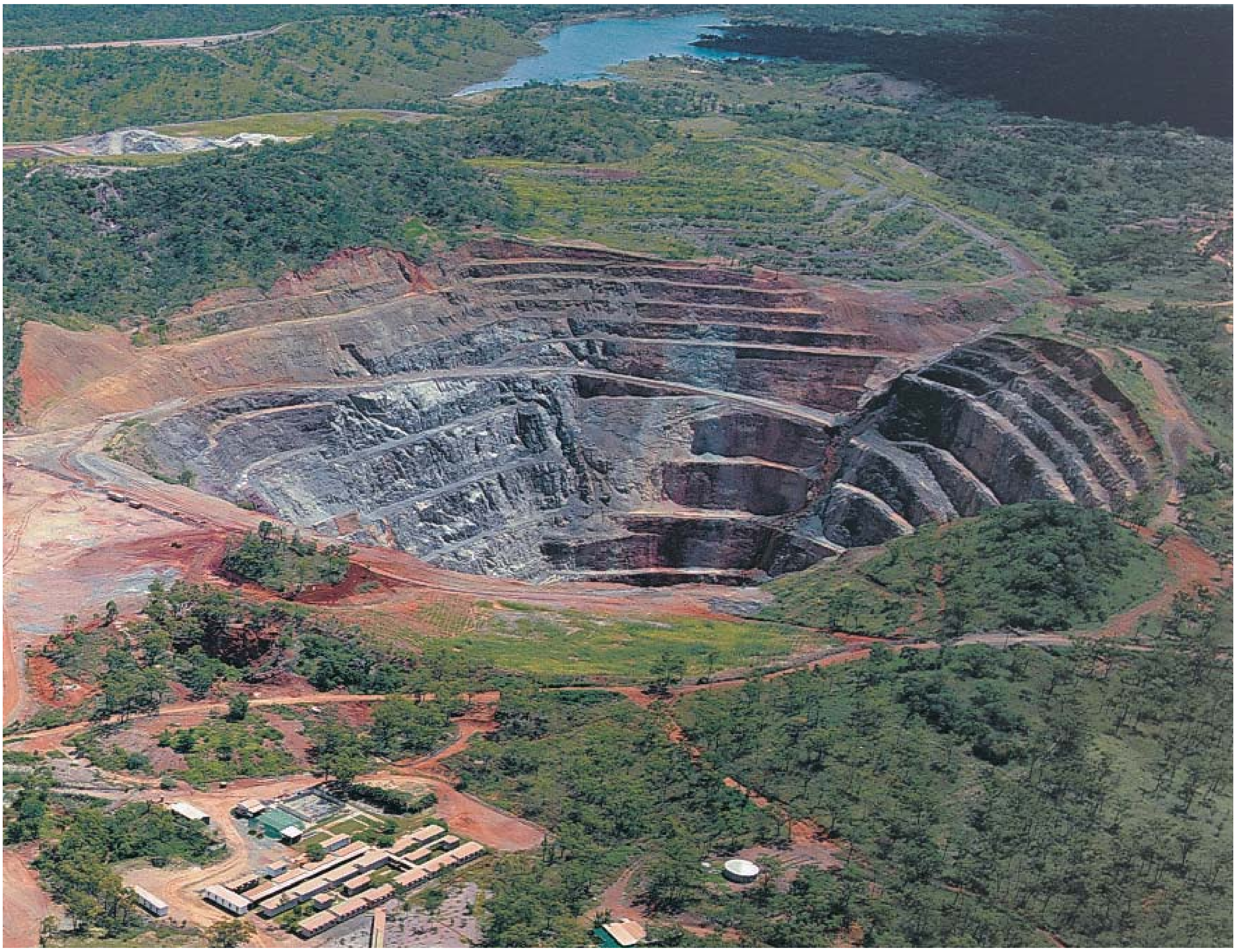
QUEENSLAND
MINERALS AND
ENERGY
REVIEW SERIES

DEPARTMENT
OF MINES
AND ENERGY

GEOLOGY AND MINERALISATION HODGKINSON PROVINCE



DEPARTMENT OF MINES AND ENERGY, QUEENSLAND

1999

ISSN 1039-5555

Updated contacts for 2011 cd version:

Geological Survey of Queensland
Department of Employment, Economic Development and Innovation
Level 10, 119 Charlotte St
Brisbane, QLD 4000
Ph: +61 7 3006 4666
Email: geological_info@deedi.qld.gov.au
Web: http://mines.industry.qld.gov.au/default.htm

Address for correspondence:
P.D. Garrad or R.J. Bultitude
Queensland Department of Mines and Energy
GPO Box 194, Brisbane, Q.
Australia, 4001

Published by the Queensland Department of Mines and Energy
© The State of Queensland, Department of Mines and Energy, 1999
ISSN 1039-5555
ISBN 0 7242 7227 5
Production editing: JW Beeston
Graphics: T Moore, L Blight, PD Garrad
Desktop publishing: SA Beeston
Printed by Colourwise Reproductions

Issued: March, 1999

REFERENCE:

GARRAD, P.D. & BULTITUDE, R.J., 1999: Geology, mining history and mineralisation of the Hodgkinson and Kennedy Provinces, Cairns Region, North Queensland. *Queensland Minerals and Energy Review Series*, Queensland Department of Mines and Energy.

Front Cover: Red Dome gold mine *(photograph by Ian Oswald-Jacobs)*
Back Cover: Abandoned tin mine north-west of Mount Garnet (*photograph by Paul Garrad)*

GEOLOGY, MINING HISTORY AND MINERALISATION OF THE HODGKINSON AND KENNEDY PROVINCES, CAIRNS REGION, NORTH QUEENSLAND

P.D. Garrad & R.J. Bultitude

CONTENTS

GEOLOGY 3

GEOLOGICAL FRAMEWORK 5

LATE PROTEROZOIC TO ORDOVICIAN ROCKS 6

Barnard Province 6

Macrossan Province 10

Hodgkinson Province 11

SILURIAN TO EARLY DEVONIAN ROCKS 22

Hodgkinson Province 22

DEVONIAN TO EARLY CARBONIFEROUS? ROCKS 24

Hodgkinson Province 24

Hodgkinson Province Rocks of uncertain age 29

STRUCTURE OF THE HODGKINSON PROVINCE 30

TECTONIC MODEL FOR THE HODGKINSON PROVINCE 30

Late Devonian Intrusive Rocks 35

LATE PALAEOZOIC SEDIMENTARY AND MINOR TO SUBORDINATE VOLCANIC ROCKS . . 37

Kennedy Province 37

LATE PALAEOZOIC IGNEOUS AND MINOR SEDIMENTARY ROCKS 40

Kennedy Province 40

Kennedy Province — Volcanic Rocks, Chillagoe–Ravenshoe Area 40

Kennedy Province — Volcanic Rocks, Cooktown–Cape Tribulation Area 71

Kennedy Province — Granites 72

Chillagoe–Herberton Area 72

Kennedy Province — Cairns–Cape Melville Area 79

Kennedy Province — Tully–Ingham Area 97

Kennedy Province — unassigned units 107

Kennedy Province — ultramafic rocks 107

Kennedy Province — dykes 108

Kennedy Province — intrusive breccias 108

MESOZOIC SEDIMENTARY ROCKS 108

CAINOZOIC VOLCANIC ROCKS 110

CAINOZOIC SEDIMENTS 113

CORRELATIONS — INTRA AND INTER-REGIONAL 115

MINING HISTORY 117
Gold 117
Tin 121
Tungsten, Bismuth and Molybdenum 124
Base Metals 126
Antimony 128
Coal 129
Fluorite 129
Iron 129
Limestone 129
Manganese 130
Clay 130
EXPLORATION REVIEW 130
KNOWN MINERALISATION AND RESOURCES 132
Antimony 133
Base Metals 136
Coal 146
Cobalt 146
Dimension Stone 147
Fluorite 147
Gemstones 147
Gold 148
Heavy Minerals 166
Iron 167
Limestone 167
Manganese 168
Molybdenum 168
Perlite 169
Phosphate 169
Silica Sand 169
Tin 170
Tungsten 184
Uranium 190
Other Commodities 191

