three materials to be used in the upgrading of public areas for the 2000 Olympic Games (Department of Resources Development, 1999). Fraser Range Holdings also produces tiles and pavers.

Esperance

Granite dimension stone, known commercially as 'Desert Brown', is medium to coarse grained, porphyritic, and reddish-brown, and can be highly polished. The most abundant minerals are potash feldspar and quartz, with significant plagioclase and biotite. 'Desert Brown' is considered potentially suitable for all applications of dimension stone from monuments to large-scale building projects. Major buildings using 'Desert Brown' for cladding include the ANZ World Headquarters in Melbourne, Westpac's Martin Place Branch in Sydney, and the Dhana Siam Project in Bangkok (Department of Resources Development, 1999).

Karlgarin

At Karlgarin, approximately 280 km east of Perth and 2 km east of Karlgarin townsite, dimension stone is produced from porphyritic, medium-grained, dark red to brown granite. The granite, known as 'Karlgarin Granite', polishes to a pink and black mottled rock. 'Karlgarin Granite' has been used for buildings in Perth.

Dimension stone potential

The numerous varieties of granite, gneiss, and mafic rocks in many localities in the Southern Cross – Esperance Region are a good source of dimension stone. Both the Esperance and Fraser Range operations are using granite and metamorphic rocks of the Albany–Fraser Orogen, which appears to contain particularly diverse rock types.

* Since this report was first compiled, fresh developments at Fraser Range include new owners of these deposits and potentially new directions for the mining operations.

Chapter 11

Gem and semi-precious stones

The only semi-precious minerals and stones that have been mined within the Southern Cross – Esperance Region are chalcedony and rubellite, but the last recorded production was in 1969 and the sites are now mainly of interest to fossickers. Diamonds have been explored for within the Southern Cross – Esperance Region, but no diamonds, kimberlite, or lamproite were found.

Chalcedony

Small quantities of chalcedony have been mined (28 t during the period from 1967 to 1969) from a series of small workings immediately south of the Tjirntu Para Para Mission, about 10 km northwest of Norseman. The chalcedony was found in the weathered zone overlying ultramafic rocks (Doepel, 1973).

Rubellite

Rubellite, which is a pink tourmaline, is known in a pegmatite at Bounty, 75 km southeast of Marvel Loch (Townsend, 1994), but has apparently not been produced commercially.

Chapter 12

Mineral potential

The mineral potential of the region has been assessed using the criteria of mineral deposit types, and the geological environments and processes believed to exist within the area. The general methodology used was developed by the United States Geological Survey (USGS), and is described in detail by Taylor and Steven (1983), Marsh et al. (1984), and Dewitt et al. (1986). The following outline of the methodology is based on Bureau of Resource Sciences and GSWA (1998).

Methodology

An assessment of the potential mineral resources of a region combines the knowledge of a region's geology, geophysics, geochemistry, and mineral deposits and occurrences with the current theories of mineral deposit genesis and results of mineral exploration. The assessment process requires a study of available geoscientific data — on a regional or local scale as required — to determine the history of geological processes and environments. Geological environments identified to have characteristics known to be associated with each specific type of mineral deposit are rated according to their likelihood of containing economic deposits of that particular style of mineralization.

The mineral deposit models of various mineralization styles that are used in this regional assessment are based on those published by Cox and Singer (1986). Although the Southern Cross – Esperance Region is considered to have potential for at least twenty different types of mineral deposits, time constraints restricted this assessment to the ten styles of mineralization that are considered to be the most significant in the area. The assessment criteria for each style of mineralization are included as Appendix 2, and the ten styles are listed below.

- Orogenic (or vein-type) gold
- Iron ore
- Nickel (with copper and cobalt) associated with komatiite
- Nickel–copper in layered mafic intrusives
- Lateritic nickel–cobalt
- Base metals related to volcanic rocks
- Stratabound base metals in sedimentary rocks
- Heavy mineral sands
- Lignite
- Diamond-bearing kimberlite or lamproite.

The appraisal process involved firstly identifying 'tracts' having similar geological and/or geophysical characteristics, then deciding which tracts were likely to contain a particular style of mineralization. This potential was rated as high (H), moderate (M), low (L), no potential (N), and unknown potential (U), based upon the professional judgement of a panel of geoscientists comprising GSWA staff and external consultants (see **Acknowledgements**). To reflect the differing amount of information available, the assessment was also categorized according to the levels of certainty to which the geological features of each tract were known in relation to the particular style of mineralization. These ratings ranged from high certainty (D) for tracts within the region already known to contain deposits of the type under consideration, through good (C) where the geology is well known and similar to that hosting deposits of the requisite type elsewhere in the world, to adequate (B) where available data suggest, but cannot be confirmed, that a particular type of deposit may occur, to (A) unknown potential. Detailed definitions of the different levels of resource potential and levels of certainty together with a diagram showing the relationship between resource potential and certainty are included in Appendix 3.

The results of the appraisal process were compiled on ten thematic maps (Figs 21 to 30) showing tracts that are prospective for each of the ten styles of mineral deposit, and shaded according to their rated mineral potential and degree of confidence in that assessment. To produce the single composite map of the region for all mineralization styles (Fig. 31), the results for each mineralization style were weighted by factors based on the perceived importance of the type of deposit to the Region's economy. The numerical values used are shown in the relationship diagram in Appendix 3, and the weighting factors for each deposit type are included in Appendix 2. A computer-generated grid was then placed over the maps, and the weighted numerical values for each deposit type, at each grid intersection point were summed. This produces a semi-quantitative estimate of the total prospectivity of the region for the ten styles of mineralization considered (Fig. 31).

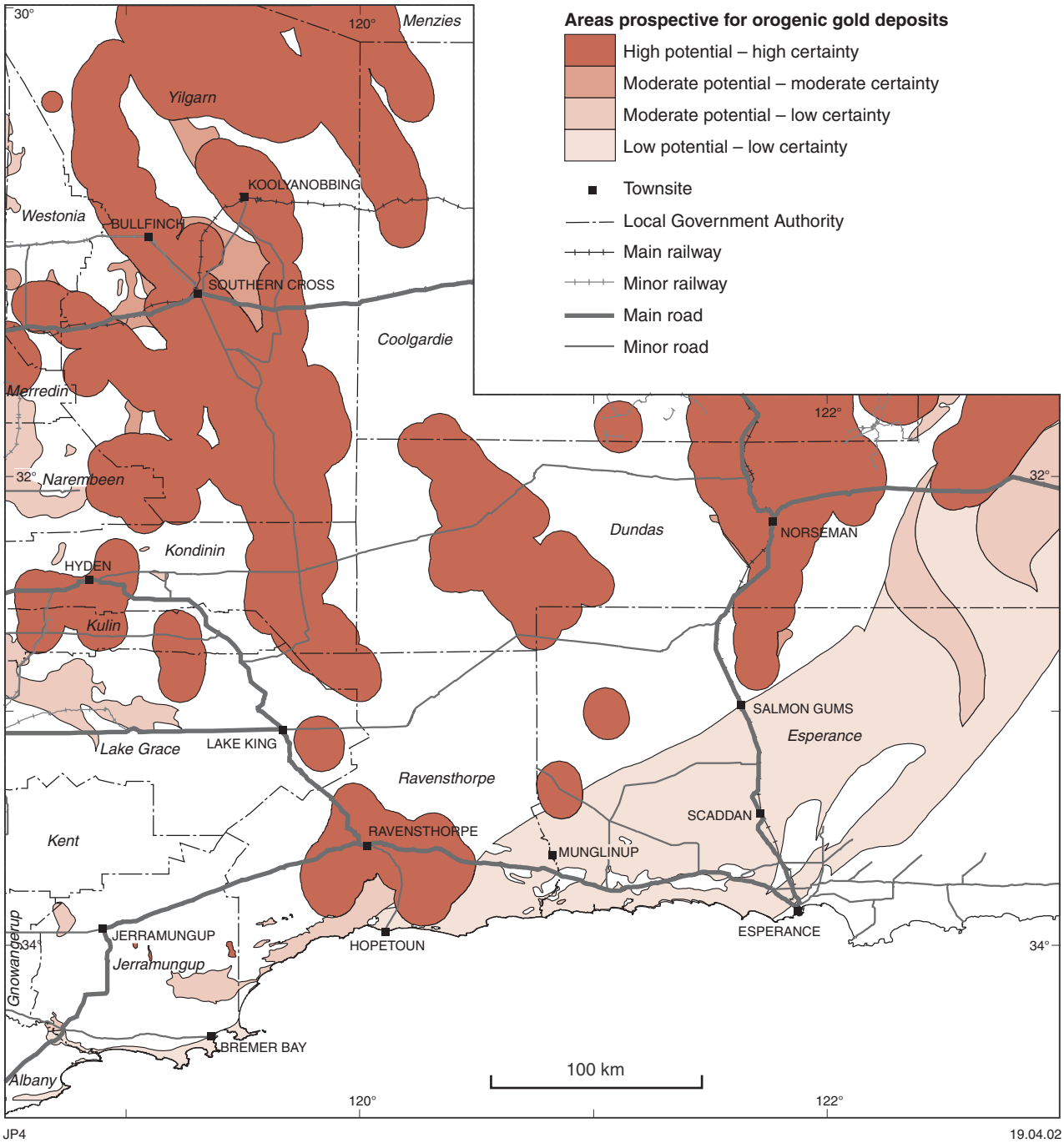

Figure 21. Areas prospective for orogenic gold deposits in the Southern Cross – Esperance Region

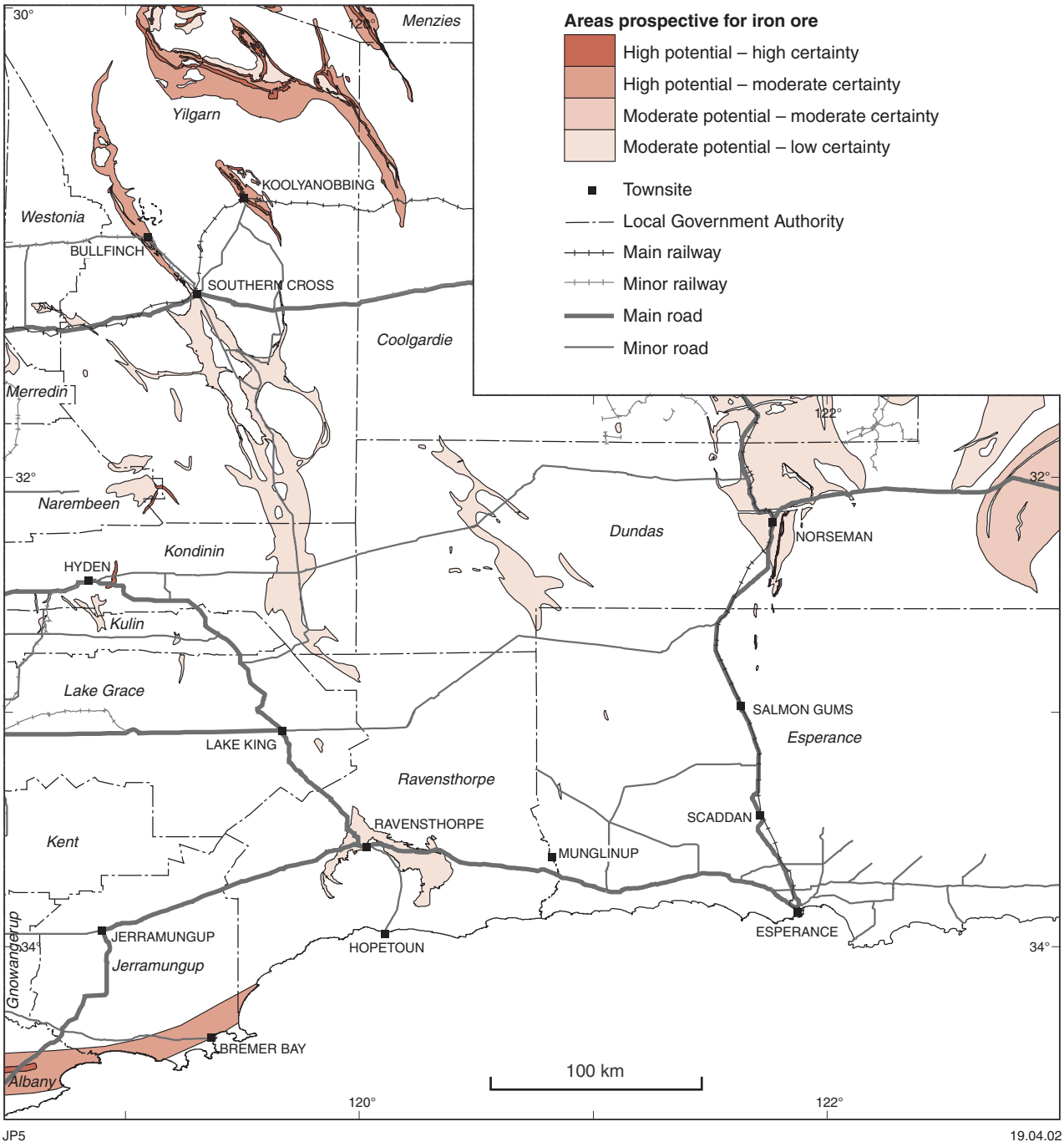

Figure 22. Areas prospective for iron ore in the Southern Cross – Esperance Region

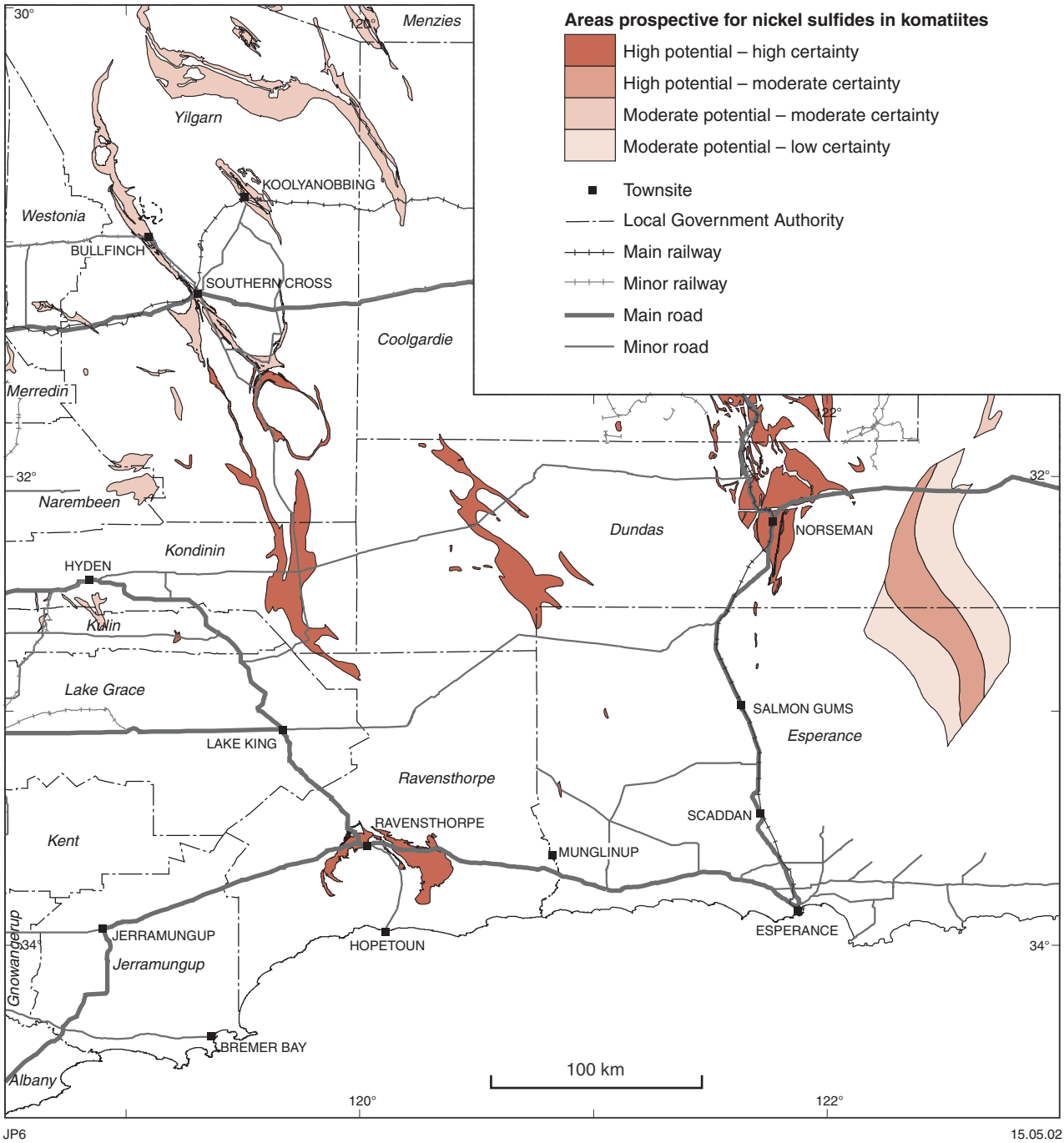

Figure 23. Areas prospective for nickel sulfides in komatiites in the Southern Cross – Esperance Region

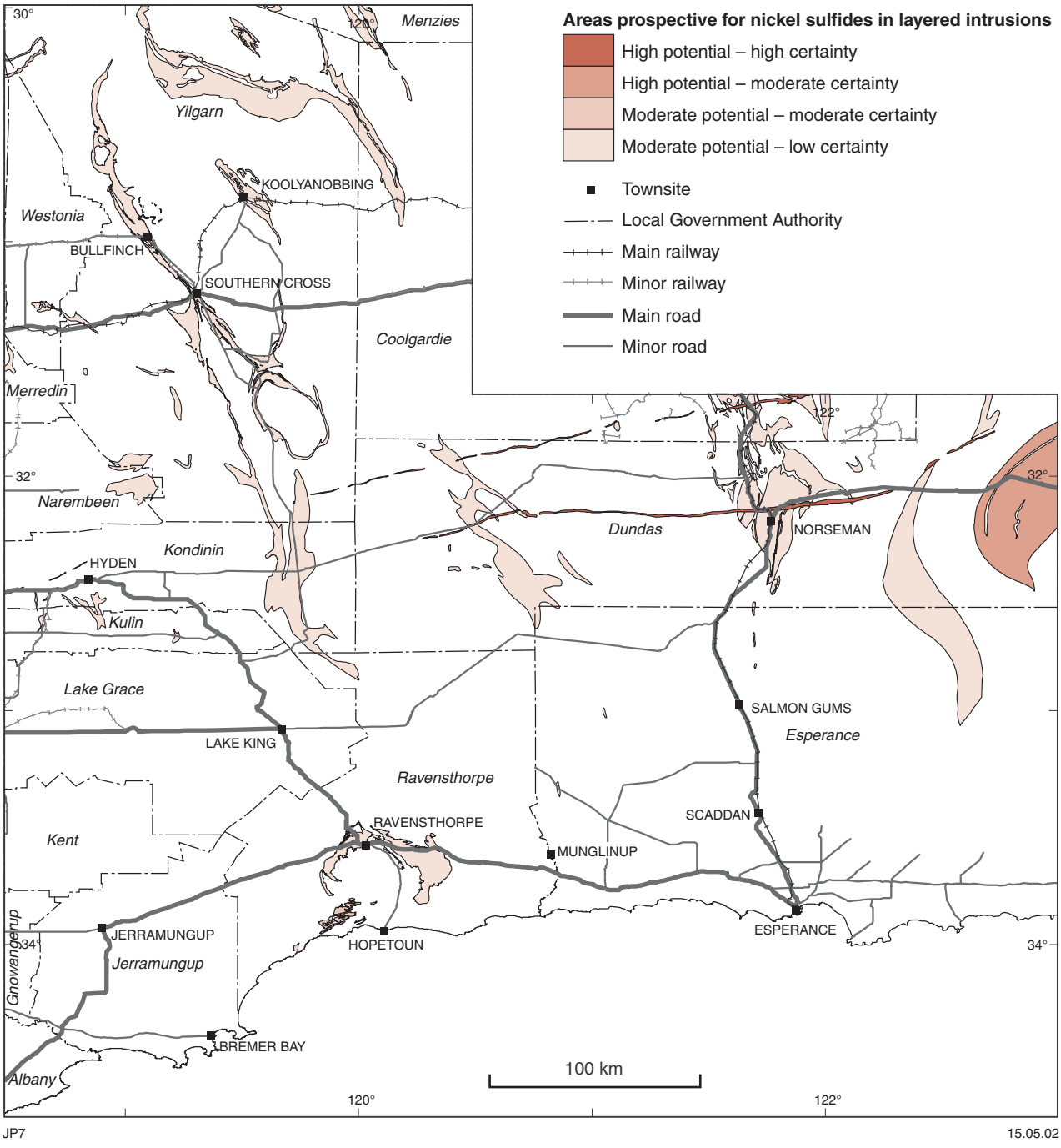

Figure 24. Areas prospective for nickel sulfides in layered intrusions in the Southern Cross – Esperance Region

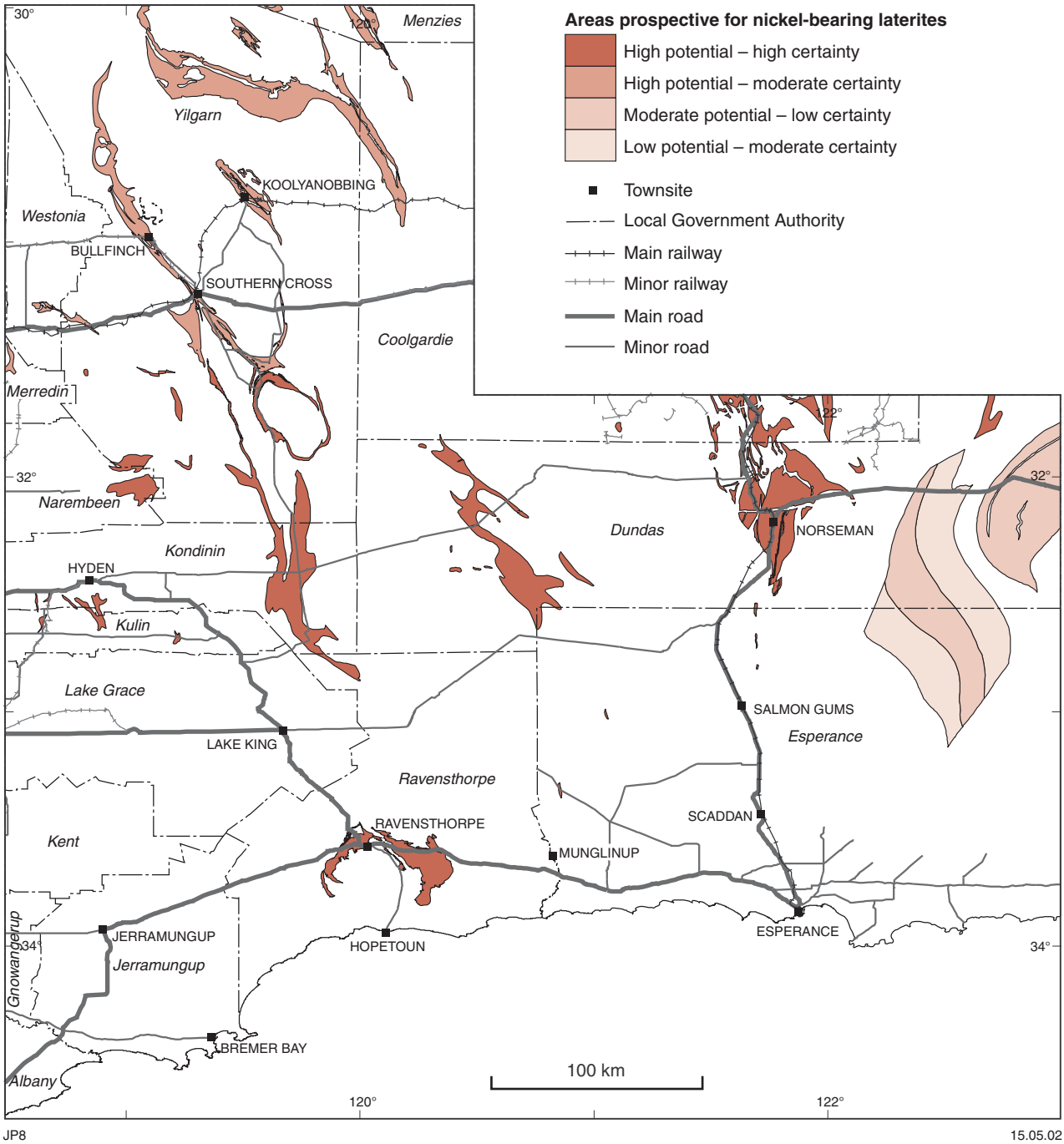

Figure 25. Areas prospective for nickel-bearing laterites in the Southern Cross – Esperance Region

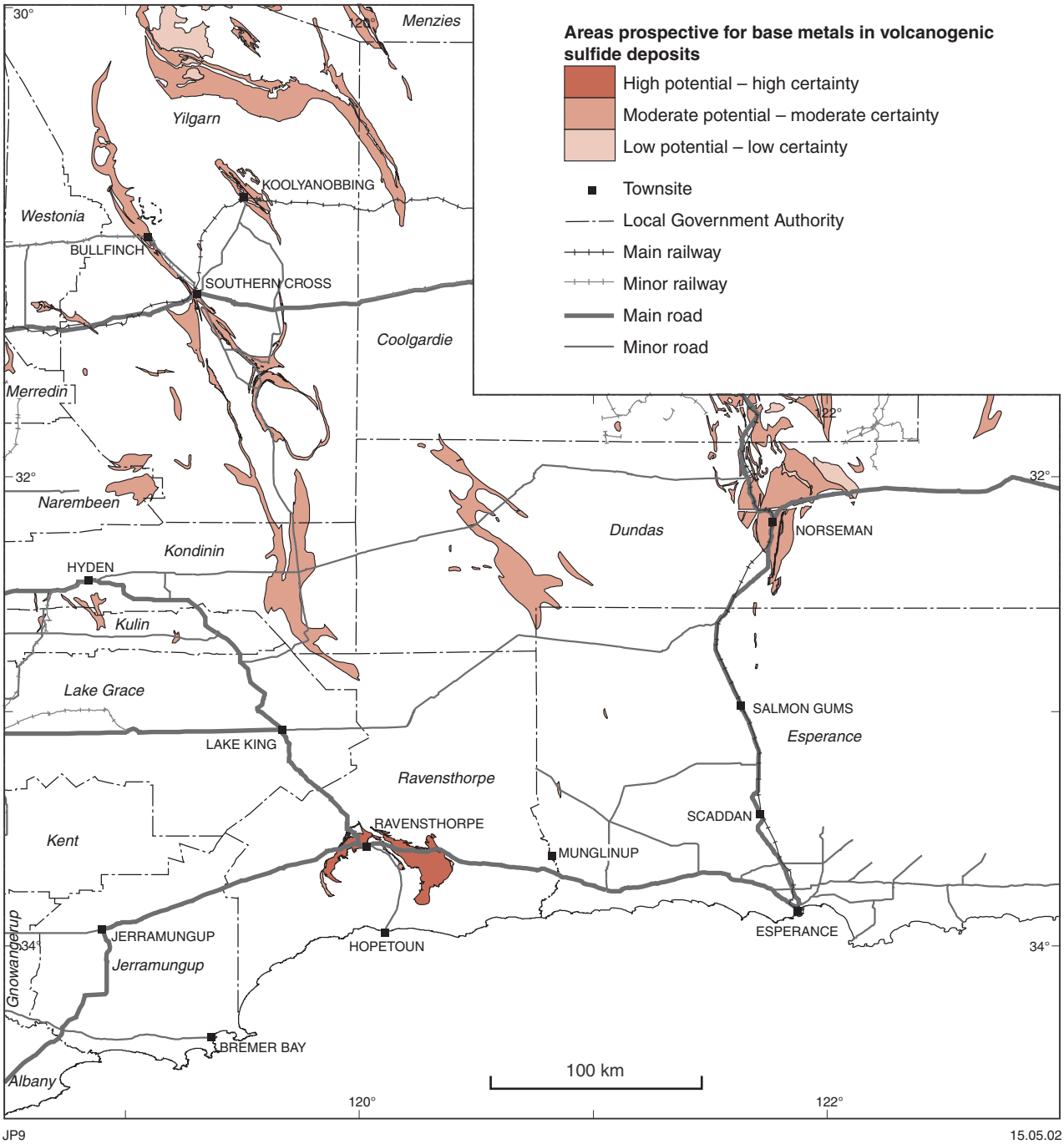

Figure 26. Areas prospective for base metals in volcanogenic massive sulfide deposits in the Southern Cross – Esperance Region

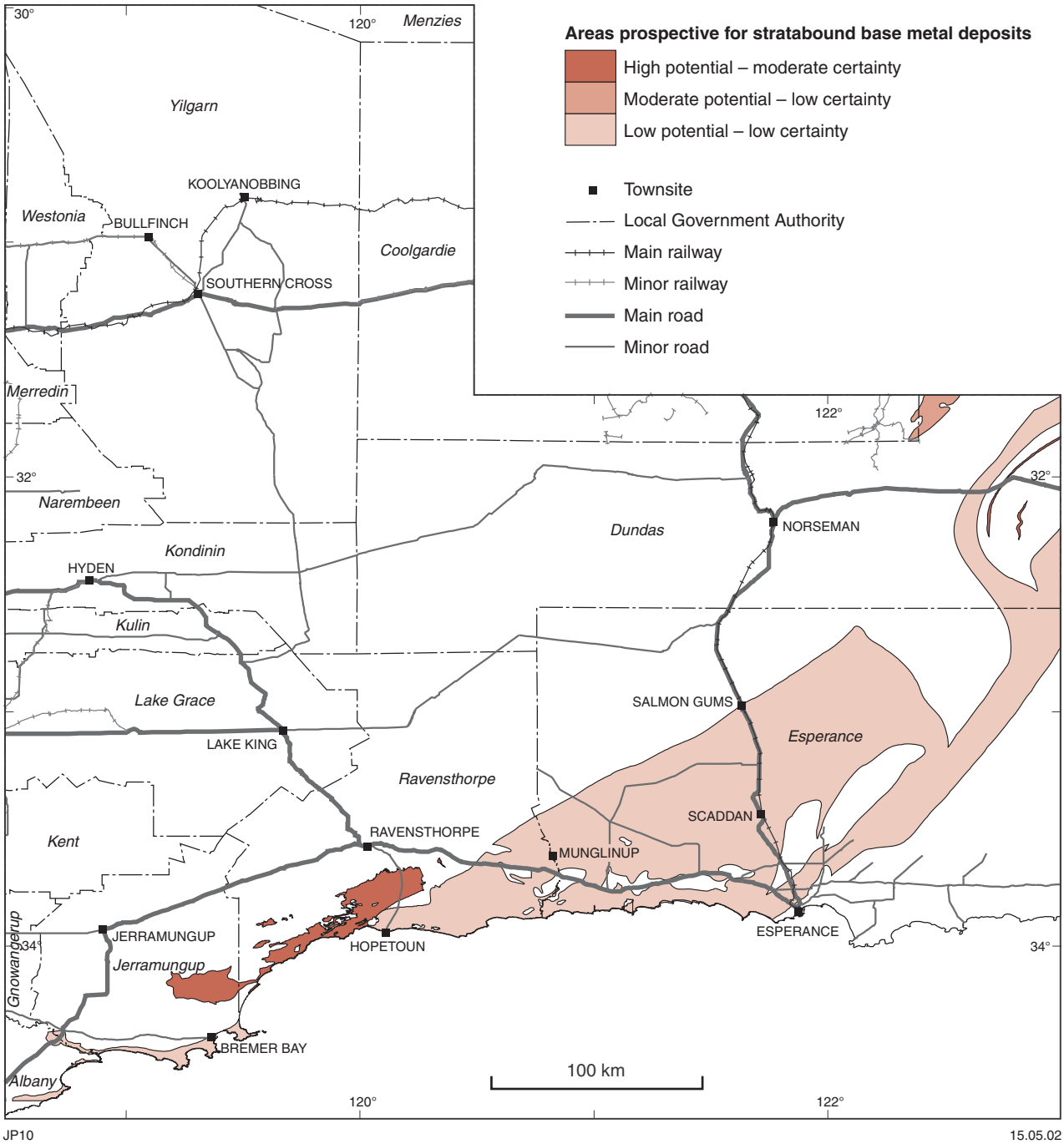

Figure 27. Areas prospective for stratabound base metal deposits in the Southern Cross – Esperance Region

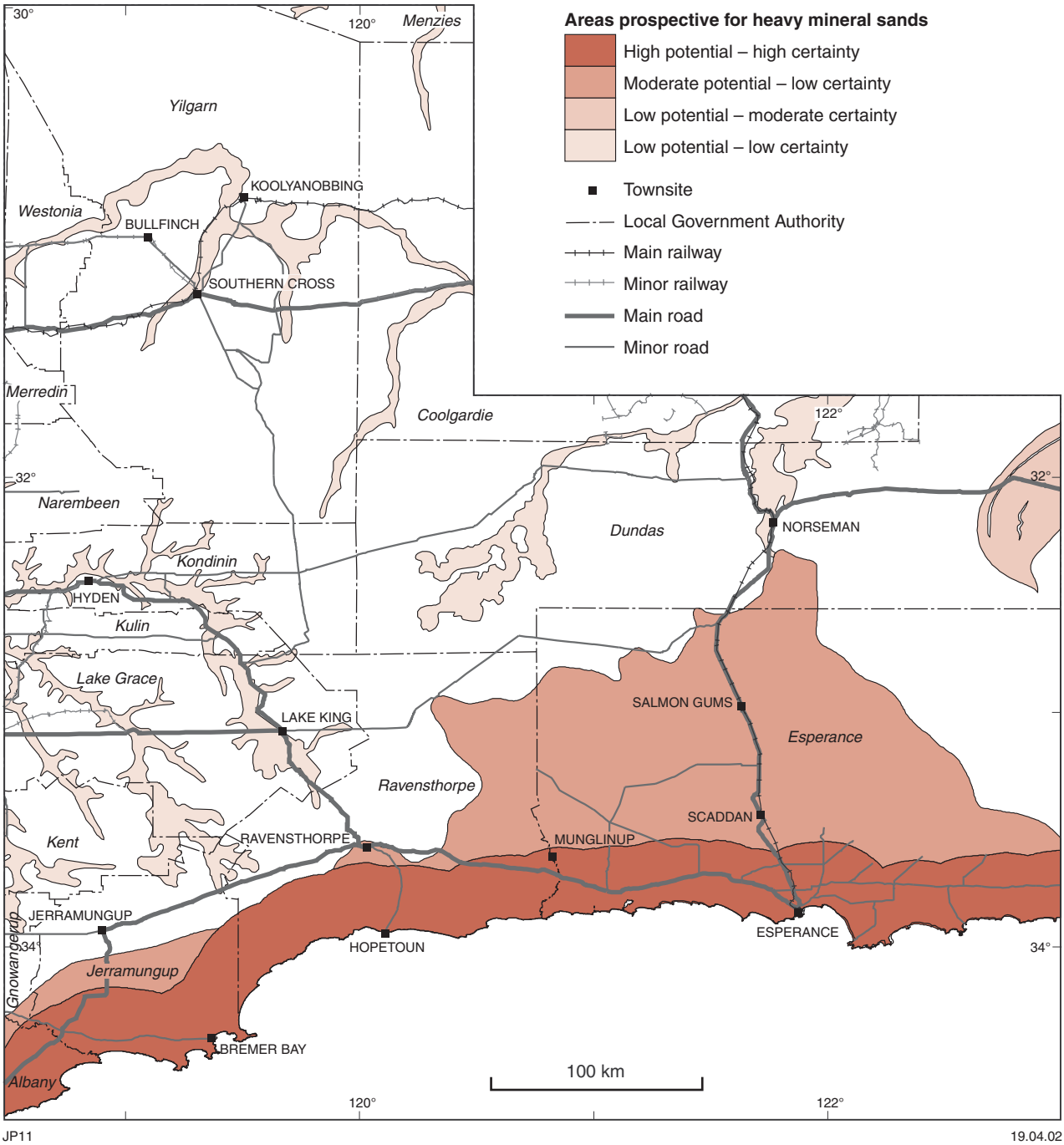

Figure 28. Areas prospective for heavy mineral sands in the Southern Cross – Esperance Region

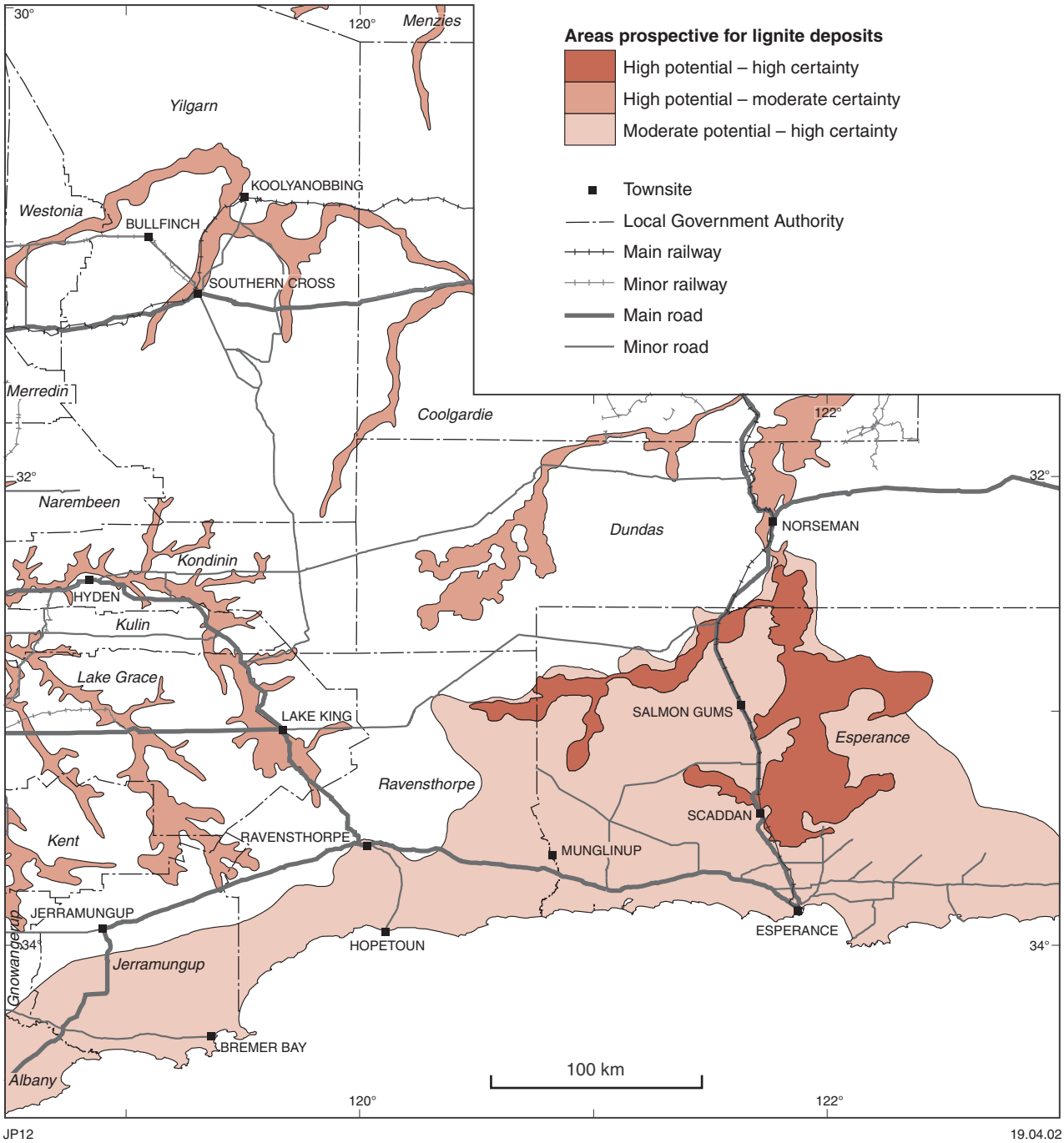

Figure 29. Areas prospective for lignite deposits in the Southern Cross – Esperance Region