MINERAL RESOURCE ASSESSMENT 193
Breccia-Hosted Deposits 194
Chert-Hosted Gold Deposits 196
Coal 198
Ecolite Subduction (ES) – Diamond Model 199
Epithermal Deposits 201
Hydrothermal Deposits 203
Intrusive Related Deposits 205
Lateritic Nickel 211
Limestone Deposits 212
Manganese Deposits 214
Mesothermal Deposits 216
Molybdenum and Bismuth 221
Placer Deposits 221
Porphyry-Type Copper or Porphyry Molybdenum 227
Shoreline Deposits 229
Skarn Deposits 232
Volcanogenic Massive Sulphide (VMS) Deposits 240
DISTRICT ANALYSIS 245
Mine distribution 245
Production distribution 245
Correlation of mineralisation and geological units 247
Structural and lineament analysis 249
Potential exploration models applicable to the Cairns Region 249
Mass Balance calculation for the Hodgkinson Formation 251
Conclusions 252
REFERENCES 252

FIGURES

1. Locality Map 3
2. Al_2O_3, Rb, Sc, and Th versus SiO_2 plots for the metamorphosed supracrustal rocks of the Barnard Metamorphics 7
3. Chemical variation diagrams highlighting the differences between Ordovician granites which intrude the Barnard Metamorphics and the enclosing metamorphic rocks. 12
4. Multi-element variation diagram showing similarities between early Ordovician felsic S-type granites which intrude the Barnard Metamorphics and early Permian granites of the Whypalla Supersuite. 13
5. Multi-element variation diagram showing similarities between late Ordovician felsic I-type? granites of the Barnard Metamorphics and selected I-type granites of similar age in the Charters Towers Region. 13

6. Selected major element (wt%) plots showing the relatively mafic, TiO_2 and FeO*-rich character of the Mount Formartine Granite. 36

7. Na_2O and CaO/Sr versus SiO_2 plots for the Claret Creek Supersuite (extrusive and intrusive rocks). 41

8. Zr (ppm) versus Ga/Al, and Zr, Ce and La (ppm) versus SiO_2 (wt%) plots for late Palaeozoic volcanic rocks in the south-eastern to south-western parts of the Cairns Region. 52

9. Zr, Y, Zn (ppm), and Ga/Al versus SiO_2 (wt%) plots for the late Palaeozoic volcanic rocks in the south-eastern part of the Cairns Region. 62

10. Rb (ppm) versus K/Rb plot for the Glen Gordon and Wallaman Falls Volcanics. 63

11. Zr, Rb, Sr (ppm), and Ga/Al versus SiO_2 or FeO* (wt%) plots for the Featherbed Volcanic Group. 66

12. Selected variation diagrams highlighting the chemical similarities between late Carboniferous volcanic rocks of the Featherbed Volcanic Group and granites of the Almaden and Ootann Supersuites. 68

13. Zr, Cr, Na_2O, and Ce versus SiO_2 plots for the Nychum Volcanics. 69

14. Modal and chemical classifications of late Palaeozoic I-type granites in the western part of the Cairns Region. 73

15. Variation diagrams showing chemical differences between granites of the Almaden, O'Briens Creek, and Ootann Supersuites 75

16. Zr, Nb, Ce (ppm), and CaO/Sr versus TiO_2 (wt%) plots for the O'Briens Creek and Ootann Supersuites and intrusive rocks in the area of Red Dome gold mine. 76

17. K_2O and Rb versus FeO*, Sr and Sr/Rb versus SiO_2, and Th and Y versus K/Rb plots for the Almaden, Claret Creek and Ootann Supersuites and 12Hammonds Creek Granodiorite. 78

18. Modal data for granites from the minor S-type supersuites of the central and eastern Cairns Region. 79

19. CaO and K_2O versus FeO* (wt%) plots for the Emerald Creek, Tinaroo and Whypalla Supersuites. 80

20. Geochemical plots for selected S-type granites of the eastern Hodgkinson Province. 82

21. Al_2O_3, P_2O_5 (wt%), and Nb (ppm) versus K/Rb, and normative Q–Ab–Or plots for the Wangetti and Mount Alto Supersuites. 84

22. Chemical variation diagrams for the major S-type granite supersuites, central and eastern Cairns Region. 86

23. Modal and chemical data for I-type granites of the eastern part of the Cairns Region. 87

24. Selected variation diagrams for the Permian I-type granites of the eastern Cairns Region and the granites (S-types?) of the Wakooka Supersuite. 88

25. Total Al versus mg-ratio for biotites in selected S- and I-type granites from the eastern Hodgkinson Province. 89

26. Total Al versus mg-ratio for biotites in selected S- and I-type granites from the eastern Hodgkinson Province. 90

27. Modal and chemical data for granites from the Cooktown and Whypalla Supersuites, showing the relatively K-feldspar and quartz-rich character of most of the members of the Cooktown Supersuite. 92

28. Plagioclase compositions (determined by electron microprobe) in granites of the Cooktown and Whypalla Supersuites. 92

29. Selected Harker-type chemical variation diagrams for the granites of the Cooktown Supersuite. 93

30. Plagioclase compositions (determined by electron microprobe) in Permian I-type granites of the eastern Cairns Region. 94

31. Chemical variation diagrams for microgranite and rhyolite dykes (Shiptons Flat Supersuite) from the north-eastern part of the Cairns Region. 96

32. Chemical variation diagrams for the Bedarra granite belt. 99

33. Total Al versus mg-ratio for biotites from selected granites of the Bedarra granite belt, and Permian I- and S-type granites of the eastern Hodgkinson Province. 100

34. Chemical variation diagrams for the granitic and mafic intrusive rocks of the Tully and Ingham Batholiths (including rocks from Garden and Goold Islands). 102

35. Selected Harker variation diagrams for the granitic and mafic intrusive rocks of the Tully and Ingham Batholiths (including rocks from Garden and Goold Islands), and the Glen Gordon and Wallaman Falls Volcanics. 103

36. Selected Harker variation diagrams for the granitic and mafic intrusive rocks of the Tully and Ingham Batholiths (including rocks from Garden and Goold Islands), and the Almaden, Cape Melville, Ootann and Yates Supersuites. 104

37. Zr, Zn, Ga, Rb, Th, and Y (ppm) versus FeO* or SiO_2 (wt%) plots for the felsic intrusive rocks of Hinchinbrook Island and the Palm Islands. 106