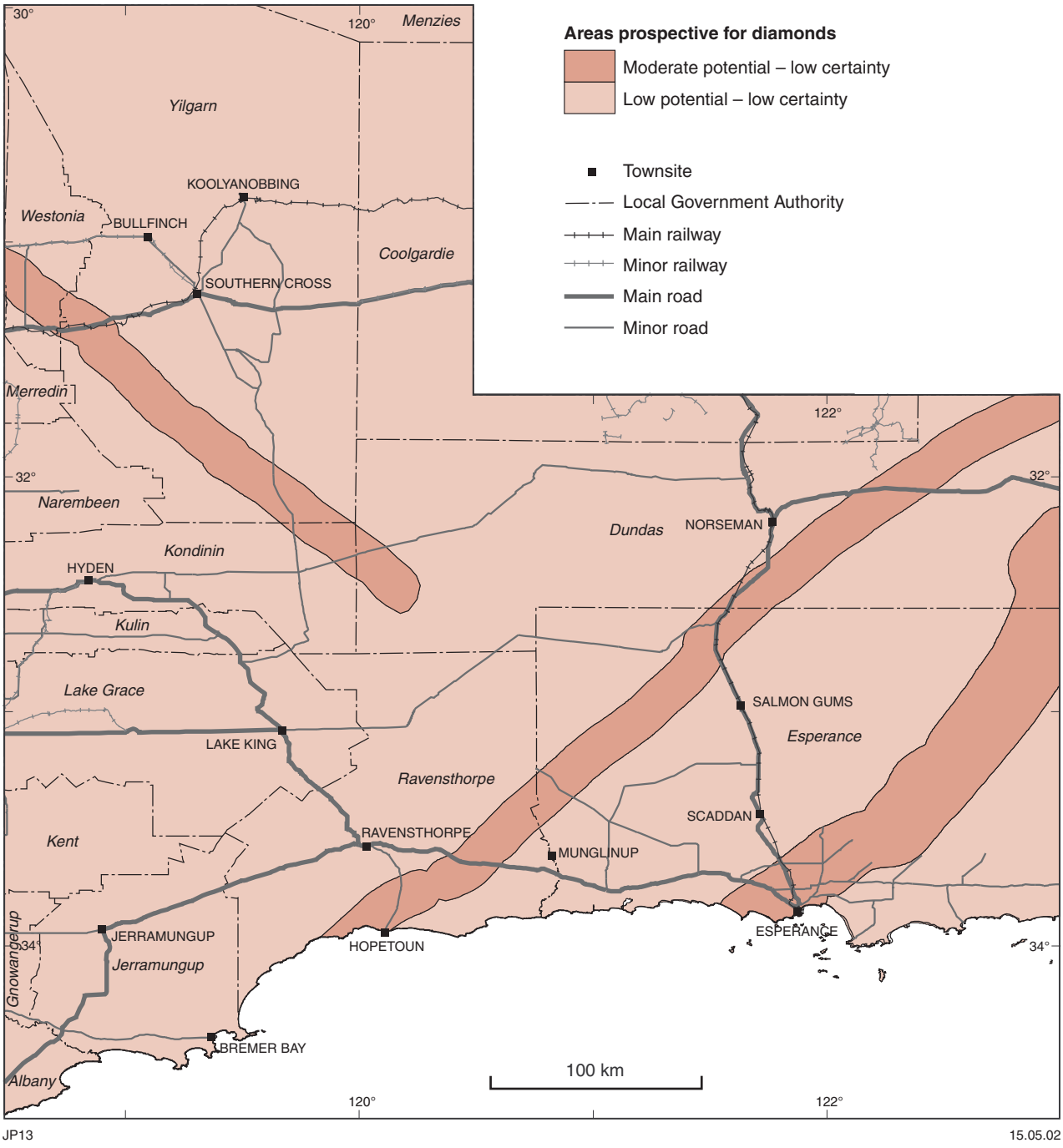

Figure 30. Areas prospective for diamonds in the Southern Cross – Esperance Region

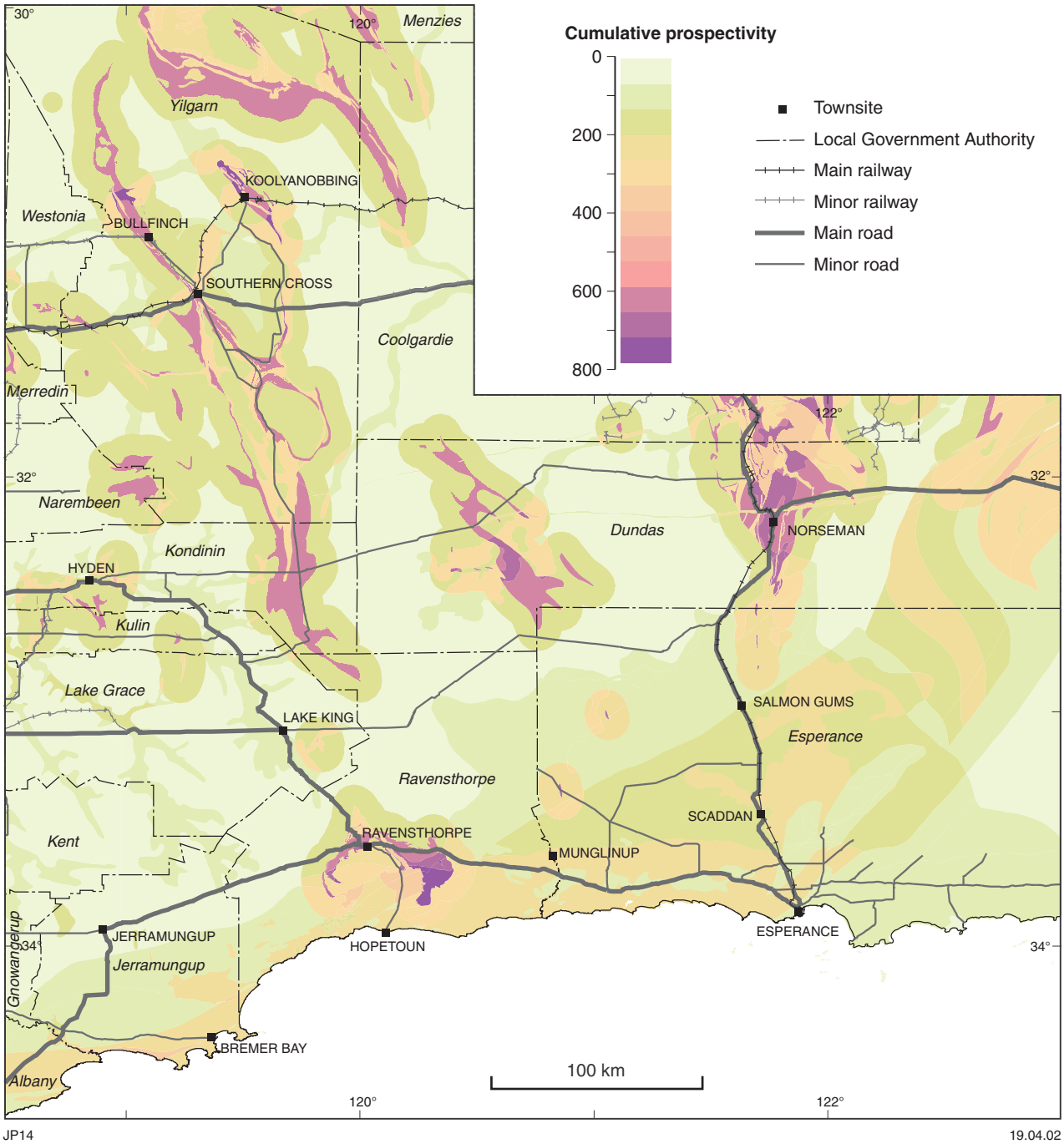

Figure 31. Cumulative prospectivity for the Southern Cross – Esperance Region

Assessment results

A brief summary of the assessment of the mineral potential of the Southern Cross – Esperance Region for each mineralization type is given below.

Orogenic gold: Greenstone belts, with their associated metasedimentary rocks and adjacent granitoids, were given the highest rating for gold-bearing veins, together with buffer zones around major faults and some isolated gold occurrences in granitoid. Lower ratings were given to areas of the Yilgarn Craton believed to contain concealed greenstones, as well as to gneisses, metasedimentary rocks, and gabbroic rocks within the Albany–Fraser Orogen (Fig. 21).

Iron ore: The highest ratings for both mineral potential and confidence were given to units of banded iron-formation that are thick enough to be shown individually within greenstone belts; a similar high rating was given to a magnetic anomaly associated with the Southdown magnetite deposit. Greenstone belts in general were also rated as having potential because of the known presence of thinner BIFs that are not shown on geological maps, although the assessment panel considered that greenstones north of Southern Cross had a higher rating than those elsewhere. The Fraser Complex was also considered to be prospective for iron ore, both on account of reports of BIF within sedimentary units, and the presence of magnetite bands in layered gabbro (Fig. 22).

Nickel sulfides in komatiites: The panel gave the highest ratings to greenstone belts known to contain this type of deposit, with high probabilities but at a lower confidence level given to other greenstones. An extension of the Yilgarn Craton into the Albany–Fraser Orogen was given a lower rating on the basis of reports that it contained greenstones that are concealed (Fig. 23).

Nickel sulfides in layered mafic intrusions: The only deposit of this type in the Region is in a Proterozoic easterly trending dyke, so intrusives of this type were given the highest rating. A high prospectivity, although at a lower confidence level, was also attributed to the Fraser Complex known to consist largely of layered intrusions. Greenstone belts, a dolerite sill in the Mount Barren Group, and a strong magnetic anomaly in the northwest of the Region were rated as having moderate potential (Fig. 24).

Nickel-bearing laterites: The most prospective tracts for this style of mineralization are greenstone belts containing appreciable proportions of komatiite and gabbro. Geological maps indicate that these rocks are more abundant south of the Parker Dome than north of it, so the more southerly belts were given a higher confidence rating. The Fraser Complex and areas believed to contain concealed greenstones were given ratings at correspondingly lower levels of prospectivity and confidence (Fig. 25).

Base metals in volcanogenic massive sulfide deposits: The only occurrences of this style of mineralization known in the Region are in the Ravensthorpe greenstone belt, which was accordingly given the highest rating. Other greenstone belts containing bimodal volcanic assemblages were considered to be the next most prospective tracts, whereas areas dominated by felsic volcanic rocks alone were assigned as having low mineral potential (Fig. 26).

Stratabound base metal deposits: Deposits of this type are important sources of base metals in other parts of Australia (e.g. Broken Hill, Mount Isa) and are typically found in Proterozoic sedimentary or metasedimentary successions. Rocks of appropriate ages and types are found within the Albany–Fraser Orogen, with the Mount Barren Group considered to be the most prospective tract following the recently discovered Trilogy deposit and some earlier geochemical work (Fig. 27).

Heavy mineral sands: Concentrations of heavy minerals are known at several localities along the coast, or in drainage channels near the coast. Accordingly, the highest rating was given to the coastal strip. The Bremer Basin was considered to have moderate potential because of some known occurrences and geological analogies with other areas, whereas the Fraser Complex and Cainozoic drainage channels were assessed to have low potential (Fig. 28).

Lignite: Lignite is known in Cainozoic drainage channels within the Region, so all of these features were given a high prospectivity rating, with the highest confidence level being assigned to those channels in which resources have been defined. Occurrences are also known in marine or estuarine sedimentary rocks in the Bremer Basin, but because of the comparatively low quality and small extent of these, the basin was given only a moderate level of prospectivity for hosting economic deposits (Fig. 29).

Diamonds: Although no diamonds or diamond indicator minerals have been reported from the Region, the panel considered that the requisite geological features of thick, stable crust and major fracture zones were present, and that there was some potential for the discovery of diamond-bearing kimberlite or lamproite. Given the nature of diamond pipes, the whole Region was considered to have at least some potential, with the more prospective tracts being situated close to major crustal fractures (Fig. 30).

Summary

This Record is a first-pass study of the geology, mineral resources, and mineral potential of the Southern Cross – Esperance Region. The study concentrates on several broad areas: interpretation of the geology at 1:500 000 scale (but presented at 1:1 000 000 scale); collation of data on mineral occurrences and deposits; review of the controls to mineralization; and a brief assessment of the mineral potential for major deposit types.

The minerals sector provides significant revenue for the region and, in 1999, mining in the study area of the Southern Cross – Esperance Region was worth about $388 million, of which the gold sector alone represents 71.2% of the total. Commodities currently mined in the Southern Cross – Esperance Region (in alphabetical order and with the percentage of the State's total production by value for 1999) are granite dimension stone (85.5%), dolomite (100%), gold (9.5%), gypsum (2.7%), iron ore (0.8%), limesand and limestone (15.7%), nickel (7.2%), salt (2.9%), and sand (0.2%). In recent years, exploration and mining expenditure within the study area has averaged about $170 million per year, but this figure does include mining production costs. Exploration expenditure data are not available separately, but exploration for gold in the Southern Cross – Esperance Region during 2000 is estimated to be about 9–10% of the value of 1999 production, that is, about $25 million.

Current gold mining projects (listed in order of production) are Marvel Loch – Southern Cross, Cornishman, Central Norseman, Yilgarn Star, Bounty, and Copperhead–Bullfinch. In 1999, the region produced 19 850 kg of gold, 9.5% of Western Australia's total production. The low gold prices in recent years have necessitated rationalization of existing operations, which has resulted in the reduction of the number of companies operating mines and exploring. Gold production in 1999 from the Southern Cross – Esperance Region decreased by 16% (3850 kg) from the previous year, and the Chalice mine ceased operations.

Total recorded production (cumulative) to the end of 1985 from the study area is 383 257 kg of gold from 102.5 Mt of ore, with an average recovered grade of 3.74 g/t Au. The majority of the gold has come from the Yilgarn Goldfield and the Norseman area. Average recovered grades vary significantly between the greenstone belts, ranging from a high of 23.7 g/t for the low-production Ravensthorpe greenstone belt to 3.04 g/t Au for the more productive Southern Cross greenstone belt.

Greenstone belts of the Southern Cross – Esperance Region exhibit a large variation in their gold productivity when viewed using historical production data and estimates of pre-mining resources. Recorded gold production varies from 68.8 kg/km^2 for the Southern Cross greenstone belt (including Holleton and Westonia), down to zero production from the Lake Johnston greenstone belt. A similar trend is evident in pre-mining resources (historical production plus existing resources of all types) — varying from 119.8 kg/km^2 for the Southern Cross greenstone belt (including Holleton and Westonia), down to zero pre-mining resources for the Lake Johnston greenstone belt. The reasons for the differences are not all geological.

Within the project area, hematitic iron ore is mined by Portman Ltd at Koolyanobbing. Total indicated and inferred resources for the Koolyanobbing deposits are estimated at 159.8 Mt at 62.24% Fe and 0.107% P. Extensive exploration is being undertaken by Portman to further define resources at the Bungalbin, Mount Jackson, and Windarling deposits. Mining from these areas is planned to commence in 2002 with production increasing by 3–4 Mt/pa over a period of 3 to 4 years. This will give the project an overall production capability of 6–7 Mt/pa by 2005–06.

Further resources have been estimated for deposits at Honman Ridge – Round Top Hill, Mount MacMahon, and Mayfield, with a sub-economic magnetite deposit at Southdown.

The recorded nickel production has come from the Forrestania deposits and Redross. Mining at Forrestania ceased during 1999, with production valued at $437 million. Pre-mining nickel sulfide resources for the Forrestania nickel deposits were 11.5 Mt of ore at an average grade of 2.0% Ni. The Redross deposit (Widgiemooltha Dome), forming part of the Kambalda project operated by WMC Ltd, was mined from 1974 to 1978 and in 1989–90, with production valued at $50 million.

Most of the nickel deposits in the region are komatiite-hosted massive nickel sulfide deposits, with Emily Ann as the only known disseminated sulfide deposit. Lateritic nickel deposits exist in the Ravensthorpe area at Bandalup (Hale Bopp, Halleys, and Shoemaker Levy) and Nindilbillup.

Tectonic Resources NL commenced mining in April 2000 at the RAV8 project at Ravensthorpe. The mine will

be both opencut and underground, have a two-year mine life, and is expected to produce 8705 t of nickel. Total reserves are 206 404 t of ore at 5.49% Ni. Recent drilling has intersected high-grade nickel mineralization outside the current pit outline, which has the potential to add as much as 50% to the current ore reserve.

Development of the Halleys nickel laterite deposit (Ravensthorpe–Bandalup project) is under consideration by BHP Billiton. Under an agreement between the previous owner Comet Resources NL and QNI Pty Ltd, the nickel and cobalt concentrate is to be shipped to QNI's Yabulu refinery in Queensland. The Ravensthorpe–Bandalup nickel project is expected to produce 35 000 t of nickel and 1300 t of cobalt per annum over a period of 20 years.

Underground mining of the Emily Ann deposit started in 2001. The project owner, LionOre, has a contract in place to sell nickel concentrate to Inco Ltd. Emily Ann is a small high-grade deposit with an estimated indicated and inferred resource of 2.1 Mt of ore grading 3.98% Ni, for 84 000 t of contained nickel. An average of 6700 tpa of nickel will be produced, with full production expected to be reached by 2002. Mining of Emily Ann increases the likelihood of mining the nearby larger, but lower grade, Maggie Hays deposit.

The coastal areas of the Southern Cross – Esperance Region have been explored for heavy mineral sands since 1940. The main target has been heavy mineral sands within beach and dune sands of the current shoreline, particularly at the outlet of present-day rivers. However, target areas along palaeoshorelines and palaeodrainage channels have also been examined. There is no reported production of heavy minerals from the region at present, but there has been minor production from Cheyne Bay. The main deposits and localities of significance are at Cheyne Bay, Gordon Inlet, Wray Bay, Condingup – Cape Arid National Park, Southern Hills, Dillon Bay, Oldfield Inlet, Margaret Cove, Stokes Inlet, Alexander River, Barker Inlet, and Kundip. None of these deposits is currently considered economic.

Most of the exploration for tungsten minerals (scheelite and wolframite) in the Yilgarn Craton was carried out during World War I. The Higginsville deposits were discovered at this time and were the first deposits in the Southern Cross – Esperance Region to be mined. Other mines for tungsten are Dallisons Reward and Hopes Hill, with a scheelite occurrence at Lake Seabrook.

Vanadium minerals are found in the Southern Cross – Esperance Region in gold mines at Holleton (vanadinite and pucherite), Westonia (pucherite and clinobisvanite), and at Ennuin, Nevoria, and Parker Range (vanadinite). Vanadium resources have only been estimated for the V–Ti Medcalf deposit in the Lake Johnston greenstone belt. In 1982, inferred resources were estimated at 16 Mt grading 0.8% V_2O_5 and 11.8% TiO_2.

Between 1966 and 1968 tin was produced at several localities near Norseman from tin-bearing lithium pegmatite dykes. Cassiterite is present in pegmatite dykes at Mount Deans, Mount Thirsty, Holleton, and Cattlin Creek. A tantalum resource in the pegmatites at Mount Deans has recently been announced.

Deposits of stratiform massive to bedded manganese oxide mineralization are found in both Archaean and Proterozoic metasedimentary rocks. There is no reported production of manganese from the area, but the Mount Chester deposit, and perhaps Elverdton as well, was mined in about 1950. Five deposits are known — Mount Chester, Elverdton, Kundip, Hamersley Gorge, and Coppermine Creek.

Three occurrences of molybdenite are known in the region — Needilup, Kumarl Siding, and Buldania. All three have low potential.

Numerous mines, deposits, and occurrences of base metals are found throughout the study region, both in rocks of the Yilgarn Craton and the Albany–Fraser Orogen, but most of the sites are in the Ravensthorpe area. Most of these deposits are vein type, with primary copper ore consisting of quartz, gold, and chalcopyrite. Many of the historical copper sites were primarily mined for gold, manganese, or iron. The last operating base metal mine in the Ravensthorpe area was Elverdton, which closed in 1971; Elverdton remains as an operating mine as the mine tailings are currently being mined for re-use as fertilizer.

There is active exploration for base metals in the region, spurred on by the discovery in 1997 of the poly-metallic sediment-hosted massive sulfide mineralization at Trilogy. Companies are also exploring for Mount Isa-style and Broken Hill-style deposits, as well as gold targets, along the southern margin of the Yilgarn Craton. Apart from Trilogy, none of the base metal deposits or prospects has reached the resource-estimation stage, and many of the tenements covering the Albany–Fraser Orogen are still in application.

Lignite deposits of Eocene age are found in the Bremer and Eucla Basins and in palaeodrainage channels on the southern Yilgarn Craton. In the Southern Cross – Esperance Region lignite is present in the Rollos Bore Formation and the Plantagenet Group. The main two deposits with developmental potential are O'Sullivan and Scaddan, with small accumulations at Fitzgerald River, Lort, and Neridup. The O'Sullivan lignite deposit is currently being assessed, with a proposal for a three-stage process of recovering kerogen and naturally occurring hydrocarbons to produce oil, in situ burning of the lignite to produce steam for power generation, and in situ bacterial oxidation of the remaining lignite to produce methane and humic acid. Obviously, any future development would be affected if there were an extension of the natural gas pipeline from either Bunbury to Esperance or from Kalgoorlie–Kambalda to Esperance.

The Southern Cross – Esperance Region of Western Australia contains a variety of industrial minerals and many of these are yet to be fully exploited. From around the late 1920s to 1999 there has been intermittent production of a number of industrial minerals from this region, but the production reported to the Department of Minerals and Energy (now MPR) in 1999 was limited to salt, gypsum, and sand, which together had a total value of $5.96 million.

There is a high potential for new industrial mineral-based projects in the Southern Cross – Esperance Region, although current production in comparison with the rest of the State is extremely small (less than 0.5% of the State's value of production of industrial minerals). Some of the industrial minerals with a promising future and known resources are magnesite, graphite, kaolin, and spongolite.

Many varieties of granite, gneiss, and mafic rocks in the Southern Cross – Esperance Region are suitable for the production of dimension stone. In recent years, dimension stone has been mined at Fraser Range ('Verde Austral'), Esperance ('Desert Brown'), and Karlgarin ('Karlgarin Granite'). The total historical production of dimension stone reported from the region amounts to 5729 t valued at $1.5 million. In 1999 the reported production from the region was 3886 t of granite valued at $0.78 million, representing about 85% of the granite dimension stone produced in Western Australia. However, production of 'Verde Austral', from an epidote–pyroxene–magnetite augen gneiss at Mount Malcolm in the Fraser Range, was scaled back in early 2000.

The only occurrences of precious minerals and semi-precious stones within the Southern Cross – Esperance Region are chalcedony and rubellite (tourmaline), with small quantities (28 t) of chalcedony mined during the period from 1967 to 1969 from northwest of Norseman. Rubellite is found in a pegmatite southeast of Marvel Loch, but has apparently not been produced commercially. Diamonds have been explored for within the Southern Cross – Esperance Region, but no diamonds, kimberlite, or lamproite have been found.

Several projects are likely to be developed or be extensively explored and evaluated within the next ten years. These are — gold in the Forrestania – Lake Cowan area and along the margin of the Yilgarn Craton; nickel in the Lake Johnston and Ravensthorpe areas; tantalum from the Norseman and Ravensthorpe areas; lignite at O'Sullivan and Scaddan in the Bremer Basin; expansion of iron ore production at Koolyanobbing; magnesite in the Bremer Basin and developed over greenstone belts; base metals in the Proterozoic Mount Barren Beds and the Albany–Fraser Orogen; gypsum; and new varieties of dimension stone.

The mineral potential for ten of the major deposit types that are known or are likely to occur within the Southern Cross – Esperance Region has been assessed.

Acknowledgements

Thanks to Wally Witt of Sons of Gwalia Ltd, Peter Collings of Portman Ltd, and John Blockley, who were members of the panel of geoscientists which assessed the mineral potential of the Southern Cross – Esperance Region. John Blockley was also involved in compiling the chapter on mineral potential.

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Appendix 1

Gazetteer of locations of mines, deposits, prospects, and occurrences in the Southern Cross – Esperance Region

Locality name	*Commodity*	*Latitude*	*Longitude*
16900 Prospect	Gold	31.3518	119.4456
Abbottshall	Gold	32.2445	121.7076
Absent Minded Beggar	Gold	32.1946	121.8142
Achilles	Gold	31.3004	119.3906
Acme	Gold	32.1868	121.8079
Ada May	Gold	30.8883	119.0262
Addie	Copper	33.6299	120.1540
Afric	Copper	33.6690	120.1877
After Years Leases	Gold	32.1990	121.7995
Agnes Reward	Gold	32.8419	119.9989
Agnes Roberts	Gold	32.3205	121.8095
Ajax	Gold	32.2012	121.8012
Ajax North	Gold	32.0499	122.0315
Albermarle	Gold	32.2916	121.8159
Albion	Gold	32.4837	121.6764
Alexander	Gold	31.4563	119.4936
Alexander Bay	Sand, silica	33.8361	122.7414
Alexander River	Heavy minerals	33.8770	122.7720
Alice	Gold	33.6665	120.2001
Alice Mary	Copper, gold	33.6580	120.1930
Alickanzer	Gold	32.2474	121.8065
Aligator	Gold	31.2766	119.3239
Alison Brown	Gold	31.2468	119.3226
All for the Best	Gold	33.5592	120.0381
All Nations GM Ltd	Gold	32.1844	121.7949
Allens Find	Gold	30.1850	119.2530
Allerton	Gold	31.2344	119.3223
Alma	Gold	32.1957	121.8133
Alpha	Gold	33.5722	119.9815
Alpha	Gold	31.6118	119.5972
Alphadar	Gold	32.2646	121.8019
Amy Castles	Gold	32.1921	121.8148
Anca	Gold	32.1898	121.7268
Andante	Gold	33.5669	120.0543
Anglo Australian & General	Gold	31.5460	119.5626
Annabelle	Gold	33.5706	120.0015
Sandalwood 2	Gold	31.4818	119.5128
Sandalwood 22	Gold	31.5095	119.5498
Ant Patricks	Copper	33.6542	120.1841
Anzac	Gold	32.2072	121.8030
Apache	Gold	31.7634	119.5990
Aphrodite	Gold	32.3676	121.7873
Aphrodites	Gold	31.7667	121.7275
Apsey South	Gold	32.0517	122.0272
Ard Patrick	Gold	33.6546	120.1837
Ardath	Gold	31.2936	119.3162
Ardpatrick	Gold	33.6551	120.1840
Artilleryman	Gold	31.2388	119.3315
Associated Mount Jackson	Gold	30.1937	119.1286
Athenia	Gold	31.1943	119.2840
Athlone	Gold	30.1189	119.1172
Athlone Reward	Gold	30.1188	119.1172
Attlee	Gold	32.2089	121.8120
Auraria	Gold	31.2477	119.3222
Aurora	Gold	30.4345	119.6414
Austral Mararoa	Gold	32.1853	121.7948
Australia	Gold	33.6691	120.1872
Australia	Gold	31.6161	119.5937
Australia United	Gold	31.1921	119.2808
Ave Maria	Gold	31.2464	119.3229
Axehandle	Gold	31.3165	119.3931
Baby Queen	Gold	30.8732	119.0336
Babylonia	Gold	31.1410	119.2092
Badaglo	Gold	31.1410	119.2092
Ballarat	Copper, gold	33.5552	120.0977
Bandalup Creek	Magnesite	33.6211	120.3154
Bandalup Hill L1	Magnesite	33.6641	120.3959
Bandalup	Magnesite	33.6098	120.3598
Bandalup N1–N5	Magnesite	33.6100	120.3598
Bandalup B4	Magnesite	33.5989	120.2598
Bandit King	Gold	32.2039	121.8137
Banker	Gold	31.5329	119.6145
Barker Inlet	Heavy minerals	33.8000	121.3333
Battler	Gold	32.2634	121.8021
Battler	Gold	31.3465	119.3906
Battler (Westonia)	Gold	31.2730	118.6272
Battlers Hill	Gold	31.8298	119.6537
Bee	Gold	31.4766	119.4878
Beechwood	Gold	30.9381	119.1997
Beete	Gold	32.6987	121.7101
Beete	Gypsum	32.6743	121.4776
Beete North	Zinc	32.5648	121.7075
Bell Bird	Gold	30.9756	119.1170
Belmont	Gold	32.1955	121.8187
Benbur	Gold	31.5082	118.5544
Benson	Gold	32.2299	121.7863
Berserker	Gold	32.2637	121.8059
Beryl	Gold	33.6746	120.2001
Beryl	Copper	33.5523	120.1009
Best Known	Gold	30.2006	119.2648
Beta	Gold	31.4761	119.4891
Bethnal Green	Gold	32.1924	121.7942
Better Luck	Gold	32.1977	121.8134
Beulah	Gold	32.8272	119.9954
Bickerton	Copper	33.5809	120.1384
Big Lode	Gold	33.6543	120.1914
Big Surprise	Copper, silver, gold	33.5803	120.1361
Birthday	Gold	33.5516	120.1025
Birthday	Gold	30.7325	118.9684
Birthday	Copper	33.5516	120.1025
Birthday Extended	Gold	32.0522	122.0429
Birthday Gift	Gold	31.1192	119.2168
Birthday Gift	Gold	32.3970	121.7853
Black and White	Gold	31.3806	119.3317
Black Barnes	Gold	31.3039	119.2932
Black Cat	Gold	32.3820	121.7714

Locality name	Commodity	Latitude	Longitude
Black Cat	Gold	31.7068	119.5748
Black Prince	Gold	32.5577	119.8342
Blackbourne	Gold	31.3012	119.2946
Blacksnake	Gold	31.5330	119.5850
Blanket	Gold	31.5072	119.5591
Block 14 Proprietary	Gold	32.1588	121.8056
Blue Haze	Gold	32.2406	119.6668
Blue Heeler	Gold	30.8846	120.1858
Blue Hills	Gold	31.6038	119.6548
Blue Ribbon	Copper, gold	33.5514	120.0860
Blue Spec	Copper	33.5906	120.1243
Blue Vein	Gold	32.1451	119.7575
Boanaernup	Nickel	33.5778	120.9800
Bobby Dazzler	Gold	32.2209	121.7847
Bobby Dazzler	Gold	33.7489	120.0137
Bodallin	Gypsum	31.2750	119.0167
Bodallin 9	Gold	31.3489	118.8225
Bohemia	Gold	31.4997	119.5383
Bohemian	Gold	32.1724	121.8001
Bohemian	Gold	31.5008	119.5387
Bon Accord	Gold	32.1930	121.8198
Bon Bon Billa	Gold	32.2450	121.7085
Bonanza	Gold	32.2099	121.8019
Bonanza North	Gold	32.2082	121.7992
Bondsman	Gold	30.9066	119.0873
Bonnie Lois	Gold	32.1989	121.7991
Boodalin Soak	Dolomite	31.2740	118.6495
Boodarockin	Gypsum	31.0087	118.7425
Boodarockin	Magnesite	31.0044	118.8015
Boomalli	Gold	31.2721	119.3210
Boondi	Gypsum	31.1988	120.3681
Boorabbin	Nickel	31.9987	120.5015
Boraginna Soak	Kaolin	32.4155	121.7681
Bottle Dump	Gold	31.5051	119.5764
Boulder Hill	Gold	32.8406	120.0065
Bounty	Rubellite	32.1811	119.7883
Bounty	Gold	31.2362	119.3309
Bounty	Gold	32.0971	119.7765
Bournville	Gold	31.3403	119.4116
Boxwood Hill	Clay, general	34.3294	118.7750
Boxwood Hill	Clay, general	34.2600	118.8328
Boxwood Hill	Clay, general	34.3828	118.8356
Boxwood Hill	Kaolin	34.3350	118.6932
Boyadup Swamp	Limesand	33.8653	122.2819
Bradley	Kaolin	32.6579	118.8356
Braeside	Gold	32.1973	121.8145
Bravo	Gold	31.5485	119.5634
Break o' Day	Gold	32.2948	121.8159
Bremer Bay	Talc	34.2045	119.3182
Bremer Range	Magnesite	32.5211	120.6848
Bridgetown	Gold	33.5744	119.9745
Brilliant	Gold	31.5090	119.5945
Brilliant	Gold	31.7723	121.8075
Brindisi	Gold	31.4193	119.4566
British & Foreign	Gold	31.2357	119.3287
British Flag	Copper, gold	33.6245	120.1484
British Hill	Gold	31.8454	119.6048
Briton	Gold	31.7835	119.6133
Brittania	Gold	31.8337	119.0637
Broken Bottle	Gold	31.7432	121.7296
Bromus	Kaolin	32.4884	121.6304
Bronco	Gold	31.5501	119.5626
Bronzewing	Gold	32.2322	121.7899
Brown Hill	Gold	31.2337	119.3219
Bryant	Gold	31.4141	119.6846
Buck NG	Gold	31.1264	119.2231
Budgeerigah	Gold	30.7737	118.9778
Buffalo	Gold	31.6565	119.5790
Buldania	Molybdenum	32.0692	122.0189
Buldania	Gold	32.0494	122.0319
Buldania Rocks	Limestone	32.0833	122.0333
Bulimba	Gold	31.5053	119.5321
Bull Ant	Gold	32.2196	121.8140
Bull Ant	Gold	30.9803	119.1239
Bullen	Gold	32.1979	121.7945
Bulletin	Gold	32.1733	121.8054
Bulletin	Gold	31.2786	119.3245
Bullfinch	Clay, general	30.9867	118.9831
Bullfinch	Magnesite	30.9322	119.0848
Bullfinch	Talc	31.1099	119.2071
Bullfinch Great Northern	Gold	30.9514	119.0625
Bullfinch	Gold	30.9800	119.1301
Bullfinch Tailings	Gold	30.9782	119.1287
Bullin Bullin	Gold	30.7761	118.9789
Bullrush GM	Gold	33.5460	120.0461
Bullseye	Gold	31.7787	121.7856
Bullwark	Gold	30.8986	119.0942
Bungalbin	Iron ore	30.3534	119.6973
Burbridge	Gold	31.5448	119.5698
Burgess Find	Gold	31.5024	118.5550
Burracoppin	Magnesite	31.0044	118.8015
Bush Pig	Gold	32.1273	119.7395
Butcher Bird	Gold	30.1818	119.2913
C & H	Gold	32.8246	119.9840
C D C	Gold	33.6294	120.1518
Cadonia	Gold	31.4251	119.4695
Caesar	Gold	32.2312	121.7922
Caledonian	Gold	32.2272	121.7894
Calyerup Creek	Gold	33.9493	119.0762
Calzoni	Gold	31.9523	119.0142
Canton	Gold	32.1961	121.8038
Cardinenup	Copper	33.5672	120.0489
Carlyle	Gold	31.6642	119.5754
Carterton	Copper	30.4720	118.9019
Catherine	Gold	31.3090	119.3801
Cattlin Creek	Tantalum, spodumene, beryl	33.5667	120.0333
Cattlin Creek	Tantalum, niobium	33.5639	120.0341
Caution Creek	Gold	30.8561	119.0555
Celt	Gold	32.1925	121.7994
Centaur	Gold	31.6480	119.5761
Centenary	Gold	31.6138	119.5954
Centipede	Gold	31.6392	119.5833
Central	Gold	31.2357	119.3287
Central Higginsville	Gold	31.7446	121.7171
Central Wealth	Gold	31.9617	121.8265
Chadwicks Reward	Gold	30.8671	119.5840
Chaffinch	Gold	30.9743	119.1209
Chalice	Gold	31.8159	121.5148
Challenge – Swordsman	Gold	31.7812	121.7742
Chance	Gold	31.0163	119.1396
Charlotte Simons	Gold	32.4773	121.7965
Charmaine	Gold	33.5795	119.9739
Charmion	Gold	33.6830	120.2055
Cheritons	Gold	31.8301	119.6603
Cheyne Bay	Heavy minerals	34.5464	118.7540
Chown Ja	Gold	31.2884	118.6988
Christiana	Gold	33.5781	119.9725
Christmas Birthday	Gold	31.2834	118.6768
Christmas Gift	Gold	31.5032	118.5536
Christmas Gift	Gold	33.6586	120.1912
Christmas Gift	Gold	31.4170	119.4548
Cinderella	Gold	31.6421	119.5710
Clifton	Gold	31.2788	119.3254
Cobbler	Gold	32.1673	121.7451
Cobra	Gold	30.1934	119.2478
Cocanarup	Beryl, lepidolite	33.6442	119.8750
Cocanarup	Beryl, lepidolite	33.6442	119.8750

Locality name	Commodity	Latitude	Longitude
Cocanarup	Tantalum	33.6414	119.8922
Cocanarup	Beryl	33.6431	119.8913
Cock Bird	Gold	31.7850	121.8308
Colleen Bawn	Gold	31.1621	119.2582
Come Again	Gold	32.1771	121.7875
Comet	Gold	32.4805	121.7966
Comet	Gold	31.2326	119.3202
Comet Eclipse	Gold	31.4626	119.4767
Commercial gold mine	Gold	32.1879	121.8071
Commonwealth	Gold	33.5474	120.0507
Comstock	Copper, gold	33.6281	120.1569
Condingup	Sand, silica	33.6206	122.4142
Condingup	Sand, silica	33.6764	122.6028
Condingup	Heavy minerals	33.6936	122.5292
Conqueror	Gold	32.1855	121.7948
Consolidated	Gold	31.2917	118.7031
Consols	Gold	31.2912	118.7028
Constance Una	Gold	31.7683	119.6009
Contemtible	Gold	31.2872	118.6898
Contest	Copper, gold	33.5526	120.0966
Coomabidgup	Clay, general	33.7094	121.4181
Copper Horseshoe	Copper	33.5731	120.0393
Copperhead	Gold	30.9765	119.1259
Coppermine Creek	Manganese	34.0664	119.6014
Coras mine	Gold	31.1840	119.2837
Coramup Hill	Clay, general	33.7658	121.9239
Cordingup Creek	Jarosite, alunite	33.6000	120.0833
Corinthia	Gold	31.1245	119.2214
Corinthian Main Reef South	Gold	31.1729	119.2734
Corio	Gold	31.2758	118.6522
Cornishman	Gold	31.2788	119.3619
Coronation	Gold	32.0517	122.0399
Coronation	Gold	33.5388	120.0583
Coronation	Gold	30.2851	119.1224
Cosmic Boy	Nickel	32.5840	119.7390
Cousins Glory	Gold	33.5700	120.0051
Cowan	Gold	32.1663	121.8601
Cowan	Gold	32.0727	121.9043
Cowan West	Copper, nickel	32.1697	121.6457
Cowan West	Nickel, copper	32.1806	121.6370
Crabb Corp	Gold	32.2003	121.8115
Crawford Quarries	Dimension stone, granite	32.5012	118.7282
Cricket	Gold	31.5680	119.3890
Croesus	Gold	31.3133	119.3863
Cromwell	Gold	31.4654	119.4947
Crooked Mick	Gold	32.8487	119.9870
Cross	Gold	31.1696	119.2703
Crown	Gold	32.1948	121.7940
Crown and Anchor	Gold	30.7806	118.9710
Crystal Contact	Gold	31.7967	121.7758
Cumberland	Gold	32.2304	121.7874
Cumberland	Gold	33.5776	119.9890
Dallisons Reward	Tungsten	33.7497	119.9973
Dalmore	Gold	31.4503	119.4511
Dalyup	Sand, silica	33.6956	121.4983
Darjeeling	Gold	32.0751	119.7465
Daughters of Erin	Gold	31.7490	121.7184
Day Dawn	Gold	31.9564	121.8267
Day Dawn	Gold	31.2440	119.3348
Daylight	Gold	33.5634	120.0246
Days Find	Gold	30.9325	119.0705
De Valra	Gold	31.2760	118.6516
Deborah	Gold	30.8305	119.0517
Debtors Friend	Gold	31.1821	119.2840
Deliverance	Gold	31.1278	119.2234
Dell	Gold	31.4788	119.4870
Democrat	Gold	31.4959	119.5272
Dempster Road	Clay, general	33.6933	121.9892
Deo Juvante	Gold	33.5681	120.0367
Derwent Jack	Gold	31.0270	119.1507
Desert Rose	Gold	31.5619	119.3823
Desirable	Gold	32.1269	121.7905
Desirable Proprietary	Gold	32.1296	121.7896
Desmond	Copper, gold	33.6217	120.1468
Despair	Gold	31.6092	119.6615
Devlins Reward	Gold	31.3198	119.3281
Diamond Jubilee	Gold	33.5797	119.9747
Dibdale	Gold	31.7170	119.5756
Dicks Reward	Gold	31.1683	118.5258
Digger Rocks	Nickel	32.7182	119.8104
Digger Rocks South	Nickel	32.7199	119.8115
Dillon Bay	Heavy minerals	34.4694	119.2706
Diorite Queen	Gold	31.2886	118.6772
Dixie	Gold	31.4847	119.5195
Dolly Pot	Gold	30.1976	119.2587
Dolly Pot Hill	Gold	30.1989	119.2608
Donovans Find	Gold	31.4889	119.5226
Doris	Gold	31.4777	119.4869
Dorothy Leslie	Gold	31.2949	119.3856
Double Eagle	Gold	31.6748	121.5572
Doubtful Island Bay	Heavy minerals	34.3283	119.4978
Dugite	Gold	30.1898	119.2656
Duke	Gold	32.2648	121.8056
Duke of York	Copper	33.5523	120.1009
Duladgin	Silica	31.1923	119.6728
Dulcie	Gold	31.7482	119.5906
Dulcie Jean	Gold	31.7673	119.6011
Dundas	Chalcedony	32.1231	121.7013
Dundas East	Copper, bismuth	32.4372	121.8272
Dundas Gold Mines	Gold	32.1862	121.7916
Dundas Queen	Gold	32.1737	121.8208
Dunkerque	Gold	32.2301	121.7914
Dunn Rock Road	Sand, silica	33.8728	122.3131
Earl Grey	Gold	32.0834	119.7467
Easter Gift	Gold	32.4117	121.7827
Easter Gift	Gold	30.9768	119.1248
Eclipse	Gold	32.1289	121.8419
Eclipse	Gold	31.4636	119.4777
Edith Eleanor	Gold	32.2115	121.8041
Edna Central	Gold	31.2906	118.7000
Edna May	Gold	31.2912	118.6998
Edwards	Gold	32.3171	121.8061
Edwards Find	Gold	31.5659	119.3853
Eenuin	Gold	30.7314	118.9643
Elbi	Gold	30.8922	119.0082
Eldorado	Gold	31.6762	119.5656
Eldridges Find	Gold	32.7007	121.7095
Eleanor Frances	Gold	32.8265	119.9847
Election	Gold	31.5091	119.5950
Elizabeth	Gold	32.2312	121.7921
Ell Ess Dee	Gold	31.6329	119.5808
Ellen Terry	Gold	32.2358	121.7845
Ellen Tommy	Gold	33.6185	119.9698
Ellendale	Gold	33.5421	120.0557
Elsie	Gold	31.2869	118.6861
Elsie May	Gold	30.8730	119.5928
Elverdton	Manganese	33.6261	120.1442
Elverdton	Copper, gold	33.6239	120.1452
Elverdton Dumps	Copper	33.6257	120.1477
Emanbe	Gold	31.6138	119.5954
Emily Ann	Nickel	32.2022	120.4824
Emily Hale	Copper	33.5545	120.0986
Emma May	Gold	31.3501	118.8280
Emmett JR	Gold	30.8672	119.5840
Emperor	Gold	31.3419	119.4134
Empire	Gold	32.3717	121.7876
Empress	Gold	31.9434	119.0197