38. Orientation of Antimony mineralised reefs in the Hodgkinson Gold Field. 134

39. Orientation of Antimony and Gold reefs in the Mitchell River area. 134

40. Orientation of Base Metal mineralisation in the Herberton Mineral Field. 140

41. Vein orientation in the Copper Firing Line area. 140

42. Orientation of reefs in the Siberia Lode Group. 141

43. Orientation of mineralised veins in the Montalbion area. 141

44. Orientation of mineralised reefs in the East and West Orient Camps. 142

45. Trend of gold reefs in the Hodgkinson Gold Field. 149

46. Reef trends in the Mount Peter Provisional Gold Field. 153

47. Reef trends in the Mulgrave Gold Field, including Kraft Creek area (Bartle Frere Gold Field). 154

48. Strike direction of reefs in the Maytown area. 156

49. Reef trends in the Groganville area. 157

50. Reef trends in the West Normanby Gold Field. 159

51. Orientation of all Manganese deposits within the study area. 168

52. Tin vein orientations in the Cannibal Creek area. 171

53. Orientation of tin veins in the Cooktown Tin Field. 171

54. Tin vein orientations in the Herberton Mineral Field. 177

55. Tin vein orientations in the Herberton Mineral Field. 186

56. Tungsten vein orientations in the Mount Carbine area. 187

57. Distribution of known breccia hosted deposits and regions favourable for breccia hosted deposits. 195

58. Distribution of known chert hosted gold deposits and and favourable regions for chert hosted gold deposits. 197

59. Distribution of known volcanic vents and diamond prospects. 200

60. Distribution of known epithermal mineralisation and regions favourable for epithermal deposits. 202

61. Distribution of known epithermal mineralisation and regions favourable for epithermal deposits. 204

62. Distribution of known Cornish style tin vein deposits in the Herberton region and permissive resource potential regions. 207

63. Grade-tonnage diagram for vein tin deposits in the Cairns region. 208
64. Distribution of known serpentinite rocks. 212
65. Distribution of limestone and limestone bearing units within the Cairns region and known limestone and marble operations. 213
66. Distribution of known manganese deposits and favourable regions for manganese mineralisation. 215
67. Distribution of known mesothermal mineralisation and regions favourable for mesothermal gold deposits. 217
68. Distribution of known quartz-stibnite deposits and regions favourable for hosting quartz-stibnite deposits. 220
69. Distribution of known alluvial and hard rock occurrences and regions favourable for alluvial gold deposits. 223
70. Distribution of known alluvial tin deposits and favourable regions. 226
71. Distribution of known porphyry deposits and the host granite plutons. 228
72. Distribution of known and potential silica sand and heavy mineral sand resources. 231
73. Distribution of known skarn deposits, granites and units containing limestone in the Cairns region. 234
74. Grade-tonnage diagrams for Copper skarn deposits. 238
75. Grade-tonnage diagram for tin skarn deposits. 239
76. Distribution of known Volcanogenic Massive Sulphide deposits and regions favourable for hosting VMS deposits. 242
77. Grade-tonnage diagram for Besshi-Kieslager deposits. 244
78. Distribution of mines classified by major commodity for the Cairns region 246
79. Grade-tonnage diagrams summarising known production of the main commodities mined in the Cairns region. 247
80. Host rock types for major commodity groups in the Cairns region. 248
81. Mine density for the Major rock classes. 250
82. Volume of rock and gold endowment calculation for the Hodgkinson Formation. 252

TABLES

1. Summary of predominantly sedimentary rock units, Cairns Region. 14
2. Summary of the main deformational events in the Hodgkinson Province. 32
3. Summary of volcanic units, Cairns Region. 42
4. Details of selected granite groups of the Cairns Region. 54
5. Geochemical characteristics of S-type granites of the eastern Hodgkinson Province. 81
6. Known total production for the main mines near the Chillagoe township. 137
7. Recorded total production from the main base metal mines in the Herberton Mineral Field. 139
8. Total Production from recent alluvial mining operations in the Palmer Gold Field. 155
9. Annual production for Red Dome. 164
10. Recent production figures for Cape Flattery. 170
11. Total production for the main alluvial tin deposits in the Herberton mineral field. 178

APPENDIXES

1. List of constituent units, selected granite supersuites, Cairns Region. 269
2. Production table for Cairns Region. 290
3. Resources table for Cairns Region. 295

SUMMARY

The Cairns region is richly endowed in mineral deposits. The main commodities are antimony, bismuth, coal, copper, gold, lead, limestone, molybdenum, perlite, silica sand, silver, tin and tungsten. Minor occurrences of uranium, manganese, gemstones, fluorite, iron and mineral sands have also been reported.

The Hodgkinson Province, the most extensive element represented in the Cairns Region, consists of early–middle Palaeozoic rocks that crop out extensively east of the Palmerville Fault, a major discontinuity in north Queensland. It forms a belt ~500km long, from south of Innisfail to Cape Melville and from the coast up to ~150km inland. The province extends out to sea for an unknown distance. Constituent units consist of mainly turbiditic sedimentary rocks, with generally subordinate interlayered limestone, chert, and basic volcanic rocks. Limestone and basic volcanic rocks are abundant in parts of the early Silurian–early Devonian Chillagoe Formation. The poorly fossiliferous late Silurian?–late Devonian Hodgkinson Formation is by far the most extensive unit.

The tectonic environment and setting for the rocks of the Hodgkinson Province are uncertain. Most previous investigators have interpreted the succession as having accumulated in a fore-arc/accretionary prism setting located to the east of an active continental magmatic arc. The abundance of relatively deep-water turbidity-current deposits in the Hodgkinson Formation, the presence of numerous thrust faults, and the widespread distribution of melange zones are the main reasons for proposing such a model. However, not all the features of the province can be readily rationalised by subduction — some, in fact, appear to support an extensional rather than a compressional regime during deposition of many of the rocks. Fissures produced during this postulated crustal extension locally acted as pathways for the eruption of submarine tholeiitic basalt and contemporaneous fluids which formed manganiferous exhalative deposits (some with anomalously high gold contents) and small, volcanogenic massive sulphide lenses (Mount Molloy and Dianne copper deposits).

The Hodgkinson Province has been affected by at least four significant regional deformational events. Many of the structures developed were the loci for synchronous or subsequent granite emplacement, as well as for major ore deposits. As with the tectonic setting and environment there is no general agreement regarding the structural and tectonic evolution of the Hodgkinson Province and many problems remain unresolved. The first regional deformation to affect the entire province was a major shortening event that resulted in extensive disruption of the succession by numerous thrust faults. This most probably occurred in the late Devonian. Extensive repetition of the sequence has been demonstrated in the Chillagoe Formation using conodonts to determine the ages of limestone lenses. Slate-belt type gold-bearing quartz veins, as well as antimony-bearing quartz veins, were deposited during one or more of these deformational events. The mineralising fluids were probably generated during regional tectonism, possibly accompanied in some cases by emplacement of granite plutons, and concentrated in dilational sites (mainly within shear zones). Ten abandoned gold fields have been proclaimed in the region. They include the rich Palmer River and Hodgkinson Gold Fields.

The last major regional deformational events were associated with the mid-Permian–Triassic Hunter–Bowen Orogeny. Many of the granites in the eastern Hodgkinson Province were emplaced during this orogenic episode.

The Cairns Region was a centre for extensive magmatic activity spanning the period from ~340Ma to ~255Ma. Numerous granite plutons were emplaced during this period (particularly in the late Carboniferous–early Permian) and several major subaerial volcanic sequences were erupted. Anomalous uranium mineralisation occurs in hot springs associated with, and infilling fractures in, some of these volcanic sequences.

The eastern Hodgkinson Province is characterised by the most extensive development of S-type granites in north Queensland. They form part of the very extensive Kennedy Province. These granites contain significant tin (south of Cooktown, and at Mount Holmes, Mount Lewis and Mount Spurgeon), and tungsten mineralisation (in skarns at the Watershed prospect, and in quartz veins at Mount Carbine).