Locality name	Commodity	Latitude	Longitude
Empress Gold Mines	Gold	32.1762	121.7983
Ennuin	Gold	30.7685	118.9859
Ennuin Daisy	Gold	30.7830	118.9716
Ennuin Star	Gold	30.7676	118.9689
Enterprise	Gold	32.1842	121.8068
Enterprise	Gold	31.6642	119.5754
Erin	Gold	31.7462	121.7176
Esperance	Building stone, granite	33.8667	121.8833
Esperance	Construction materials	33.7722	121.9192
Esperance	Construction materials	33.8320	121.8752
Esperance	Dimension stone, granite	33.8667	121.8833
Esperance	Sand, silica	33.8381	121.8722
Esperance	Sand, silica	33.8897	121.8242
Esperance	Limesand	33.8510	122.2813
Esperance	Construction materials	33.8753	121.8990
Esperance	Construction materials	33.7709	121.9206
Esperance	Construction materials	33.8307	121.8767
Esperanto	Gold	32.1969	121.7977
Esperanza	Gold	32.1960	121.7969
Eundynie	Gold	31.7756	121.8140
Eureka	Gold	33.5588	120.0372
Eureka Boulder	Gold	31.2357	119.3189
Eva Lake	Gypsum	31.0488	119.8181
Eveless Eden	Gold	31.4706	119.5013
Eveline Gold Mine	Gold	31.3403	119.4116
Evelyn Molly	Gold	31.3403	119.4117
Everlasting	Gold	32.1783	121.8629
Excelsior	Gold	31.2368	119.3178
Excelsora Magna	Gold	32.2312	121.7820
Exhibition	Gold	31.4647	119.4939
Fair Play	Gold	31.7477	121.7235
Fair Play	Gold	33.6763	120.1972
Fair Play	Copper	33.6767	120.1959
Fairlic	Copper	33.6281	120.1569
Fairplay	Gold	31.7487	121.7240
Fed Prospect	Copper, silver	33.5954	120.1198
Federal	Gold	32.3228	121.8023
Federal	Gold	31.2788	119.3250
Federal	Copper	33.5526	120.0966
Federation	Gold	32.1674	121.7823
Felsteads Reward	Gold	31.5951	119.0816
Fenian	Gold	32.2224	121.8076
Finniss GM	Gold	33.6546	120.1932
Fire King	Gold	32.2464	121.8032
Firelight	Gold	31.4636	119.4935
Fitzgerald River	Clay, general	33.7497	119.3475
Fitzgerald River	Coal	34.0174	119.4529
Fitzgerald River	Kyanite	33.9300	120.0119
Fitzgerald River	Dimension stone, spongolite	34.0223	119.3729
Flag	Gold, copper	33.6843	120.2004
Flemington	Gold	30.2184	119.3002
Floater	Gold	33.5504	120.0375
Floater	Copper, gold	33.5504	120.0375
Flolene	Gold	31.2361	119.3238
Florence Mabel	Gold	31.2820	118.6517
Flying Fox	Nickel	32.4178	119.6890
Flying Fox	Gold	32.4251	119.6890
Flying Pig	Gold	31.5615	119.5720
Footes Find	Gold	31.7568	121.6598
Forrestania	Rubellite	32.1798	119.7898
Fortuna	Gold	31.7637	119.5940
Fortunatus	Gold	30.9388	119.1975
Four Jolly Smiths	Gold	32.0837	121.8192
Four Threes	Gold	31.4791	119.4887
Frances	Gold	31.2308	119.3186
Frances May	Gold	30.9757	119.1282
Frances Furness	Gold	31.4973	119.5342
Fraser Range	Dimension stone, granite	32.2183	122.8336
Frasers South	Gold	31.2432	119.3331
Frasers	Gold	31.2396	119.3312
Free Gift	Gold	32.4548	121.8023
Frodo	Gold	30.4015	119.8087
G G	Gold	32.2171	121.7856
Gairdner South	Kaolin	34.2294	118.9376
Gandine	Gold	31.4683	119.4805
Ganymedes	Gold	31.4218	119.4507
Garibaldi	Gold	31.6786	119.5646
Gee Gee Syndicate	Gold	32.1934	121.7920
Geelong	Gold	31.4664	119.4775
Gem	Gold	32.4181	121.7745
Gem	Gold	31.2847	119.3248
Gem	Copper, gold	33.6671	120.2003
Gem Consolidated	Gold	33.6727	120.2021
General Jackson	Gold	30.2067	119.2692
Gentle Annie	Gold	31.4665	119.4798
Geordie Rock	Gypsum	32.8655	121.3848
Gibb Rock	Gold	32.0533	118.9784
Gibson	Clay, general	33.5969	121.7736
Gibson	Clay, general	33.5417	121.7317
Gibson	Clay, general	33.6647	121.7864
Gibson	Kaolin	33.5905	122.0015
Gibsyn	Gold	31.8029	121.7843
Gift	Gold	32.1774	121.7982
Gift	Gold	31.6493	119.5695
Gilbert GM Ltd	Gold	33.5504	120.0375
Gladstone Proprietary	Gold	33.6546	120.1932
Gladys	Gold	32.8650	120.0085
Glascow	Gold	32.1799	121.7983
Glen Dower	Gold	31.3562	119.4139
Glen Esk	Gold	30.1941	119.1290
Glendower	Gold	31.3401	119.4117
Glenelg Queen	Gold	31.9498	119.0063
Glenn Innes	Gold	31.3562	119.4139
Glide Away	Gold	30.9140	119.0854
Gloaming	Gold	32.2597	121.8257
Glory	Gold	32.2022	121.7985
Gold Mount	Gold	31.3229	119.2363
Golden Allie	Gold	32.1734	121.7979
Golden Area	Gold	30.9690	119.0527
Golden Arrow	Gold	31.3134	119.3816
Golden Bounty	Gold	31.2350	119.3304
Golden Butterfly	Gold	31.5310	119.6171
Golden Calf	Gold	32.1901	121.7996
Golden Crown	Gold	30.9008	119.0315
Golden Cube	Gold	31.5189	119.5700
Golden Dawn	Gold	31.9544	119.0726
Golden Dragon	Gold	32.1387	121.7853
Golden Dream	Gold	31.7170	119.5756
Golden Fleece	Gold	31.2854	119.3242
Golden Friday	Gold	30.8595	119.5878
Golden Gate	Gold	31.4815	119.5118
Golden Hole	Gold	30.9064	119.0866
Golden Key	Gold	31.6130	119.5961
Golden Lighthouse	Gold	31.6063	119.6577
Golden Link	Gold	33.5634	120.0246
Golden Links	Gold	31.7191	119.5758
Golden Mile	Gold	31.2766	119.3239
Golden Ole	Gold	32.2663	121.8049
Golden Orb	Gold	30.2856	119.1823
Golden Pig	Gold	31.2329	119.3209
Golden Reef	Gold	30.2924	119.1216
Golden Rock	Gold	31.2518	119.3124
Golden Rod	Gold	31.6062	119.6585
Golden Slipper	Gold	30.3992	119.8131
Golden Valley	Gold	30.8601	118.9929
Golden Valley Mines	Gold	30.9174	119.0842
Golden Venture	Gold	31.6082	119.6570

Locality name	Commodity	Latitude	Longitude
Golden Wishbone	Gold	30.8787	119.5882
Goldfinch	Gold	30.9757	119.1282
Goldstream	Gold	30.2079	119.2806
Good Brothers	Gold	31.6786	119.5646
Gordon	Gold	30.9384	119.2112
Gordon Highlander	Gold	31.6661	119.5747
Gordon Inlet	Heavy minerals, ilmenite, zircon	34.2956	119.5004
Gordon Inlet North	Ilmenite, zircon	34.2589	119.5116
Gordon Inlet South	Heavy minerals, rutile, ilmenite	34.3196	119.4968
Grafter	Gold	33.5438	120.0503
Grafter	Copper	33.5438	120.0503
Grand National	Gold	31.5579	119.5737
Grand View	Gold	32.2534	121.8041
Grass Patch	Gypsum	33.2322	121.8181
Graveyard	Gold	31.7648	121.7167
Great Battler	Gold	31.2720	118.6274
Great Beacon GM Co NL	Gold	31.9365	119.0348
Great Bingin	Gold	30.8285	119.0524
Great Boulder No 2	Gold	31.1903	119.2885
Great Boulder Proprietary	Gold	32.2197	121.7864
Great Britain	Gold	33.6754	120.2020
Great Eastern	Gold	31.4631	119.4950
Great Empire	Gold	32.2577	121.7927
Great Leviathan	Gold	31.2995	119.3801
Great Oversight	Gold	33.5973	120.1220
Great Southern	Gold	32.5247	119.8280
Great Surprise	Gold	31.2855	119.3168
Great Unknown	Gold	30.1977	119.2625
Great Victoria	Gold	31.5443	119.5737
Great Western Consolidated	Gold	30.9030	119.0322
Great Willow	Gold	30.8907	119.0503
Green Bird	Gold	31.4246	119.4759
Green Harp	Gold	30.9171	119.0833
Green Harp New	Gold	30.9167	119.0862
Green Jacket	Gold	31.4686	119.4815
Greenbird	Gold	31.4246	119.4759
Greenfinch	Gold	31.2879	118.6908
Greenfinch Proprietary GM	Gold	31.2884	118.6891
Greenmount	Gold	31.2896	119.3148
Greentree	Gold	30.1962	119.2467
Grimsby	Copper	33.5732	120.0354
Groper	Gold	31.5971	119.6405
Groundlark Gold Mines	Gold	32.1765	121.7926
Haddon	Gold	31.2312	119.3190
Halberts	Graphite	33.6643	120.8592
Hale Bopp	Nickel	33.6665	120.3994
Halleys	Nickel	33.6348	120.3762
Hamersley Gorge	Manganese	33.9018	119.8945
Hamersley Lakes	Gypsum	30.4321	118.9181
Hampton Consols	Gold	31.2901	118.6978
Hampton Plains	Gold	32.2464	121.8058
Hampton Uruaquay	Gold	32.2464	121.8058
Hansfordhaven	Gold	30.9862	119.2203
Harbour View	Copper, gold, silver	33.6793	120.1969
Hardy Junction	Gold	32.1959	121.7992
Harlequin	Gold	32.1137	121.7940
Harp of Erin	Gold	31.7400	121.7165
Harris Find	Gold	31.5437	119.6942
Hatt & Langs	Gold	31.2341	119.3264
Hatters Hill	Gold	32.8246	119.9839
Haupt of Erin	Gold	31.7400	121.7165
Havelock	Gold	31.6573	119.5673
Hawick	Gold	33.5640	120.0118
Haycraft	Gold	32.3732	121.7871
Hazel Merle	Gold	30.1908	119.1258
Headframe	Gold	31.5057	119.5826
Heany Find	Vermiculite	31.6167	119.5500
Heather Bell	Gold	32.1971	121.8036
Hecla	Copper	33.6713	120.2253
Helio	Gold	30.7806	118.9710
Herbert	Gold	32.1402	121.8587
Hick	Heavy minerals	34.3846	118.8374
Hidden Secret	Gold	31.7815	121.8145
Higginsville	Clay, general	31.7767	121.6925
Higginsville	Magnesite	31.7488	121.7014
Higginsville	Gold	31.7199	121.7543
Higginsville	Copper	31.6758	121.7012
Higginsville	Tungsten	31.7477	121.7158
Hill End	Gold	32.2103	121.8008
Hill End	Gold	33.6727	120.2038
Hill End	Gold	31.2765	118.6229
Hill View	Gold	32.2336	121.7873
Hill View	Gold	31.1797	119.2804
Hillsborough	Gold	33.6747	120.1980
Hillsborough	Copper	33.6747	120.1979
Hinemoa	Gold	31.9626	121.8259
Hit or Miss	Gold	32.2015	121.8137
Hoffmans GM	Gold	32.2342	121.8069
Holleton	Gold	31.9518	119.0114
Holleton	Tin	31.9574	119.0139
Hollow & Heatons Reward	Gold	31.9517	119.0114
Homeward Bound	Gold	31.2312	119.3190
Honman Ridge	Iron ore	32.4187	120.6328
Hope	Gold	30.8800	119.0456
Hope Still	Gold	31.1842	119.2851
Hopefinch leases	Gold	31.1753	119.2725
Hopeful	Gold	31.2918	118.6966
Hopes Hill	Gold	31.1818	119.2823
Hopes Hill	Tungsten	31.1867	119.2865
Hopetoun	Limesand, limestone	33.9194	120.1361
Hopetoun	Limestone	33.9194	120.1361
Hopetoun	Gold	32.0957	121.8151
Hornblende	Gold	33.9361	119.0960
Horseshoe	Gold	32.1899	121.8147
Houghton	Gold	32.0891	121.8168
Hurst	Heavy minerals	34.3360	118.8617
HV1	Gold	32.1123	121.7831
Hyden	Graphite	32.6139	118.8903
Hyden East	Construction materials	32.4101	119.6390
I X L	Gold	31.5270	119.5819
Illawarra	Gold	30.9768	119.0585
Imperial	Gold	31.2936	119.3256
Independent	Gold	31.2742	118.6358
Ine Zella	Gold	31.2475	119.3201
Inglewood	Gold	30.2008	119.2774
Inspiration	Gold	30.8983	119.0854
Iona	Gold	32.1218	121.8100
Ireland	Gold	31.4631	119.4950
Irene	Gold	30.9651	119.0860
Irene Betty	Gold	31.1912	119.2892
Iris	Gold	32.1762	121.7956
Irish Breakfast	Gold	32.0782	119.7470
Iron Channel	Gold	31.5073	119.5850
Iron Duke	Gold	32.2627	121.8065
Iron King	Gold	32.2365	121.8020
Iron King North	Gold	32.2400	121.8029
Ironclad	Gold, copper	33.6091	120.1391
Ironsides	Gold	32.3171	121.8061
Ironstone	Gold	32.2627	121.8065
Island View Hill	Gold	31.6850	121.8721
Ivy Bushes	Gold	32.2036	121.8134
IXL	Gold	32.0511	122.0310
Mountain Queen	Gold	31.4732	119.4841
Jack & Jim	Gold	31.4683	119.4805
Jacks Come Home Again	Gold	33.6535	120.1927
Jackson	Gold	30.0886	119.1248

Locality name	Commodity	Latitude	Longitude
Jackson Wonder	Gold	30.2228	119.1299
Jacoletti	Gold	31.4685	119.4787
Jacup Creek	Kaolin	33.7655	119.1681
Jaguar	Gold	31.3315	119.2417
James Henry	Gold	33.5673	120.0077
Janetta	Gold	31.7836	119.6134
Jasmine	Gold	32.0723	119.7473
Jean Nichol	Gold	31.2849	119.3160
Jean Rose	Gold	31.1868	119.2873
Jedda Bird	Gold	30.9856	119.2188
Jeffreys	Gold	31.9455	122.1523
Jerramungup	Clay, general	33.9078	119.0403
Jerramungup	Dimension stone, granite	33.9266	119.0182
Jerramungup	Copper	33.8769	118.9689
Jessie Graham	Gold	31.2849	119.3160
Jessie Margaret	Gold	32.1668	121.7988
Jessie No 1	Gold	31.2836	118.6515
Jester	Gold	31.5285	119.5832
Jewel	Gold	32.2026	121.8184
Jim Dunn	Gold	33.6140	119.9728
Jimberlana	Nickel	32.1913	120.4685
Jimmy Bob	Gold	32.8632	120.0100
John Bull	Gold	32.2313	121.7904
Johns mine	Gold	31.6304	119.5817
Johnson FR	Tantalum, niobium	33.5661	120.0411
Joke	Gold	30.9423	119.1901
Jolly Fair	Gold	30.8832	119.0448
Jones	Heavy minerals	34.2375	119.0789
Jubilation	Gold	32.1226	121.8378
Jubilee	Gold	33.5802	119.9733
Jupiter	Nickel, copper	31.2740	119.3233
Jupiter	Gold	32.2360	121.7822
Jupiter	Gold	30.9769	119.1226
Just in Time	Gold	32.3515	121.7902
Just in Time	Gold	30.1922	119.2592
Just-in-Time	Gold	31.6142	119.5969
Kaolin	Gold	33.6712	120.2029
Karlgarin	Dimension stone, granite	32.5019	118.7314
Karlgarin	Kaolin	32.5183	118.6959
Karli West	Gold	30.4110	118.7029
Karli W	Gold	30.3923	119.8028
Kathleen	Gold	30.8866	119.0273
Kelly Star	Gold	31.5098	119.6606
Kemball Grant	Gold	32.2249	121.8076
Ken & Gwen	Gold	32.2060	121.8019
Kennyville	Gold	31.2960	119.3751
Kernel	Gold	31.6448	119.5698
Kerola	Gold	32.2316	121.7913
Kerrigan	Kaolin	32.6655	118.8348
Kia Ora	Gold	33.6560	120.1933
Kia Ora	Gold	31.7230	119.5785
Killaloe	Gold	31.9629	121.9517
King	Gold	32.2418	121.8033
King Arthur	Gold	32.4799	121.7965
King Brown	Gold	30.1198	119.1163
King Edward VII	Gold	31.3027	119.2934
King George	Gold	32.0511	122.0434
King George	Gold	32.8543	120.0192
King of the Cross	Gold	31.2325	119.3008
King of the Range	Gold	31.7124	119.5752
King T G	Gold	30.9022	119.2130
King William	Gold	32.1732	121.7893
Kingston	Gold	33.5516	120.0894
Kingston	Copper	33.5559	120.1051
Kington	Copper	33.5515	120.0894
Kipping Road	Construction materials	33.8379	121.8759
Kirkpatrick	Gold	32.2339	121.7883
Kitty	Gold	31.2759	118.6493
Klondyke	Gold	32.2115	121.7986
Known Best	Gold	30.2041	119.2708
Kookaburra	Gold	31.6751	119.5663
Koolyanobbing A	Iron ore	30.8378	119.5393
Koolyanobbing C	Iron ore	30.8445	119.5482
Koolyanobbing D	Iron ore	30.8455	119.5571
Koolyanobbing F	Iron ore	30.8676	119.5906
Koolyanobbing K	Iron ore	30.7970	119.5186
Koolyanobbing North	Nickel	30.7306	119.4578
Koolyanobbing South	Construction materials	30.8751	119.5245
Koomarlin	Gold	31.5270	119.5819
Kooyaura	Gold	33.5497	120.0458
Kumarl Siding	Molybdenum	32.7889	121.5536
Kundip	Heavy minerals	33.7000	120.1389
Kundip	Manganese	33.6644	120.1967
Kundip	Manganese	33.6889	120.2700
Kundip	Talc	33.6989	120.1404
Kundip	Copper, gold	33.6789	120.1983
Kundip B3	Magnesite	33.6614	120.2334
Mount Iron	Gold	33.6546	120.1932
Kurracea	Gold	33.5487	120.0387
Kurrajong	Gold	31.5129	119.6115
Kyneton	Gold	32.2644	121.8019
L S D	Gold	31.6327	119.5806
La Mascotte	Gold	32.2646	121.8019
Lady Agnes	Gold	30.9651	119.0860
Lady Bella	Gold	32.2244	121.8078
Lady Edeline	Gold	31.2330	119.3255
Lady Edeline GM Co NL	Gold	31.2343	119.3257
Lady Edna	Gold	31.2888	118.6946
Lady Ellen	Gold	30.8978	119.0945
Lady Eunice	Gold	32.2272	121.7894
Lady Evelyn	Gold	32.2557	121.8270
Lady Florence	Gold	31.1861	119.2866
Lady Gladys	Gold	31.4937	119.5249
Lady Gladys Gwendolen	Gold	32.1989	121.7992
Lady Helen	Gold	32.4799	121.7954
Lady Jean	Gold	32.1984	121.8035
Lady Jessie	Gold	33.5636	120.0344
Lady Kathe	Gold	31.1952	119.2845
Lady Loch Mines	Gold	31.4701	119.4792
Lady Luck	Gold	31.5585	119.3814
Lady Mary	Gold	31.5611	119.3836
Lady Mary	Gold	32.2538	121.8044
Lady Mavis	Gold	32.2665	121.8057
Lady Miller	Gold	32.2453	121.8066
Lady Mollie	Gold	30.8273	119.0517
Lady Nina	Copper, gold	33.5523	120.0873
Lady Verona	Gold	32.1956	121.8159
Lady Veronica	Gold	31.2621	119.3495
Lake Baladjie	Construction materials	30.9400	118.9900
Lake Baladjie	Gypsum	30.9655	118.9181
Lake Baladjie	Sand	30.9403	118.9903
Lake Biddy	Gypsum	33.0155	118.9348
Lake Biddy	Salt	33.0043	118.9398
Lake Buchan	Gypsum	33.1487	119.0848
Lake Burkett	Gypsum	33.1004	119.0431
Lake Camm	Gypsum	32.9868	119.5523
Lake Chandler	Alunite	31.0096	119.6332
Lake Chidnup	Gypsum	33.3655	119.8848
Lake Cobham	Dolomite	33.4351	119.2634
Lake Cobham	Gypsum	33.4339	119.2649
Lake Cowan	Clay, general	32.0706	121.6797
Lake Cowan	Gold	31.8202	121.7559
Lake Cowan	Limestone	32.1575	121.7675
Lake Cowan	Gypsum	32.2237	121.7321
Lake Cowan North	Gypsum	32.0988	121.7348

Locality name	Commodity	Latitude	Longitude
Lake Deborah East	Salt	30.6673	119.4067
Lake Deborah East	Construction materials	30.9631	119.4559
Lake Dundas	Gypsum	32.4822	121.8848
Lake Gilmore	Clay, general	32.7733	121.5458
Lake Gilmore	Gypsum	32.5988	121.6348
Lake Gilmore West	Gypsum	32.6322	121.5181
Lake Gulson	Gypsum	32.8207	119.4656
Lake Julia	Gypsum	31.0320	119.3681
Lake Kathleen	Gypsum	32.9851	119.7020
Lake King	Gypsum	33.0904	119.5917
Lake King	Gypsum	32.9725	119.7121
Lake Kirk	Gold	32.2549	121.7336
Lake Lockhart	Gypsum	33.2396	119.0798
Lake Magenta	Dolomite	33.4296	119.2695
Lake Magenta	Gypsum	33.3989	119.2015
Lake Magenta	Kaolin	33.2489	119.1848
Lake Magenta	Limestone	33.4167	119.2500
Lake Mends	Gypsum	33.0655	121.0348
Lake Ned	Gold	32.4584	119.7468
Lake Seabrook	Fluorite, copper	30.8500	119.5500
Lake Seabrook	Silica	30.8725	119.5906
Lake Seabrook	Tungsten	30.8942	119.5936
Lake Seabrook	Gypsum	30.9865	119.6417
Lake Tay	Gypsum	33.0244	120.7786
Lake View	Gold	32.2529	121.8114
Lake View	Gold	30.8775	119.0230
Last Chance	Copper, gold	33.5566	120.1059
Last Hope	Gold	32.3173	121.8064
Last Hope	Gold	31.1774	119.2780
Last Try	Gold	30.8839	119.0289
Last Venture	Gold	33.7884	119.8827
Le Trois	Gold	31.2858	118.6461
Learys Lament	Gold	31.9187	119.0020
Lenneberg	Gold	31.3860	119.4590
Lenneberg Laterites	Gold	31.3562	119.4362
Lenodo Leases	Gold	31.4678	119.4776
Leonards Find	Gold	31.5437	119.6931
Leviathan	Gold	31.2987	119.3789
Liberty	Gold	31.2656	119.3186
Light Wing	Gold	30.8347	119.0440
Lightning	Gold	30.3962	119.8142
Lilly	Gold	33.6754	120.1964
Lily	Gold	32.1754	121.7951
Lily of the Valley	Gold	30.9035	119.0376
Lily West	Gold	32.1765	121.7926
Liquid Acrobat	Nickel	32.5401	119.7378
Little Baby	Gold	31.1394	119.2082
Little Gladys	Gold	31.7862	121.7927
Little Gladys	Gold	32.1921	121.8148
Little Gladys	Gold	32.8650	120.0086
Little Hill	Gold	30.9737	119.1183
Little Jim	Gold	32.1726	121.8213
Little Mary	Gold	33.6550	120.1920
Little Mary	Gold	31.2881	118.6864
Little Pearle	Gold	32.1278	121.7892
Little Suzy	Gold	31.5466	119.6153
Little Wonder	Gold	32.2929	121.8196
Little Wonder	Gold	33.6399	120.1781
Little Wonder	Gold	31.2860	119.3263
Liz	Gold	31.5083	119.5873
Lochlee	Gold	31.1410	119.2092
Lone Chance	Gold	30.1938	119.2877
Lone Hand	Gold	32.2139	121.7844
Lone Hand	Gold	31.6278	119.5667
Lone Pine	Gold	30.7301	118.9658
Lone Star	Gold	33.6684	120.1858
Lookout Hill	Magnesite	31.9877	119.0571
Lord Cardigan	Gold	31.2378	119.3250
Lord Hopetoun	Gold	32.1964	121.8143
Lord Kitchener	Gold	31.6242	119.5673
Lord Roberts	Gold	31.2654	119.3191
Lort	Coal	33.1334	121.1981
Lort River	Kaolin	33.0290	121.0565
Louis	Gold	31.6681	121.8970
Lounge Lizard	Gold	32.4301	119.6876
Lovelly Lady	Gold	31.9578	119.0201
Luckey Spot	Tungsten	31.7483	121.7162
Lucky Call	Gold	32.2659	121.8028
Lucky Dip	Gold	31.2893	119.3147
Lucky Hit	Gold	32.1736	121.7891
Lucky Hit	Gold	31.6786	119.5646
Lucky Seven	Gold	31.5437	119.6567
Lucy	Gold	33.5695	120.0021
Lydia	Gold	31.6327	119.5806
Lynette	Gold	31.3869	119.2874
MacMahon	Gold	32.4271	119.6881
Madge	Gold	31.2892	119.3296
Mafeking	Gold	32.3145	121.8072
Maggie Hays	Nickel	32.2357	120.5037
Magill	Gold	32.3733	121.7844
Magill Block	Gold	32.3735	121.7846
Magpie	Gold	30.9300	119.1021
Majestic	Gold	32.2310	121.7930
Majestic GMs	Gold	32.3674	121.7938
Maloney	Gold	32.1763	121.7876
Manmine	Gold	31.2275	119.3188
Manxman	Gold	30.9066	119.0873
Maori Chief	Gold	33.5468	120.0602
Maori Lass	Gold	31.2468	119.3198
Maori Queen	Gold	33.5438	120.0633
Mararoa	Gold	32.1943	121.7943
Marbellup Hill	Sand, silica	33.9125	122.1122
Marco Paolo	Gold	31.4546	119.4873
Marda	Copper	30.3402	119.1992
Marda East	Gold	30.2163	119.2869
Margaret Cove	Heavy minerals	33.8587	121.0198
Margaret Ellen	Gold	32.3663	119.7558
Margaret Rose	Gold	31.6421	119.5710
Margeurite	Gold	30.9134	119.0862
Marian Martin	Gold	33.5781	120.0390
Maries Find	Gold	30.8332	119.0474
Marion Martin	Gold	33.5767	120.0390
Marionete	Gold	30.7916	118.9886
Marjorie B	Gold	31.5247	119.5902
Marjorie Glen Reward	Gold	31.3842	119.3053
Marnoo	Copper	33.6200	120.1448
Maroomba	Gold	31.7551	119.5946
Martins	Gold	31.6026	119.6612
Marvel Loch	Limestone	31.4661	119.4694
Marvel Loch Tailings	Gold	31.4901	119.5212
Marvel Loch Dumps	Gold	31.4587	119.4884
Marvel Loch	Gold	31.4626	119.4925
Mary	Gold	33.5493	120.0947
Mary	Gold	31.2942	118.7124
Mary Eileen	Gold	32.1201	121.8359
Mary Lena	Gold	31.4226	119.4745
Maschu	Gold	32.2073	121.8154
Maud	Gold	31.7151	119.5751
Mawsons Reward	Gold	32.3700	121.7948
May Bell	Gold	32.3704	121.7940
May Bell	Gold	33.5926	120.2220
May Crown	Gold	31.4122	119.4514
May Day	Gold	33.6790	120.1932
May Day	Copper	33.6790	120.1928
May Queen	Gold	31.4138	119.4524
Maybe	Gold	32.3669	121.7935
Maybell	Gold	32.3662	121.7948

Locality name	Commodity	Latitude	Longitude
Maydo	Gold	31.5243	119.5903
Mayfield	Iron ore	30.5709	118.9375
McCabons	Gold	31.2906	118.7000
McCosker	Gold	31.5164	119.5952
McIntosh	Gold	31.6493	119.5695
Medcalf	Vanadium, tungsten	32.5331	120.7964
Medic	Gold	33.6790	120.1932
Meiers Find	Gold	31.4387	119.6673
Mellors Hill	Gold	31.1963	119.2879
Melrose	Gold	32.2901	121.8023
Mercury	Gold	32.3645	121.7881
Merivale	Sand, silica	33.8261	122.1044
Merivale	Dimension stone, granite	33.7967	122.0317
Midas	Gold	31.4773	119.4875
Middle Ironcap	Gold	32.5041	119.7551
Middlerise	Gold	32.4805	121.7966
Middleton	Gold	32.1978	121.8036
Mildura Leases	Gold	32.2016	121.7990
Milesis	Gold, tungsten	31.7477	121.7158
Millenium	Gold	30.9434	119.2049
Millionaire	Gold	31.3051	119.2924
Miners Dream	Gold	30.2045	119.2766
Minerva	Gold	32.0517	122.0271
Minna	Gold	33.6735	120.2023
Missing Link	Gold	33.6830	120.2055
Mistletoe	Gold	30.9323	119.0700
Mistral	Gold	31.5465	119.5703
Mitchell	Gold	31.7709	121.7331
Monarch	Gold	32.2474	121.8026
Monita	Gold	31.7151	119.5751
Monjigup Lake Road	Clay, general	33.7992	121.7994
Moonlight	Gold	32.3161	121.8070
Moorine Rock	Magnesite	31.2655	119.1237
Moorine Rock	Gypsum	31.3926	119.1348
Morning Glory	Gold	30.7938	118.9803
Morning Star	Gold	32.1774	121.7982
Mornington	Gold	31.2990	119.3887
Morrell	Gold	32.2493	121.7954
Mosaic	Gold	33.6627	120.2380
Mosaic Prospect	Copper, silver	33.6629	120.2380
Mount Agnes Reward	Gold	32.8243	119.9869
Mount Barker	Gold	32.1862	121.8067
Mount Benson	Gold	32.2319	121.7843
Mount Benson	Copper, gold	33.5516	120.0894
Mount Cattlin	Copper, gold	33.5683	120.0488
Mount Caudan	Gold, pyrite, pyrrhotite	31.6148	119.5521
Mount Chester	Manganese	33.6057	120.1459
Mount Day	Feldspar, beryl, lepidolite	32.1333	120.5000
Mount Deans	Tin, tantalum	32.3070	121.7850
Mount Desmond	Copper, gold	33.6190	120.1477
Mount Dimer	Gold	30.3926	119.8934
Mount Doran	Gold	33.6128	119.9728
Mount Eaton	Gold	31.7604	121.6622
Mount Eliza	Gold	33.6140	119.9728
Mount Garrity	Copper	33.5906	120.1243
Mount Henry	Gold	32.3748	121.7870
Mount Holland	Limestone	32.1000	119.8333
Mount Holland	Gold	32.1462	119.6467
Mount Hope	Gold	31.1797	119.2804
Mount Jackson	Iron ore	30.2512	119.2448
Mount Jackson	Gold	30.1916	119.1281
Mount Kathrine	Gold	30.8856	119.0258
Mount Malcolm	Dimension stone, granite	32.2164	122.8412
Mount Mallet	Kaolin	32.5655	118.7282
Mount Mary	Gold	32.8419	119.9989
Mount McMahon	Iron ore	33.5160	120.0659
Mount McMahon	Copper	33.5506	120.1045
Mount Norcott	Fluorite	32.1167	122.0000
Mount Palmer	Vermiculite	31.3597	119.7017
Mount Palmer	Gypsum	31.4487	119.7098
Mount Palmer North	Gold	31.3894	119.6942
Mount Pleasant	Copper, gold	33.6712	120.2253
Mount Rankin	Gold	31.3229	119.2367
Mount Ridley	Fluorite	33.3092	122.1353
Mount Stennet	Gold	33.6480	120.1873
Mount Thirsty	Tantalum, tin	32.0742	121.6625
Mount Thirsty	Nickel	32.0951	121.6416
Mount Victor	Gold	31.1935	119.2823
Mount Walker	Gypsum	32.0543	118.6904
Mount Walter	Halloysite	30.9322	120.2070
Mount Woodward	Gold	30.8752	119.0078
Mountain Devil	Gold	31.7707	119.6028
Mountain King	Gold	31.4854	119.5195
Mountain Oaks	Gold	30.8872	119.0249
Mountain Prince	Gold	31.4712	119.4818
Mountain View	Gold	32.2539	121.8064
Mountain View	Copper	33.6276	120.1582
Mousehollow	Gold	31.7838	121.8190
Mundy Hills 1	Gold	31.5437	119.6931
Munglinup	Clay, general	33.7144	120.8772
Munglinup	Clay, general	33.7472	121.0658
Munglinup	Magnesite	33.6586	120.8556
Munglinup	Vermiculite	33.5423	120.9906
Munglinup River	Graphite	33.6597	120.8542
Myrtle	Gold	32.1886	121.7900
Myrtle Central	Gold	31.2909	118.7007
N S M Ltd	Gold	31.3892	119.6931
Napoleon	Gold	31.6618	121.8823
Narembeen	Gypsum	32.3155	118.5015
Narracoorte	Gold	32.2070	121.8162
Narweena	Gold	32.2071	121.8157
Needilup	Molybdenum	33.9514	118.7500
Nellie Ray	Gold	31.5447	119.6889
Nelly May	Gold	32.1245	121.7925
Netty	Copper	33.8769	118.9689
Never Despair	Gold	32.1768	121.7876
Never Never	Gold	31.5062	119.5817
Nevertire	Gold	31.2727	118.6401
Nevoria	Gold	31.5082	119.5906
Nevoria East	Gold	31.5071	119.5865
New Brilliant	Gold	31.7723	121.8075
New Chum	Gold	32.1932	121.8161
New Chum	Gold	31.3010	119.3924
New Democrat	Gold	31.4959	119.5272
New Green Harp	Gold	30.9154	119.0876
New Hope	Gold	31.7499	121.7186
New Hope	Gold	31.5410	119.6903
New Italy	Gold	30.9454	119.2113
New Jacoletti	Gold	31.4681	119.4793
New King	Gold	32.2424	121.8023
New Maori Queen	Gold	33.5438	120.0633
Kilmore	Copper	33.5557	120.0958
New Mararoa	Gold	32.1994	121.7951
New Maries Find	Gold	30.8295	119.0495
New Marvel Loch	Gold	31.4661	119.4958
New Moon	Gold	32.1549	121.7890
New Moon	Gold	33.5557	120.0958
New Morning	Nickel	32.4529	119.6801
New Nevoria	Gold	31.5084	119.5901
New Ophir	Gold	32.2070	121.7956
New Queensland	Gold	32.1964	121.8143
New Radio	Gold	30.9304	119.1032
New Valkyrie	Gold	32.2078	121.8015
New Years Gift	Gold	31.5069	119.5865
New Yilgarn GM NL	Gold	31.5347	119.6164