Highly fractionated I-type granites of the O'Brien's Creek Supersuite are the main sources of the extensive tin, tungsten and complex polymetallic tin-bearing veins in the Herberton Tin Field. Skarns related to the O'Brien's Creek Supersuite near Mount Garnet contain large sub-economic fluorite and tin deposits. At Wolfram Camp and Bamford Hill, rich deposits of wolframite, molybdenite and bismuthinite are present in vughy pipes, and quartz veins and sheets in endogreisens developed in cupolas in high-level granite of the Ootann Supersuite.

In the western part of the region limestone of the Chillagoe Formation has been intruded by I-type granites of the Almaden and Ootann Supersuites, resulting in the formation of mineralised skarns containing gold, silver, base metals and minor tin. Nickeliferous, serpentinised, ultrabasic–basic bodies exposed near Julatten probably represent mantle-derived material, emplaced along a major crustal suture. Lateritic deposits developed on these bodies are currently uneconomic.

Sapphires, zircons and rare diamonds have been found in the Lakeland Downs area, where they are associated with Cainozoic pyroclastic deposits.

Keywords: regional geology; stratigraphy; igneous geology; geochemistry; economic geology; mineralisation; deposit models; mineral resources; mining history; Hodgkinson Province; Kennedy Province; Palaeozoic; Mesozoic; Cainozoic; Cairns Region.

GEOLOGY

R.J. Bultitude

The Cairns Region (Figure 1) mainly covers the area east of the Palmerville Fault of de Keyser & Lucas (1968). It extends beyond the trace of the fault in the south. There, the irregular boundary with the adjoining Charters Towers Region has been placed to exclude the early–middle Carboniferous granites of the Kangaroo Hills Mineral Field and environs. The Cairns Region contains mainly rocks of the Hodgkinson and Kennedy Provinces. It also contains the Barnard Province, in the far south-east, and elements of several other provinces, such as the Cambrian–Ordovician Macrossan Province and the Cainozoic East Australian Basalt Province. The very extensive Hodgkinson Province is confined to the region. The region, as currently defined, excludes the rocks of the Laura and Kalpower Basins (Quincan Region; Draper & others, 1997).

This review is based on a report presented in the joint AGSO-GSQ publication on the geology of north Queensland (Bain & Draper, 1997). A second edition 1:500 000-scale geological map of the Hodgkinson Province (Bultitude & others, 1997) accompanies this review. Some units listed in the tables are not shown on the 1:500 000-scale map. Readers should refer to the relevant 1:250 000 and 1:100 000-scale maps of the region as they are produced to find these units. The study has benefited significantly from four weeks' research at the Australian National University (in April–May 1997). It also incorporates results of several weeks field work in the Mount Mulligan and Palmerville areas between 1995 to 1997, when the writer was a member of Earth-Watch archaeological expeditions. Consequently, this review is an update of that presented in Bain & Draper (1997, Chapter 7).

Terminology

Province, region, and structural element nomenclature used in this report follows that recently adopted in the report of the geology of north Queensland (Bain & Draper, 1997). The Kennedy Province, for example, consists of the late Palaeozoic igneous and associated sedimentary rocks of north Queensland. It, therefore, includes the Coastal Ranges Igneous Province of Stephenson & Griffin (1976) and

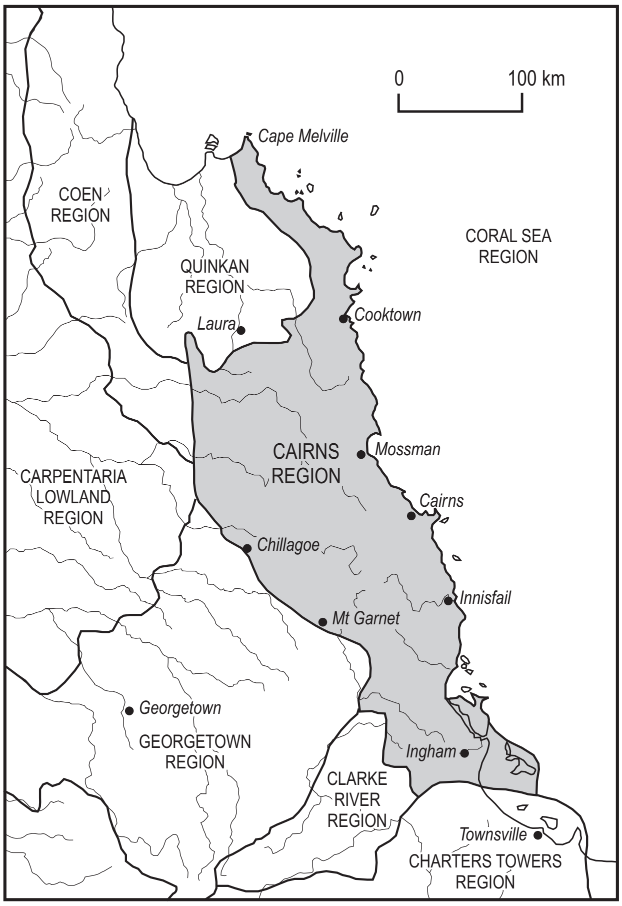


Figure 1. Locality Map.

the North Queensland Volcanic and Plutonic Province of Day & others (1983).

In this work 'arenite' is used as a general name for consolidated sedimentary rocks consisting mainly of sand-sized grains irrespective of composition. Terms describing metamorphic facies are as defined by Turner & Verhoogen (1960). The term 'concordant' is used to describe contacts between strata displaying parallelism of bedding or structure where a hiatus cannot be recognised but may exist (Bates & Jackson, 1980).

The term 'migmatite' is used to describe a composite (mixed) rock consisting of igneous or igneous-looking and metamorphic components which are generally distinguishable megascopically (Bates & Jackson, 1980); injection of magma, *in situ* melting, or both, may have taken place.

The terms 'broken formation' and 'melange' are used interchangeably to describe extensively disrupted sequences characterised by a chaotic block-in-matrix fabric. The fabric is generally defined by irregular to lozenge-shaped arenite or siltstone fragments in a dark grey to black mudstone matrix. The broken formation or melange zones are preferentially developed in sequences of interlayered, thin to medium-bedded arenite, siltstone, and mudstone. Modes of formation are thought to range from disruption of only partly lithified sediments to tectonic disruption of interbedded arenite-siltstone-mudstone sequences. Broken formation is considered to be equivalent to melange, used in its non-genetic sense as recommended by Jacobi (1984).

The term 'cauldron' is used in the sense of Smith & Bailey (1968) for all volcanic subsidence structures regardless of shape or size, depth of erosion, or connection to the surface. The term, therefore, includes cauldron subsidences and collapse calderas. Silica (SiO_2) content was used to classify the late Palaeozoic volcanic rocks. Analyses were first recalculated to 100% on a volatile-free basis and the following subdivisions were used:

- basalt - $\leq 53\%$ SiO_2
- low-silica andesite - $>53\%$ SiO_2, $\leq 57\%$ SiO_2
- high-silica andesite - $>57\%$ SiO_2, $\leq 63\%$ SiO_2
- dacite - $>63\%$ SiO_2, $\leq 67\%$ SiO_2
- rhyodacite - $>67\%$ SiO_2, $\leq 70\%$ SiO_2
- rhyolite - $>70\%$ SiO_2

The non-genetic classification of Cas & Wright (1987, table 12.7, page 356) was used for volcaniclastic rocks.

The standard Wentworth size classification and rock terms (Wentworth, 1922; *in* Pettijohn, 1957, page 19) were used to subdivide and describe the clastic sedimentary rocks, unless otherwise indicated. The following grainsize classification, based on the average size of groundmass grains, was used for the granitic rocks:

- fine grained - <1mm,
- medium grained - 1–5mm, and
- coarse grained - >5mm.

The AGSO geological timescale (Jones, 1995) was used to assign isotopically dated igneous rocks to periods and epochs.

Classification of the granites

Mineralogical and chemical characteristics have been used to group most of the granites into supersuites following the approach of White & Chappell (1983), and Chappell & White (1984). The supersuites and constituent units are listed and briefly described in Table 4 and Appendix 1. Some of the granites — those in the south-east of the region in particular — have not been grouped into suites and supersuites. The Innisfail–Ingham area, for example, has not been mapped in sufficient detail to delineate most of the individual plutons, and there is insufficient chemical data to classify some units.

The granites for which there is adequate chemical data have been classified using several parameters. The I-, S-, and A-type classification scheme is based on interpreted source rock compositions and provides some primary constraints on magma compositions during partial melting. However, from the mineralisation perspective, important features of granites are the aluminium saturation index (ASI[1]), the degree of fractionation, and the oxidation state. These factors determine the minerals which crystallise from the melt and, therefore, the behaviour of ore elements in the magmas and hydrothermal fluids. For consistency, most of the parameters used in this report (Appendix 1) are the same as those used by Champion & Heinemann (1994) for granites of the southern part of the Cairns Region, namely:

- mafic/felsic index; mafic rocks have SiO_2 contents $\leq 68\%$ (*e.g.* Ewart, 1979; le Maitre, 1984, 1989);

- oxidation state (using Fe_2O_3/FeO versus FeO^{*}[2] plots and fields modified from Ishihara & others, 1979; Blevin & Chappell, 1992);

- degree of fractionation; fractionated granites are defined as felsic rocks ($SiO_2>68\%$) which show evidence of the removal of feldspars by various processes; such units are

1 ASI = aluminium saturation index = $(Al_2O_3/101.94)/(CaO/56.08 + Na_2O/61.98 + K_2O/94.2 - P_2O_5/42.59)$
2 $FeO^* = FeO + 0.8998Fe_2O_3$

distinguished on a Rb–Sr–Ba triangular diagram using the fields of El Bouseilly & El Sokkary (1975); and

- potassium content using K_2O versus SiO_2 plots and mainly the fields of Peccerillo & Taylor (1976).

Chemical analyses

Most of the chemical analyses used to generate the variation diagrams shown in subsequent parts of this report were determined either at the Government Chemical Laboratory, Queensland Department of Health, or at the Department of Geology, The Australian National University, Canberra, using mainly XRF techniques.

Acknowledgements

The writer was in charge of the party which mapped most of the Cairns Region, between 1982 and 1994. Other members of the group, in particular, P.J.T. Donchak, B.G. Fordham, R.W. Halfpenny, R.A. Hegarty, I.P. Rienks, J. Domagala, K.G. Grimes, L.C. Cranfield, S.R. Law, and I.D. Rees made significant contributions to the understanding of the evolution of the region. The assistance of D.C. Champion (AGSO) and J. Knutson (formerly AGSO) with the interpretation of the geochemical characteristics of metamorphic rocks (Barnard Metamorphics), granites (Kennedy Province), and Cainozoic basaltic rocks is gratefully acknowledged — as is that of Emeritus Professor B.W. Chappell (The Australian National University — ANU) in providing chemical analyses of many of the granites in the region. The U–Pb zircon (SHRIMP[3]) analyses of selected samples were provided by Mark Fanning (RSES, ANU[4]). M.J. Woodbury (ANU) supplied analyses of intrusive rocks in the Red Dome and Mungana areas.

Dick England (consulting petrologist, Townsville), and Brett Davis and Stephen Wegner (Department of Earth Sciences, James Cook University of North Queensland, Townsville) are also gratefully acknowledged for providing assistance and constructive discussions on mineralogical and structural aspects of some of the rocks of the Barnard Metamorphics and structure of the region.

GEOLOGICAL FRAMEWORK

Eight main lithological groups are represented in the region, namely (from oldest to youngest):

1) metamorphic rocks of the late Proterozoic–Cambrian? Barnard Metamorphics and Babalangee Amphibolite (**Barnard Province**), which form a narrow north-trending belt east of the Russell–Mulgrave Shear Zone in the south-east;

2) extensively deformed, early and late Ordovician granites of the Macrossan Province; these are poorly exposed in the coastal strip where they intrude the supracrustal rocks of the Barnard Metamorphics; only the Tam O'Shanter Granite was delineated during the GSQ survey, the other outcrops being included in the Barnard Metamorphics (however, Bultitude & others, 1998a show a more up-to-date interpretation);

3) early–middle Palaeozoic sedimentary and intercalated basic volcanic rocks of the **Hodgkinson Province** which crop out extensively east of the Palmerville Fault; the early Ordovician? Mulgrave Formation is included in the Hodgkinson Province although it may form part of an older province extensively exposed in south-eastern Australia;

4) Carboniferous to Permian granitic, volcanic and associated sedimentary rocks of the **Kennedy Province**;

5) middle–late Permian, fluviatile to estuarine? sedimentary rocks of the **Mount Mulligan Coal Measures**;

6) Mesozoic sedimentary rocks of the eastern **Carpentaria Basin** and the **Pepper Pot Sandstone**;

7) Tertiary and Quaternary basaltic rocks of the **East Australian Basalt Province**; and

8) Tertiary and Quaternary **sediments and residual deposits**; these deposits are most extensive in the north-eastern and south-eastern parts of the region.

3 SHRIMP = sensitive high-resolution ion microprobe
4 Research School of Earth Sciences, The Australian National University, Canberra, ACT

LATE PROTEROZOIC TO ORDOVICIAN ROCKS

BARNARD PROVINCE

Barnard Metamorphics

The Barnard Metamorphics crop out in the south-east of the region, between Tam O'Shanter Point and High Island. They were interpreted by de Keyser (1964, 1965) as higher grade equivalents of the Barron River Metamorphics. The latter represent Hodgkinson Formation rocks which have been metamorphosed to the greenschist facies (de Keyser, 1965; de Keyser & Lucas, 1968; Bultitude & others, 1990; Bultitude & Garrad, 1997).

The results of investigations by GSQ (1992–95) and researchers at James Cook University (*e.g.* Richards, 1977; Jones, 1978; Rubenach, 1978; Hammond & others, 1986) indicate at least parts of the Barnard Metamorphics are significantly older than the nearby Hodgkinson Formation. Furthermore, the two units are separated by a major shear zone (the Russell–Mulgrave Shear Zone of Hammond & others, 1986).

The unit consists predominantly of meta-arenite, quartzite, phyllite, 'greenstone', chlorite schist (mainly sheared and altered 'greenstone'), muscovite–chlorite and biotite–muscovite schists, and subordinate biotite gneiss, migmatitic gneiss, and metagranite (see below).

Other rock types recorded include hornblende granulite (Bultitude & others, 1996a; Bultitude & Garrad, 1997), massive amphibolite, garnet-bearing para?-amphibolite, metagabbro, metamorphosed ultramafic rocks (Cowley Ophiolite Complex; Bultitude & others, 1998a), and talc-rich rocks. The high-grade rocks are commonly, but not exclusively, located where there is a high proportion of granite (of Ordovician age).