Locality name	Commodity	Latitude	Longitude
Newfield Central	Gold	30.4953	118.8899
Newfield East	Gold	30.4955	118.8931
Newington	Gold	30.4925	118.8931
Newmarket	Gold	30.2224	119.2972
Newry	Gold	31.5076	119.5887
Nil Desperandum	Gold	31.2288	119.3169
Nil Desperandum	Copper	33.5481	120.1030
Nindilbillup	Nickel	33.5929	120.2805
No. 1 Central	Gold	31.2336	119.3258
No. 1 North Norseman	Gold	32.1861	121.8014
No Trumps	Gold	31.3229	119.2363
Noombenberry Rock	Kaolin	31.6739	118.8098
Norseman	Chalcedony	32.1167	121.6917
Norseman	Construction materials	32.1792	121.7717
Norseman	Magnesite	32.1988	121.7681
Norseman	Pyrite	32.2378	121.8006
Norseman / Blake & Norton	Tin	32.3002	121.7789
Norseman	Gypsum	32.2215	121.7316
Norseman / Jones	Tin	32.1962	121.7781
Norseman / McDonald	Gypsum	32.1920	121.7491
Norseman	Opal	32.1231	121.7013
Norseman / Weston	Copper	32.1962	121.7781
Norseman / WESTON	Tin	32.3184	121.7858
Norseman Associated GMs	Gold	32.1876	121.8058
Norseman Associated Gold Mines	Gold	31.7463	121.7169
Norseman East	Gypsum	32.1988	121.8515
Norseman GM	Gold	32.1889	121.7972
Norseman Rose	Gold	32.2026	121.8179
Norseman	Tungsten	32.2076	121.7987
Norseman Tailings	Gold	32.1779	121.7731
North and South	Gold	32.8250	119.9816
North Comet	Gold	31.4611	119.4764
North End	Gold	31.9379	119.0187
North End leases	Gold	30.9769	119.1226
North Harbour View	Copper, gold	33.6789	120.1983
North Ironcap	Gold	32.3657	119.6851
North Mararoa GM Co NL	Gold	32.1844	121.7949
North Palmer	Gold	31.4061	119.6881
North Poseidon South	Gold	31.7227	121.7293
North Radio	Gold	30.9129	119.0836
North Revival	Gold	33.5361	120.0615
North Royal	Gold	32.1206	121.8101
North Star	Gold	31.4061	119.6881
North Star No 1	Gold	32.1751	121.7993
North Yilgarn	Gold	30.1812	119.1258
Northern Star	Gold	32.1774	121.7982
Northern Star	Gold	31.2444	119.3253
Northumberland	Gold	31.2363	119.3236
Norton	Gold	31.5087	119.5928
Norwood	Gold	31.1598	119.2564
Numeralla	Gold	30.1206	119.1136
O K	Gold	32.2190	121.7851
O K	Gold	30.9065	119.0760
O'Sullivan	Lignite	32.8462	121.4156
Okay	Gold	32.2190	121.7851
Okay ballast	Construction materials	32.2176	121.7834
Old Lodge	Gold	31.7813	121.8151
Old Miller	Gold	32.2481	121.8066
Oldfield Inlet	Heavy minerals	33.8729	120.7906
Oldfield River	Nickel	33.5018	120.5465
Olga	Gold	31.7170	119.5756
Omaha	Copper, gold	33.6783	120.1977
Omega	Gold	31.5043	119.5684
One Under	Gold	30.9303	119.0672
Ongerup	Kaolin	33.7706	118.5849
Onkaparinga	Gold	32.2337	121.7894
Ophir	Gold	32.2048	121.7982
Oreb	Gold	32.1735	121.7886
Orion	Gold	32.0517	122.0369
Our Selection	Copper	33.5472	120.0949
Outsider	Gold	31.4941	119.5284
Oversight	Gold	32.2295	121.7918
Oversight Leases	Gold	32.2282	121.7926
P L P	Copper. Gold	33.6160	120.1441
Pallinup	Ilmenite, rutile	34.2489	119.0849
Pallinup	Ilmenite, zircon	34.3907	118.8349
Pallinup River	Kaolin	34.3155	118.5015
Pallinup River	Magnesite	34.4322	118.8071
Palmerston	Gold	31.4077	119.6873
Pariah	Gold	31.4787	119.4879
Parisian	Gold	31.1554	119.2512
Parker Range	Gypsum	31.6322	119.6181
Parkers Range	Gold	31.6304	119.5867
Patalena	Gold	31.4502	119.4510
Pathfinder	Gold	31.5498	119.6143
Pathway Hill	Gold	32.0509	122.0400
Patricia Lea	Gold	30.6307	118.8876
Patronis	Gold	31.3450	119.3878
Pearl	Gold	32.1819	121.7940
Pencil Tiger	Gold	30.1954	119.2406
Pendrea	Gold	31.2687	119.3537
Peninsula	Gold	31.9618	121.8267
Peninsula	Gold	31.7723	121.8075
Penneshaw	Gold	32.2581	121.8269
Perseverance	Gold	31.2339	119.3262
Persian	Gold	30.2152	119.2974
Persic	Gold	33.6830	120.2055
Pertha M	Gold	31.2749	118.6530
Peter Pan	Gold	30.9413	119.1891
Phar Lap	Gold	31.2893	118.6888
Phoenix	Gold	31.1816	119.2817
Phoenix	Gold	31.5559	119.5739
Phoenix Tailings	Gold	32.1954	121.7920
Pick & Shovel	Copper, gold	33.6666	119.9286
Piemonte	Gold	31.6416	119.5712
Pilot	Gold	31.1610	119.2598
Pine Hill	Gold	30.8883	119.0262
Pingaring	Kaolin	32.7294	118.6279
Pink Lake	Salt	33.8326	121.8481
Pioneer	Gold	30.8859	119.0263
Pioneer	Gold	31.8473	121.6803
Pioneer BB	Nickel	31.9838	121.6416
Pioneer JH	Nickel	31.9723	121.6431
Plain Bill	Gold	32.1937	121.7994
Planet	Gold	33.5474	120.0524
Plantagenet	Gold	33.5474	120.0524
Point View	Gold	32.2511	121.8093
Pointer 4	Gold	31.6634	119.5757
Polar Bear	Gold	31.9362	121.8398
Polasis South	Gold	31.2573	119.3431
Pomeranian	Gold	31.7647	119.6001
Port Royal	Gold	31.2761	119.3241
Poseidon	Gold	31.7226	121.7292
Pretoria	Gold	31.2420	119.3096
Pride of the Hills	Gold	31.2363	119.3236
Primrose	Gold	32.1254	121.7908
Prince	Gold	31.4773	119.4875
Prince George	Gold	31.5497	119.5644
Prince of the West	Gold	32.1422	121.7939
Princess Royal	Gold	33.6140	119.9728
Princess Royal GM	Gold	32.1378	121.8088
Priscilla	Gold	32.1961	121.7999
Pro Patria	Gold	31.4925	119.5402
Pryoress	Gold	31.1963	119.2879
Puis Sheila	Gold	31.2906	118.6964
Pyramid Lake	Gypsum	33.1654	120.9515
Python	Gold	30.2015	119.2709
Qualinup Swamp	Clay, bentonite	34.4031	119.0475

Locality name	Commodity	Latitude	Longitude
Quandang	Gold	31.5134	119.6118
Queen	Gold	32.2443	121.8029
Queen Alexandra	Gold	32.2039	121.8222
Queen Ann	Gold	31.2419	119.3094
Queen Elizabeth	Gold	31.1912	119.2886
Queen Mab	Gold	31.5008	119.5387
Queen Marie	Gold	30.8258	119.0531
Queen of Sheba	Gold	31.6295	119.5753
Queen of the Earth	Gold	33.6739	120.2000
Queen of the Hills	Gold	30.2212	119.2771
Queen of the West	Gold	32.1744	121.8212
Queensland Consols	Gold	31.6033	119.6540
Queensland United	Gold	31.6137	119.5956
Queenslander	Gold	30.9063	119.0765
Radio	Gold	30.9254	119.0940
Radio Deeps	Gold	31.5015	119.5404
Railway	Gold	31.1936	119.2823
Rainbow	Gold	31.7919	121.7947
Rainbow	Gold	31.3005	119.3897
Rand	Gold	31.2747	119.3214
Range Road	Limestone	31.2701	119.3508
Ratbat	Nickel	32.5485	119.7378
Raven	Gold	31.6212	119.5918
Ravensthorpe	Clay, bentonite	33.6022	120.2075
Ravensthorpe	Clay, general	33.5833	120.1464
Ravensthorpe	Building stone, spongolite	33.6986	119.9819
Ravensthorpe	Copper	33.6204	120.1482
Ravensthorpe / Belli	Copper	33.7884	119.8827
Ravensthorpe / Egerton	Copper	33.6856	120.1984
Ravensthorpe / Frayne	Lithium	33.5654	120.0381
Ravensthorpe	Tantalum	33.5637	120.0397
Ravensthorpe	Lithium	33.5655	120.0381
Ravensthorpe	Jarosite	33.5741	120.1299
Ravensthorpe 1	Nickel	33.5881	120.2179
Ravensthorpe 4 Laterite	Nickel	33.5751	120.2209
Ravensthorpe 4	Nickel	33.5751	120.2209
Ravensthorpe 5	Nickel	33.5954	120.2417
Ravensthorpe 8	Nickel	33.6042	120.3006
Ravensthorpe B4	Magnesite	33.6000	120.2583
Ravensthorpe B6	Magnesite	33.5503	120.1376
Ravensthorpe B7	Magnesite	33.5836	120.1473
Ravensthorpe B8	Magnesite	33.5933	120.2265
Ravensthorpe	Copper, gold, silver	33.5688	120.0477
Ravensthorpe Copper Mines	Gold	33.6231	120.1482
Ravensthorpe GM	Gold	33.6818	120.1965
Razorback	Gold	32.1412	119.7309
Record	Gold	32.1583	121.8063
Recoup	Gold	32.2360	121.7830
Recovery	Gold	32.2359	121.7830
Recovery	Gold	31.2884	118.6912
Red Robin	Gold	30.7968	118.9943
Red White & Blue	Copper, gold	33.6850	120.2002
Red White and Blue	Gold	32.2440	121.8031
Red Wings	Gold	31.1858	119.2839
Redross	Nickel	31.6854	121.6487
Referenda	Gold	31.7213	119.5774
Regent	Gold	32.1795	121.7928
Renegade	Gold	31.1910	119.2899
Rescue	Gold	32.1298	121.7898
Research	Gold	31.4698	119.4803
Resurrection	Gold	31.5493	119.5645
Resurrection	Copper, gold	33.6077	120.1314
Reta Alice	Gold	32.1890	121.7994
Revival	Gold	33.5384	120.0587
Revivification	Gold	32.3704	121.7950
Reward	Gold	31.2330	119.3256
Reynolds Find	Gold	30.9014	119.2102
Rhodda Drilling	Gold	32.1250	121.7916
Rhys	Gold	31.5463	119.5652
Rio Tinto	Gold	33.6009	120.1233
Rising Star	Gold	31.5483	119.5639
Rising Sun	Gold	32.2340	121.7864
Rising Sun	Gold	30.9742	119.1259
Roberts Find	Gold	30.8699	119.5935
Roddas Reward	Gold	31.1864	119.2868
Rona Daphne	Gold	30.8980	119.0947
Rondi	Gold	31.6062	119.6577
Rosalie	Gold	30.9063	119.0765
Rosehole	Gold	32.3156	121.8047
Round Top Hill	Iron ore	32.1634	120.4548
Royal Dane	Gold	32.1919	121.8009
Royal Flush	Gold	31.2820	118.6517
Royal George	Gold	31.2836	119.3258
Royal Prince North	Gold	32.1371	121.8063
Royal Slipper	Gold	32.1362	121.8076
Royal Victoria South	Gold	31.3041	119.2932
Ruapehu	Gold	31.2423	119.3117
Ruggle	Copper	33.5720	120.0447
Rutherfords Reward	Gold	31.3360	118.7695
Ryans Find – Mount Walter	Halloysite	30.9322	120.2070
Ryans Reward	Gold	30.8342	120.1782
Rythum Court	Gold	31.2282	119.3164
Sailfish	Gold	32.0834	121.7953
Salmon Gums	Clay, general	32.9281	121.6175
Salmon Gums	Construction materials	32.9798	121.6637
Salvation	Gold	31.4928	119.5305
Sand King	Gold	30.8275	119.0520
Sandfly	Gold	31.5261	119.5759
Saturn	Gold	30.8082	119.5676
Scaddan	Gypsum	33.3988	121.7348
Scaddan	Gypsum	33.3348	121.7373
Scaddan	Lignite	33.3515	121.8459
Scadden	Clay, general	33.3864	121.6928
Scadden	Clay, general	33.1678	121.7117
Scandinavian	Gold	32.1800	121.7979
Scorpio	Gold	31.4646	119.4987
Scots Greys	Gold	31.7657	119.5969
Scotch Lassie	Gold	31.5333	119.6161
Scotia	Gold	32.4704	121.7923
Seagull	Nickel	32.5568	119.7376
Searchlight	Gold	31.3647	119.3931
Searchlight North	Gold	31.6267	119.5769
Second Front	Gold	32.2074	121.8154
Second Try	Gold	32.2580	121.8109
Selene	Gold	32.4129	121.7825
Shoe	Gold	31.7432	121.7232
Shoemaker Levy	Nickel	33.5757	120.3259
Sign of Four	Gold	32.2276	121.7866
Sink or Swim	Gold	30.9651	119.0860
Sirdar	Gold	33.5457	120.0595
Skeleton Rocks	Kaolin	32.0044	119.5148
Snowdrop	Gold	31.7698	119.6070
Sons of Erin	Gold, tungsten	31.7469	121.7178
Sons of Gwalia	Gold	31.7487	121.7240
Sophia Brigitte	Gold	31.6771	121.8895
South Charmaine	Gold	33.5822	119.9727
South Gift	Copper, gold	33.6609	120.1915
South Ridge	Gold	32.4148	121.7835
South Side	Gold	31.7653	119.5938
Southdown	Iron ore	34.5393	118.5018
Southern Boulder	Gold	31.2357	119.3189
Southern Cross	Gypsum	31.2166	119.3466
Southern Cross	Gypsum	31.2447	119.2867
Southern Cross	Magnesite	31.3597	119.3500
Southern Cross	Magnesite	31.2667	119.3500

Locality name	Commodity	Latitude	Longitude
Southern Cross	Talc	31.1766	119.2723
Southern Cross	Gold	32.1853	121.8001
Southern Cross	Gold	31.2337	119.3215
Southern Cross Boulder	Gold	31.2733	119.3230
Southern Cross	Limestone	31.2610	119.3445
Southern Cross Options	Gold	31.5432	119.6893
Southern Hills	Heavy minerals, Ilmenite	32.1094	122.8000
Southern Kingfisher	Gold	31.5285	119.5832
Southern Queen	Gold	30.9046	119.0373
Southern Star	Gold	31.5949	119.6490
Sovereign	Gold	32.2061	121.7999
Speedie	Gold	31.4084	119.6893
Sphinx	Gold	31.7180	119.5777
Splendid Kingfisher	Gold	31.7122	119.5745
Spring Hill	Gold	31.6621	119.5756
St Agnes	Gold	32.2097	121.8020
St Claire No 2 South	Gold	30.8143	119.5877
St Clare	Gold	32.2448	121.8022
St George	Gold	31.2847	119.3248
St Patrick	Gold	32.1755	121.7971
St Patrick	Gold	31.5130	119.6115
Standard	Gold	30.2205	119.3020
Stapleton	Gold	32.2581	121.8268
Star	Gold	32.1923	121.8143
Star of Ennuin	Gold	30.7958	118.9912
Star of Erin	Gold	32.2175	121.7857
Star of Hope	Gold	30.9433	119.2081
Star of the Range	Gold	31.7032	119.5751
Starfinch	Gold	31.4575	119.4916
Stella May	Gold	32.2496	121.8165
Stennet	Gypsum	32.6330	121.5170
Stennetts Lake	Gypsum	33.2155	119.9681
Stokes Inlet	Heavy minerals	33.8284	121.1676
Stokes Inlet	Sand, silica	33.8183	121.1508
Stowaway	Gold	33.6741	120.2014
Strathbogie	Gold	32.0508	122.0344
Stumpy Doodle	Gold	30.8301	119.0512
Sudden	Gold	32.1754	121.8005
Sugar Gum	Gold	31.7480	121.7242
Sun	Gold	32.1576	121.8179
Sun leases	Gold	32.1561	121.8197
Sunbeam	Gold	31.2812	119.3255
Sunday Gift	Gold	32.8246	119.9828
Sunrise	Gold	32.3161	121.8070
Sunrise	Gold	31.2446	119.3248
Sunset	Gold	30.8002	118.9997
Sunset	Copper	33.5807	120.0386
Sunshine	Gold	31.5678	119.3862
Supreme	Gold	32.1958	121.7923
Surprise	Copper, gold	33.5811	120.0349
Surprise	Gold	32.2531	121.8064
Swanage	Gold	32.1892	121.8071
Sweet Alice	Gold	30.9123	119.0863
Sweet William	Gold	30.4814	118.8913
Swordfish	Gold	32.1340	121.7676
Sydney	Gold	31.2766	119.3248
Syncline	Gold	30.7308	118.9658
Taipan	Gold	30.1998	119.2598
Takedown	Gold	31.2326	119.3202
Tamarin	Gold	31.5889	119.4051
Tanami	Gold	32.2224	121.8076
Tarcoola	Gold	31.2477	119.3130
Tarpeena	Gold	32.2096	121.8158
Tasman	Gold	32.1543	119.6601
Teddy Bear	Gold	32.1123	119.6081
Telegraph Line	Gold	32.3476	121.7903
Ten Mile	Dimension stone, granite	32.0815	122.6664
The Prince Alfred	Gold	32.2022	121.8015
The Richmond	Gold	32.1874	121.8017
Thelma Joyce	Gold	32.2104	121.8102
Therese	Gold	31.2762	118.6506
Third Call	Gold	33.6559	120.1870
Thirteenth	Gold	31.6578	119.5673
Thisisit	Gold	30.7867	118.9735
Thistle and Shamrock	Gold	33.6294	120.1518
Three Boys	Gold	31.2318	119.3173
Three Colonies	Gold	32.1247	121.7887
Three Colors	Gold	30.8336	119.0200
Three Kingdoms	Gold	32.1763	121.7876
Three Kings	Gold	30.2360	119.3238
Three Queens	Gold	31.2355	119.3310
Three Star Lake	Gypsum	32.9973	120.6348
Three Star	Gold	32.2352	121.7848
Tiger Show	Gold	30.1989	119.2608
Titanic	Gold	30.2224	119.2972
Tommy Adkins	Gold	32.1674	121.7823
Tommy Atkins	Gold	32.1798	121.7983
Tommy Atkins	Gold	31.2742	118.6358
Toomey Hills	Gold	31.6037	119.6542
Trafalgar	Gold	31.3473	119.3895
Transvaal	Gold	31.2812	119.3225
Treasury	Gold	31.4215	119.4822
Triad	Gold	31.3643	119.4453
Trigg Hill	Gold	30.7973	118.9941
Trilogy	Copper	33.7546	120.2084
Triumph	Gold	31.6785	119.5649
Trough Well	Nickel	30.6732	118.8948
Trump	Gold	32.1808	121.8061
Trump	Gold	30.5529	118.9135
Trump Card	Gold	32.2458	121.8073
Try Again	Gold	33.6840	120.2035
Try Again	Gold	31.1800	119.2807
Tunnel	Gold	32.1704	121.8240
Turn of the Tide	Copper	33.5732	120.0483
Turnbulls Leases	Gold	31.4721	119.4825
Twertup Creek	Building stone, spongolite	34.0072	119.3922
Twisties Knob	Gold	31.5904	119.5515
Two Bar	Gold	31.4618	119.4926
Two Bobs	Gold	33.5469	120.0584
Two Bobs	Gold	31.7627	119.5969
Two Boys	Gold	30.9328	119.0703
Two Boys	Gold, copper	33.6726	120.2020
Two Boys	Gold	31.7429	121.7253
Two in the Bush	Gold	32.2901	121.8023
Two Japs	Gold	32.2124	121.8142
Two Seas	Gold	30.8765	119.0406
Two Williams	Gold	32.1757	121.7884
Twos & Threes	Gold	31.4697	119.4976
Ulverston	Gold	31.4674	119.4801
Undaunted	Gold	31.4610	119.4915
Union	Gold	32.2312	121.7921
Union Jack	Gold	32.2319	121.7932
Union Jack	Gold	31.4586	119.4910
United Australia	Gold	31.2936	119.3162
United Miners	Gold	32.2015	121.8137
United Scotchman GM Co NL	Gold	32.2029	121.7965
Unknown South	Gold	30.1991	119.2670
Up and Down	Gold	32.2066	121.8155
Vale	Gold	32.1947	121.8142
Valhalla	Gold	32.1754	121.7882
Valkyrie	Gold	32.2078	121.8015
Valley Queen	Gold	30.9018	119.0366
Valley Wonder	Gold	30.8831	119.0247
Van Uden	Gold	32.1507	119.6512
Vance	Gold	31.6138	119.5954
Vauxhall	Gold	31.5611	119.3836