Foliated, medium-grained biotite granite and granodiorite, of Ordovician age extensively intrude the supracrustal rocks of the Barnard Metamorphics. They represent the northernmost exposures of the Macrossan Province and are particularly common in the South Mission Beach–Narragon Beach–Garners Beach–Thorpe Island area. Granite forming extensive outcrops at Tam O'Shanter Point was delineated as the Tam O'Shanter Granite during the GSQ survey. The very poorly exposed granitic rocks inland from the coast have been recently mapped as the Mission Beach Granite Complex by S. Wegner (James Cook University of North Queensland; Bultitude & others, 1998a).

Scattered outcrops of metagabbro, such as those on High Island and at the northern end of Bramston Beach, are probably significantly younger than the supracrustal rocks they intrude. They may be late Palaeozoic (early Permian?). The ultramafic rocks were most probably emplaced in the Permian–Triassic during the Hunter–Bowen Orogeny. Their age of formation is uncertain. They are interpreted as part of an ophiolite complex with possible links to the Babalangee Amphibolite.

Chemical characteristics

Whole-rock geochemical data for the Barnard Metamorphics indicate a wide range in compositions, from metabasite to quartzose meta-arenite or quartzite. Most samples analysed are metamorphosed pelites and psammopelites, with SiO_2 contents between 60% and 75% and Al_2O_3 contents between 12% and 20%.

The siliciclastic metasedimentary rocks of the Barnard Metamorphics contrast with most of those analysed from the nearby Hodgkinson Province (Figure 2). The latter, particularly the arenites, generally have mineralogical and chemical characteristics (*e.g.* relatively high SiO_2 and Na_2O and low Al_2O_3, Rb, and Sc contents, and low CIA[5]) indicating they were derived mainly from a rapidly eroded, unweathered felsic source of predominantly granitic or metagranitic composition — *i.e.* from source rocks similar to those presently exposed in the Coen, Yambo, Dargalong, and Georgetown Inliers west of the Palmerville Fault.

Structure

The Barnard Metamorphics are multiply and complexly deformed. Three major, *regional*

5 CIA = chemical index of alteration = $100Al_2O_3/(Al_2O_3 + CaO^* + Na_2O + K_2O)$, where CaO* = amount of CaO in silicate minerals (Nesbitt & Young, 1982)

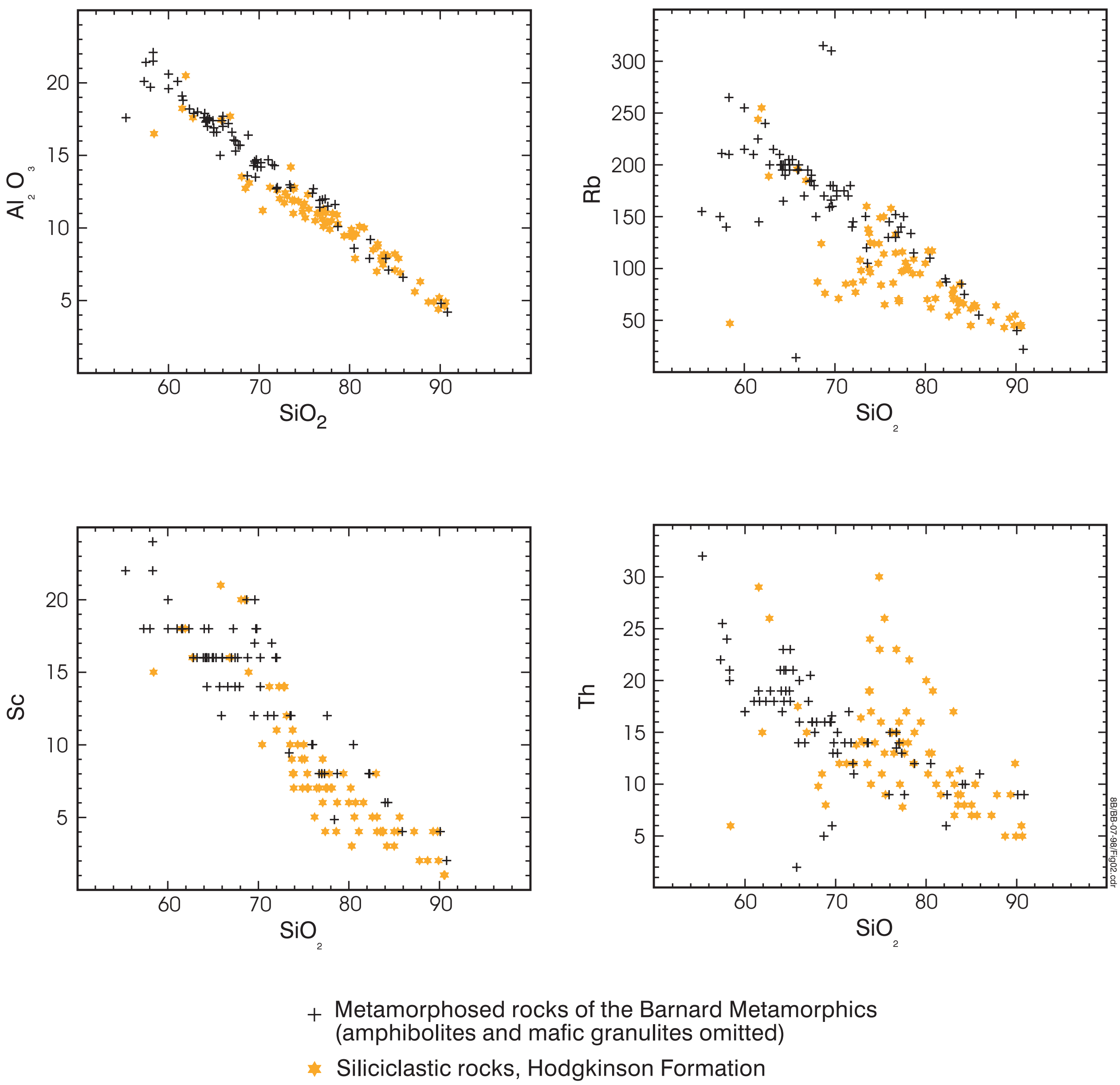


Figure 2. Al_2O_3, Rb, Sc, and Th versus SiO_2 plots for the metamorphosed supracrustal rocks of the Barnard Metamorphics. Also shown for comparative purposes are analyses of siliciclastic rocks from the Hodgkinson Province. Major oxides are in weight per cent (wt %), trace elements in parts per million (ppm).

deformational events were recognised during the GSQ investigation. Several other, possibly local events have also been reported (*e.g.* Richards, 1977; Jones, 1978; Hammond & others, 1986). Richards, for example, recognised two relatively weak events (b^6D_4, bD_5)[7] in the Mulgrave River area and on High Island. In addition, the metamorphic rocks on Dunk Island preserve a well-developed fabric which may be related to the emplacement of the early–middle Carboniferous granites forming the southern half of the island (*e.g.* Donchak, 1997).

The first two deformational events, bD_1 and bD_2, produced well-developed foliations; bS_2 being the dominant fabric in most outcrops examined.

First regional deformation (bD_1)

The first *regional* deformation (bD_1) produced a finely differentiated mylonitic fabric in the

6 *b* refers to deformational events and tectonic fabrics in the Barnard Province; *h* to those in the Hodgkinson Province

7 structural terminology after Bell & Duncan (1978):
D = deformation, L = lineation, S = surface/foliation, F = fold, M = metamorphism,
$_2$ = second deformation event, ^{1} = first surface or lineation deformed;
e.g. $F^1{}_2$ = folding of a first generation foliation by a second generation deformation

upper greenschist and higher grade rocks (Hammond & others, 1986) and a bed-parallel slaty cleavage (bS_1) in lower grade rocks. The well-developed gneissic layering in the high-grade rocks is also thought to have been produced during this deformation. Gneiss inclusions in the Tam O'Shanter Granite are commonly oriented so that the gneissic foliation trends at high angles to the pervasive foliation (bS_2) in the granite. The bD_1 deformational event, therefore, occurred before the late Cambrian–early Ordovician (the crystallisation age of the Tam O'Shanter Granite) and pre-dates the oldest (middle Ordovician?) deformation in the Hodgkinson Province (Bultitude & others, 1996b).

Second regional deformation (bD_2)

The second major, *regional* deformational event (bD_2) which affected the Barnard Province extensively transposed the *b*S1 fabric, producing an intense crenulation or schistosity. The main foliation in most outcrops is bS_2. The Tam O'Shanter Granite also has a pervasive bS_2 foliation. The felsic I-type? granites (Mission Beach Granite Complex) were deformed during the same event, although the foliation is commonly not as well developed as that in the S-types. The data imply a maximum age of late Ordovician (~460Ma — indicated by the SHRIMP age yielded by one of the felsic I?-type granites) for bD_2.

Third regional deformation (bD_3)

The third major, *regional* deformation (bD_3) to affect the unit produced widespread crenulations and mesoscopic folds, particularly in the lower grade rocks in the Bramston Beach–Mourilyan Harbour area. A steeply dipping to subvertical bS_3 crenulation cleavage is commonly present in these rocks. It is particularly well developed in high-strain zones. In contrast, bS_3 is only weakly developed in the relatively coarse-grained, high-grade gneissic rocks of the Mission Beach area and Frankland Islands, being defined by local new platy mineral (mainly mica) growth. In the south, mesoscopic bF_3^2 folds have been reported in relatively high-grade rocks (schist, gneiss, migmatite) at Bingal Bay (Rubenach, 1978).

The bS_3 foliation trends in a north-westerly direction north of the Barnard Islands. The foliation is essentially parallel to what has been tentatively interpreted, mainly from geophysical data, as a north-west trending shear zone/basement discontinuity in the Bramston Point–Russell Heads area. Farther south, bS_3 trends are more northerly, more or less parallel to the Russell–Mulgrave Shear Zone.

The bD_3 deformation was a relatively young event (or events), and formed part of the Hunter–Bowen Orogeny. As well as producing a pervasive, steeply dipping, north-westerly striking slaty cleavage in the adjacent Hodgkinson Formation, the bD_3 event intensely deformed early Permian (~280Ma–285Ma) granites of the Bellenden Ker Batholith. An intense mylonitic foliation (with ribbon quartz) is developed in the summit area of Bellenden Ker Centre Peak and along the eastern margin of the Bellenden Ker Range north of Babinda (*e.g.* at Fishery Falls). An east-block-up sense of shear is indicated at most localities (*e.g.* at GR 37855 809125, GR 3802 80991, GR 3885 80941 — Bartle Frere 1:100 000 Sheet area) by kinematic indicators such as the orientations of porphyroclasts, stretching lineations, and 'S–C'[8] planes.

Intensely tectonised granite in the Bramston Point area has a similar deformational fabric. However, the orientations of the stretching lineations imply a significant sinistral shear component and a west-block-up movement sense (S. Wegner, James Cook University of North Queensland, personal communication, 1996; Donchak, 1997). The deformation fabrics in this area may be related to the presence nearby of a north-westerly striking shear zone. The postulated shear zone separates the high-grade rocks (including the hornblende granulites) of the Frankland Islands and adjacent mainland to the west from lower grade rocks to the south and south-west.

Origin and significance of the high-grade metamorphic rocks

Mineral assemblages in the high (middle to upper amphibolite and, locally, granulite)-grade rocks (mainly migmatitic to massive biotite gneiss), such as the presence of sillimanite rather than kyanite, indicate these rocks formed under relatively high temperature and low pressure conditions. In the south, the high-grade metamorphic zones are generally located where there is a high

8 'S–C' planes are the asymmetric fabrics typically developed in mylonites; 'S' = schistosity plane, 'C' = *cisaillement* (or shear plane); after Berthé & others (1979)

proportion of Ordovician granite. This spatial association implies the emplacement of the granites may have been responsible, at least partly, for locally elevated temperatures during the metamorphism of the supracrustal rocks of the Barnard Metamorphics.

However, a close spatial association between high-grade metamorphic zones and Ordovician granite is not apparent in the northernmost outcrops — *i.e.* those on the Frankland Islands and in a small area north of the junction of the Russell and Mulgrave Rivers. The metamorphic grade in these areas is also relatively high (mainly upper amphibolite–granulite), but there is very little, if any, exposed Ordovician granite nearby.

Interlayered mafic (SiO_2 = ~47%) hornblende granulite (locally containing metamorphic olivine) and migmatitic cordierite–sillimanite–K-feldspar-bearing biotite gneiss form scattered outcrops at the southern end of the Malbon Thompson Range (~GR 3849 80996, Bartle Frere 1:100 000 Sheet area; Bultitude & Garrad, 1997). These are the highest grade rocks found in the Barnard Metamorphics. *Furthermore, they are the highest grade rocks reported in the northern Tasman Fold Belt.*

Migmatitic quartzofeldspathic gneisses associated with the mafic granulites contain abundant sillimanite — as coarse, tabular grains and aggregates of fine acicular grains (fibrolite) — and unaltered cordierite. Green spinel (hercynite?) is a common accessory mineral in some of these rocks, but is scarce in the more quartz-rich layers.

These rocks are intruded by early Permian granite forming the Malbon Thompson Range. Whether or not the P–T conditions associated with the emplacement of this major granitic unit were sufficiently high locally to produce regional-type granulite facies rocks is uncertain. Regional-type high-grade metamorphic rocks are not extensively developed around any of the other late Carboniferous–Permian granites of the Cairns Region, with the exception of the Tinaroo Batholith (— see subsequent section) and, to a much lesser extent, the Cannibal Creek Granite.

However, preliminary results of U–Pb dating of monazites (using SHRIMP) from the migmatitic biotite gneiss imply they recrystallised (with resultant resetting of the U and Pb isotopes) at ~270Ma. If more detailed work confirms these preliminary results, then it would appear the high-grade metamorphic rocks in the Malbon Thompson Range– Frankland Islands area at least, most probably formed at about the same time as, and are related to the emplacement (in the early Permian) of the Bellenden Ker Batholith. Geophysical and limited outcrop data (from the Bramston Point area) imply this belt of predominantly high-grade rocks is truncated to the south by a north-westerly trending shear zone. The shear zone may represent a reactivated basement discontinuity. It was probably active during the Permian–Triassic Hunter–Bowen Orogeny which significantly affected the New England Fold Belt farther south, between ~255Ma and 230Ma (Fergusson, 1991; Henderson & others, 1993) — early Permian granites are extensively deformed adjacent to the shear zone (*e.g.* in the Bramston Point area). Many of the granites in the eastern Hodgkinson Province have yielded reset late Permian–Triassic K–Ar isotopic ages (*e.g.* Bultitude & Champion, 1992).