Locality name	Commodity	Latitude	Longitude
Venture	Gold	32.1698	121.7890
Vesuvius Hill	Titanium, vanadium	32.5282	120.7909
Victor	Gold	32.2492	121.8073
Victoria	Gold	31.3454	119.4169
Victoria Reef	Gold	30.1814	119.1151
Victors	Gold	32.2487	121.8072
Victory	Gold	31.6036	119.6544
Viking	Gold	32.2059	121.7973
Vini Vidi Vici	Gold	32.2447	121.8074
Vintage Crop North	Gold	31.5530	119.5723
Vinto-La	Gold	31.3436	119.4148
Violet	Gold	30.8804	119.0406
Virginia	Gold	32.2473	121.7725
Volcano	Gold	30.9467	119.2136
WA Gold Development	Gold	30.9145	119.0826
Wainui	Gold	30.8986	119.0942
Walkover	Gold	32.1990	121.8136
Wallace	Gold	31.3457	119.3872
War Time	Gold	31.7474	121.7183
Warallakin	Clay, general	31.0258	118.5417
Waratah	Gold	32.3144	121.8072
Waratah	Gold	33.5756	120.0036
Warren Deeps	Gold	30.9760	119.1276
Watsonia	Gold	31.5415	119.6113
Waverley	Gold	32.0765	121.9006
We Come Again	Gold	32.1751	121.7876
Welcome	Gold	32.2272	121.7894
Welcome	Gold	30.8692	118.9990
Welcome Stranger	Copper	33.6275	120.1506
Well Known	Gold	30.1994	119.2618
Wellstead	Sand, silica	34.4842	118.6172
West Quest	Gold	32.2546	119.7712
West Quest	Nickel	32.2626	119.7723
West River	Kaolin	33.6641	119.7348
West River	Copper	33.7835	119.8843
West Wickham	Gold	30.1845	119.1274
Westeria	Gold	33.5695	120.0022
Western Gem	Gold	33.6726	120.1993
Western Mining	Gold	31.2361	119.3238
Western Options	Gold	31.2886	118.6772
Westons Reward	Gold	31.2701	118.6489
Westonia	Magnesite	31.2753	118.7015
Westonia	Tungsten	31.2906	118.7000
Westonia	Dolomite	31.2733	118.6481
Westonia	Gold	31.2912	118.6998
Westralia Long Tunnel	Gold	32.1976	121.8112
Westralia Waiki	Gold	32.1780	121.7955
Wheel	Gold	32.1940	121.8165
Wheel North	Gold	32.1935	121.8164
Wheel of Fortune	Gold	32.1963	121.8172
White Hope	Gold	30.9768	119.1276
White Horse	Gold	31.6857	119.5736
White Horseshoe	Gold	31.6857	119.5736
White Lake	Clay, general	33.7200	121.8403
White Reef	Gold	32.2346	121.8090
Who Can Tell	Gold	30.9468	119.2144
Who Can Tell	Copper	33.5570	120.0769
Willbee	Gold	31.1910	119.2899
William Tell	Gold	31.2317	119.3230
Wimmera	Gold	31.2337	119.3219
Windarling Range	Iron ore	30.0123	119.2875
Woolcock	Gold	31.5057	119.5812
Wray Bay	Heavy minerals	34.4506	118.9083
Wyworry	Gold	30.7825	118.9709
Yellowdine	Gypsum	31.1322	119.7181
Yellowdine	Mica	31.3582	119.7025
Yellowdine gold areas	Gold	30.4955	118.8931
Yellowdine	Gold	31.4096	119.6896
Yellowdine Options	Gold	31.2328	119.3163
Yellowdyne North	Gold	31.2814	119.6890
Yess	Gold	31.2446	119.3248
Yilgarn Consols	Gold	31.2420	119.3096
Yilgarn	Gold	31.5053	119.5807
Yilgarn Perseverance	Gold	31.3027	119.3848
Yilgarn Star	Gold	31.5332	119.6787
Yorkshire Pudding	Gold	32.2303	121.7887
Young Bill	Gold	32.3159	121.8067
Young River	Graphite	33.5472	120.9917
Young River	Nickel	33.5779	120.9765
Young River	Vermiculite	33.5391	120.9937
Zealandia	Copper	33.5731	120.0433
Zieglers Find	Gold	32.2249	121.8076

Appendix 2

Mineral potential assessment criteria and weighting factors for major deposit types in the Southern Cross – Esperance Region

General assessment criteria

1. *Orogenic gold*

- Presence of greenstone belts
- Shear zones
- Late fractures
- Internal granitoids

2. *Iron ore*

- Presence of BIF
- Magnetic anomaly

3. *Nickel sulfides in komatiites*

- Presence of greenstone belts

4. *Nickel sulfides in layered mafic intrusions*

- Presence of layered intrusions

5. *Nickel-bearing laterites*

- Underlain by greenstones, layered intrusions
- Presence of laterite

6. *Base metals in volcanogenic massive sulfides*

- Felsic volcanic–volcaniclastic rocks
- Bimodal volcanic rocks

7. *Stratabound base metal deposits*

- Proterozoic and younger sedimentary rocks
- Proximity to major rift-related fractures

8. *Heavy mineral sands*

- Strandlines
- Fluvial placer deposits

9. *Lignite*

- Cainozoic drainage
- Non-marine sediments

10. *Diamonds*

- Thick stable crust
- Crustal-scale fractures

Table 2.1. Weighting factors of mineralization models (in decreasing order of weighting)

Weighting factor	*Mineralization model*
10	Orogenic gold
7	Iron ore
7	Nickel sulfides in komatiites
7	Nickel-bearing laterites
4	Nickel sulfides in layered mafic intrusions
4	Base metals in volcanogenic massive sulfides
4	Stratabound base metal deposits
4	Lignite
2	Heavy mineral sands
1	Diamonds

Appendix 3

Definition of levels of resource potential and levels of certainty

The following is based on Taylor and Steven (1983), Marsh et al. (1984), Dewitt et al. (1986), and Bureau of Resource Sciences and Geological Survey of Western Australia (1998).

Levels of resource potential

The mineral potential of an area is assessed for specific types of mineral deposits. For each type of deposit considered in a given area, the mineral potential is ranked in qualitative terms as 'high', 'moderate', 'low', 'no' or 'unknown', based upon professional judgement of geoscientists involved in the assessment. The rankings are defined as follows:

HIGH (H): An area is considered to have a high mineral resource potential if the geological, geophysical, or geochemical evidence indicate a high likelihood that mineral concentration has taken place and that there is a strong possibility of specific type(s) of mineral deposit(s) being present. The area has characteristics that give strong evidence for the presence of specific types of mineral deposits. The assignment of high resource potential does not require that the specific mineral deposit types have already been identified in the area being assessed.

MODERATE (M): An area is considered to have a moderate mineral resource potential if the available evidence indicates that there is a reasonable possibility of specific type(s) of mineral deposit(s) being present. There may or may not be evidence of mineral occurrences or deposits. The characteristics for the presence of specific types of mineral deposits are less clear.

LOW (L): An area is considered to have a low mineral resource potential if there is a low possibility of specific types of mineral deposit(s) being present. Geological, geophysical, and geochemical characteristics in such areas indicate that mineral concentrations are unlikely, and evidence for specific mineral deposit models is lacking. The assignment of low potential requires positive knowledge and cannot be used as a valid description for areas where adequate data are lacking.

NO POTENTIAL (N): The term 'no' mineral resource potential can be used for specified types of mineral deposits in areas where there is a detailed understanding of the geological environment and geoscientific evidence indicates that such deposits are not present.

UNKNOWN POTENTIAL (U): If there are insufficient data to classify the areas as having high, moderate, low, or no potential, then the mineral resource potential is unknown.

The ranking of Moderate to High (*M–H*) is used for areas intermediate between *H* and *M*, and Low to Moderate (*L–M*) is used for areas intermediate between *M* and *L*.

Table 3.1 Relationship between levels of resource potential (H, M, L, N, U) and levels of certainty (D, C, B, A), including numerical values for ranking (in brackets)

	Level D	*Level C*	*Level B*	*Level A*
	Decreasing level of certainty →			
Decreasing level of mineral potential ↓	H/D (18) High potential	H/C (18) High potential	H/B (15) High potential	U/A Unknown potential
	M/D (12) Moderate potential	M/C (12) Moderate potential	M/B (9) Moderate potential	
	L/D (6) Low potential	L/C (6) Low potential	L/B (6) Low potential	
	N/D (0) No potential			

Levels of certainty

To reflect the differing amount of information available, the assessment of mineral potential is also categorized according to levels of certainty (denoted by letters *A* to *D)*.

A: The available data are not adequate to determine the level of mineral resource potential. This level is used with an assignment of unknown mineral resource potential.

B: The available data are adequate to suggest the geological environment and the level of mineral resource potential, but either the evidence is insufficient to establish precisely the likelihood of resource occurrence or the occurrence and/or genetic models are not well enough known for predictive resource assessment.

C: The available data give a good indication of the geological environment and the level of mineral resource potential.

D: The available data clearly define the geological environment and the level of mineral resource potential.

Numerical values for ranking resource potential and certainty

In order to produce a plan of the composite or cumulative mineral potential of the region, the mineralization models are weighted (see Appendix 2) and each combination of level of resource potential and level of certainty (for each model) is assigned a numerical point score. This varies from an arbitrary 18 for areas or tracts of high potential (i.e. *H/D*) to a value of 0 for areas or tracts with no potential (Table 3.1).

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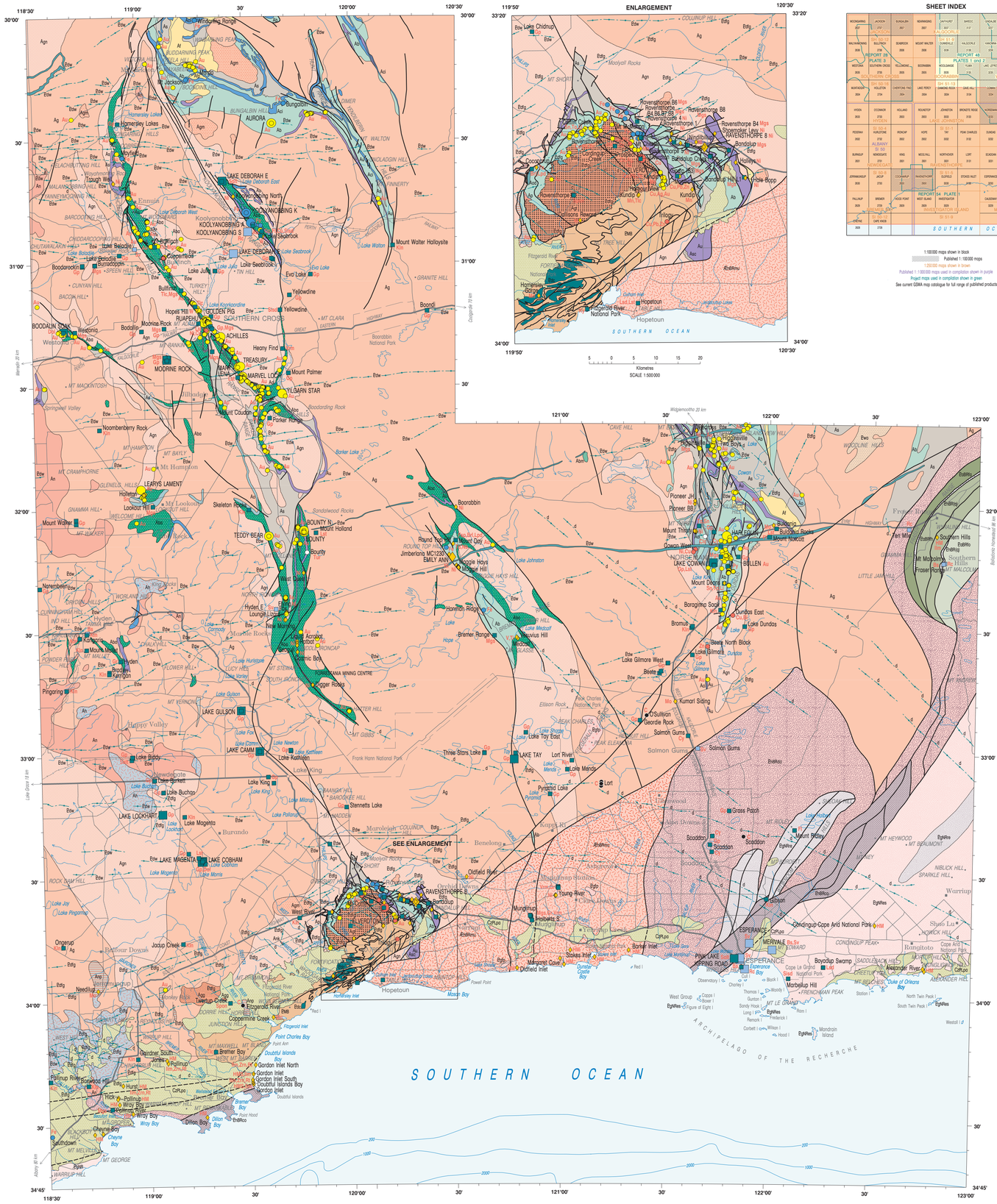
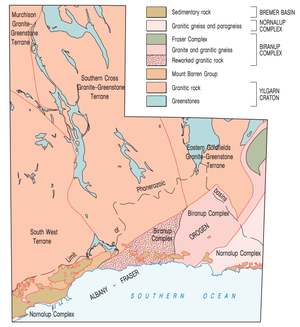


ENLARGEMENT

SHEET INDEX

1:100 000 maps shown in black
Published 1 : 100 000 maps
1:250 000 maps shown in brown
Published 1:100 000 maps used in compilation shown in purple
Project maps used in compilation shown in green
See current GSWA map catalogue for full range of published products

TECTONIC UNITS



- Sedimentary rock
- Granitic gneiss and paragneiss
- Fraser Complex
- Granite and granitic gneiss
- Reworked granitic rock
- Mount Barren Group
- Granitic rock
- Greenstones

BREMER BASIN
NORNALUP COMPLEX
BIRANUP COMPLEX
YILGARN CRATON

Geological boundary
Fault
exposed
concealed
Primary road
Secondary road
Railway
National park boundary
Townsite
population 1000–10 000
less than 1 000
Homestead
Watercourse
Bathymetric contour, depth in metres
Operating mine — Bungalbin
Mineral deposit or occurrence — KOOLYANOBBING A

MINERAL DEPOSITS
ORE OCCURRENCES — OPERATING MINE

ALLOYING AND SPECIALTY METALS
Beryllium, lithium, manganese, molybdenum, nickel, tantalum, tin, titanium, tungsten, vanadium, zirconium
BASE METALS
Copper, lead, zinc
CONSTRUCTION MATERIALS
Sand, gravel, aggregate, ornamental dimension stone
ENERGY MINERALS
Lignitic coal
GEM AND SEMI-PRECIOUS STONES
Chalcedony, rutile/tile (tourmaline)
INDUSTRIAL MINERALS
Clays, dolomite, fluorite, graphite, gypsum, jarosite, kyanite, limestone, magnesite, pyrite, pyrrhotite, salt, silica, spongolite, talc, vermiculite
IRON
Iron ore
PRECIOUS METALS
Gold

MINERAL OCCURRENCES

Aggregate	Rc	Limestone	Lst
Beryl	Brl	Lithium	Li
Bismuth	Bi	Magnesite	Mgs
Building stone	Bs	Manganese	Mn
Chalcedony	Clc	Molybdenum	Mo
Clay	Cy	Nickel	Ni
Coal	C	Niobium	Nb
Copper	Cu	Pyrite	Py
Dolomite	Dol	Rutile	Rt
Feldspar	Fsp	Salt	Solt
Fluorite	Fl	Sand	Sv
Gemstones, semi-precious	Gs	Silica sand	Slsd
Gold	Au	Silver	Ag
Graphite	Gr	Spongolite	Spon
Gypsum	Gp	Talc	Tlc
Heavy mineral sands	HM	Tantalum	Ta
Ilmenite	Ilm	Tin	Sn
Iron	Fe	Titanium	Ti
Jarosite	Jar	Tourmaline	Tur
Kaolinite	Kln	Tungsten	W
Kyanite	Ky	Vanadium	V
Lead	Pb	Vermiculite	Vrm
Lepidolite	Lpd	Zinc	Zn
Limesand	Lsd	Zircon	Zrn

Geology compiled by F. Vanderhor 2000 using published geological data (references in GSWA Record 2002:3)

Mine and mineral deposit data extracted from MINEDEX, April 2001
Mineral occurrence data extracted from WAMIN, April 2000

Edited by F. Eddison and C. Brien

Cartography by D. Wallace, P. Taylor, B. Williams, and K. Greenberg

Topography from the Department of Land Administration Sheet SH 50, SH 51, SI 50, and SI 51, with modifications from geological field survey

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Web: www.mpr.wa.gov.au Email: geological_survey@mpr.wa.gov.au

Plotted by the Geological Survey of Western Australia

The recommended reference for this map is:
VANDERHOR, F., 2002, Geology and mineral resources of the Southern Cross - Esperance region (1:1 000 000), in Geology and mineral resources of the Southern Cross - Esperance region of Western Australia *compiled by* P. B. ABEYSINGHE, D. J. FLINT, J. LUCKETT, S. A. McGUINNESS, J. PAGEL, D. B. TOWNSEND, and F. VANDERHOR: Western Australia Geological Survey, Record 2002/3, Plate 1.

PHANEROZOIC

CAINOZOIC

Pentagreen Group

- CzPLpo — **PALLINUP SILTSTONE:** siltstone, silty sandstone, and spongolite

PROTEROZOIC

- d — Dolerite dyke, intruded into Precambrian rock; interpreted from aeromagnetic data where dashed
- Edfg — **FRASER and GNOWANGERUP DYKE SWARMS:** dolerite dyke, interpreted from aeromagnetic data

Albany – Fraser Orogeny (Stage II)

NORNALUP COMPLEX

- EghR — Undivided granitic gneiss
- EghWes — **ESPERANCE GRANITE:** weakly to moderately deformed and recrystallized granite; even-grained or porphyritic
- EghWre — **RECHERCHE GRANITE:** moderately to strongly deformed and recrystallized granite; heterogeneous; even-grained or porphyritic

Albany – Fraser Orogeny (Stage I)

BIRANUP COMPLEX

FRASER COMPLEX

- EdBRo — Garnet amphibolite
- EdBRh — Pyroxene granulite
- EdBRo — Metagabbro
- EsBRq — Quartzite, quartz–mica schist, pelitic schist, and banded iron-formation
- EmBRco — **CORAMUP GNEISS:** granitoid gneiss, heterogeneous; mainly derived from **RECHERCHE GRANITE**, deformed with orthogneiss and paragneiss
- EmBRdo — **DALYUP GNEISS:** granitic augen gneiss and granitoid gneiss

MESOPROTEROZOIC

- Ewo — **WOODLINE FORMATION:** cremaceous and argillaceous metasedimentory rocks, including silicified evaporite
- Edo — **COWERDUP SILL:** metadolerite and mafic schist
- EMB — **Mount Barren Group:** shale, sandstone, phyllite, and schist; quartzite and dolomite
- Eyfg — **FITZGERALD PEAKS SYENITE:** syenite and quartz syenite
- Edw — **WIDGIEMOOLTHA DYKE SWARM:** dolerite dyke, sill, and plug; interpreted from aeromagnetic data where dashed

PALAEOPROTEROZOIC

BIRANUP COMPLEX

- EmBRmu — **MUNGLINUP GNEISS:** granitoid gneiss, heterogeneous; Archaean and Proterozoic granitoid rock deformed and metamorphosed during Mesoproterozoic Albony–Fraser Orogeny

ARCHAEAN

YILGARN CRATON

- Ap — Pegmatite
- Ag — **Granitoid rock; monzogranite dominant**
- Agg — Granodiorite
- Agm — Monzogranite
- Agn — Foliated, gneissic, and migmatitic granitoid
- Agt — **Tonalite**

- An — Gneiss
- Ank — Calc-silicate gneiss and amphibolite
- Anp — Paragneiss and schist
- Ah — **Granulite and migmatite; high-grade metamorphic rock**

- As — Metasedimentary rock dominant
- Asc — Metamorphosed conglomerate
- Aci — Banded iron-formation and chert, with minor mafic and ultramafic volcanic rock; metamorphosed

- Af — Felsic to intermediate volcanic and volcanogenic rock, undivided; metamorphosed
- Afp — Felsic porphyry; quartz and feldspar phenocrysts; metamorphosed

- Ao — Metamorphosed mafic intrusive rock; metagabbro and metadolerite
- Aod — Mafic intrusive rock; metadolerite
- Ab — Mafic volcanic rock with minor mafic and ultramafic intrusive rocks; minor felsic rock; metamorphosed
- Abo — Amphibolite
- Abm — Metamorphosed ultramafic volcanic rock; komatiitic basalt, high-Mg basalt, and tremolite–chlorite–talc schist
- Au — Metamorphosed ultramafic rock dominant

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SCALE 1:1 000 000

10 000 0 10 20 30 40 50 60 70 80 90 100
Metres — Kilometres

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
HORIZONTAL DATUM: GEOCENTRIC DATUM OF AUSTRALIA 1994
VERTICAL DATUM: AUSTRALIAN HEIGHT DATUM
BATHYMETRIC DATUM: LOWEST LOW SEA LEVEL
Ticks on the neatlines are at 0.1° interval

GDA — The Map Grid Australia (MGA) is based on the Geocentric Datum of Australia 1994 (GDA94)
GDA94 positions are compatible within one metre of the datum WGS84 positions

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

RECORD 2002/3 PLATE 1

GEOLOGY AND MINERAL RESOURCES OF THE SOUTHERN CROSS — ESPERANCE REGION