Conclusions

The available data are consistent with the interpretation of the Barnard Metamorphics as an uplifted basement assemblage on the south-eastern margin of the Hodgkinson Province. There is no evidence of large-scale strike-slip displacement on the late Permian–Triassic Russell–Mulgrave Shear Zone. Granite of probable early Permian age forming the Malbon Thompson Range (east of the shear zone) is similar mineralogically, texturally, and chemically to early Permian granite forming the Bellenden Ker Range (west of the shear zone). Instead, an east-block-up sense of shear is indicated at most localities west of the shear zone by kinematic indicators such as the orientations of porphyroclasts, stretching lineations, and 'S–C' planes.

The presence of metasedimentary rocks farther to the east (offshore), in the western part of the Queensland Plateau, similar to those in the Hodgkinson Formation (Feary & others, 1993) also supports the hypothesis that movements on the shear zone have been mainly vertical.

Other possible 'basement' sequences

The recognition of the Russell–Mulgrave Shear Zone as a major structural discontinuity separating the Barnard Metamorphics of the Cairns Region from Hodgkinson Formation rocks to the west may have implications regarding the affinities of some of the rocks in the Cairns area currently mapped as part of the Hodgkinson Formation.

The metasedimentary rocks exposed at Yorkeys Knob, ~15km north-north-west of Cairns, for example, are structurally anomalous compared with Hodgkinson Formation rocks exposed elsewhere in the coastal belt (Donchak, 1997). These rocks, therefore, may form part of an older assemblage rather than part of the Hodgkinson Formation.

In addition, the rocks (delineated as Dh_s on the second edition 1:500 000-scale Hodgkinson Province geological map) exposed west and north-west of the Tinaroo Batholith form an anomalously wide, high-grade (up to upper amphibolite grade) zone compared with rocks of the Hodgkinson Formation exposed elsewhere in the coastal belt (where the highest metamorphic grade attained is the biotite zone of the greenschist facies).

Furthermore, they are characterised, at least locally, by a mylonitic foliation (Hammond & others, 1986) which has not been reported in the nearby lower grade rocks of the Hodgkinson Province. These rocks, therefore, may also form part of an older 'basement' assemblage.

Some of the relatively large enclaves or screens of metasedimentary rocks exposed in the marginal zones of the Bellenden Ker Granite in the northern part of the Malbon Thompson Range may also correlate with the Barnard Metamorphics rather than the Hodgkinson Formation.

Babalangee Amphibolite

The Babalangee Amphibolite (de Keyser, 1964) crops out over ~20km^2 east of Babinda. The unit is very poorly exposed and contacts with the nearby Barnard Metamorphics have not been observed. The Babalangee Amphibolite pre-dates and has been metasomatised by the Bellenden Ker Granite forming the Graham Range. Tourmaline is relatively abundant and widespread in amphibolite adjacent to the granite (de Keyser & Lucas, 1968). A possible equivalent of the Babalangee Amphibolite is present in the subsurface farther south — boulders, up to ~1m across, of amphibolite are very common in the Cainozoic pyroclastic deposits of Stephens Island.

The Babalangee Amphibolite typically contains ~75% hornblende, ~23% plagioclase (calcic andesine), and 1–2% titanite, apatite, epidote/clinozoisite and sulphide(s) (de Keyser & Lucas, 1968). The fabric ranges from massive to schistose. The amphibolite has been affected by the Permian–Triassic Hunter–Bowen Orogeny. It is cut by north-westerly trending shear zones and is commonly extensively deformed and variably recrystallised and retrogressed (de Keyser & Lucas, 1968).

The massive, relatively uniform character of the amphibolite away from shear zones implies it probably represents a basic intrusion, or several basic intrusions.

The Babalangee Amphibolite has yielded a K–Ar age (corrected) of 642Ma (Richards & others, 1966). The significance of this age is uncertain. Richards & others (1966) postulated the age was likely to be anomalously old because of the probable presence of extraneous argon. It was not regarded as significant by later workers (*e.g.* de Keyser, 1965).

However, the age is consistent with recent age and Nd-isotopic data obtained from granites in the nearby Barnard Metamorphics. These indicate the enclosing supracrustal rocks of the Barnard Metamorphics are older than early Ordovician (~485Ma) and at least some are probably late Neoproterozoic–early Palaeozoic (Champion, 1991; Champion & Bultitude, 1994).

MACROSSAN PROVINCE

Ordovician granites in the Barnard Metamorphics

The Barnard Metamorphics are extensively intruded by early Palaeozoic granite, particularly in the South Mission Beach–Tam O'Shanter Point area. However, only the Tam O'Shanter Granite has been delineated as a discrete unit on the 1:500 000-scale map, the remaining granites subsequently being included in the *Mission Beach Granite Complex* (Bultitude & others, 1998a).

Mineralogical and chemical characteristics

The granites form three main groups based on mineralogical and chemical characteristics — mafic I-, felsic I?-, and felsic S-types. The postulated I-type granites crop out mainly as irregular dykes and pods, whereas S-type granite also forms a relatively large pluton (delineated as the Tam O'Shanter Granite) with extensive pavements and massive outcrops in the South Mission Beach–Tam O'Shanter Point area. The S-type granites contain large flakes of biotite (commonly extensively recrystallised) and muscovite (generally <biotite), rare aggregates consisting mainly of fine mica (possibly representing altered cordierite grains), numerous lensoidal biotite-rich clots (up to ~3cm long) and inclusions of quartz (up to ~15cm) and biotite gneiss (up to ~1m). The inclusions are scattered throughout the plutons.

The felsic I?-type granites are distinguished from the felsic S-types by more equigranular habits, a relative abundance of plagioclase, a relative scarcity of muscovite, apatite, and inclusions (especially quartz), and the interstitial habit of the biotite grains. The mafic I-type granites are characterised by relatively high concentrations of mafic minerals and low quartz abundances. Those examined south of Garners Beach (GR 4052 80296) and on Timana Island (GR 4087 80114) appear to form small pods and lenses.

The granites analysed form three reasonably tight groups on most chemical variation diagrams (*e.g.* Figure 3), despite having been extensively recrystallised and slightly to moderately altered. The relatively high ASI values yielded by the felsic S- and I?- type granites may indicate Na, K, and possibly Ca were removed during metamorphism and partial recrystallisation. Conversely, the felsic I?-type granites may actually be S-types.

The felsic S-type granites have relatively high TiO_2, FeO*, K_2O, Ce and Rb contents, as well as ASI (~1.4–1.9) and Rb/Sr ratios, and low Na_2O and total alkalis compared with the felsic I?-type granites (ASI = ~1.1–1.4) of similar SiO_2 contents (Figure 3). The mafic I-type granites are characterised by relatively low SiO_2 contents (~62%), and element concentrations which show a considerable range from one intrusion to another (Figure 3). They are also characterised by anomalously high ASIs (>1.1) for mafic I-type rocks, implying some element transfer during metamorphism and alteration.

The S-type granites are also chemically distinct from the enclosing supracrustal high-grade gneisses. The latter are characterised by lower CaO, Na_2O, and Sr, and higher or similar K_2O and Th contents, as well as higher ASIs and Rb/Sr and Ga/Al ratios (Figure 3). In contrast, the S-type granites are very similar chemically (and isotopically) to early Permian S-type granites of the Whypalla Supersuite (in the nearby Hodgkinson Province; Figure 4), implying a common source or, at least sources of very similar compositions (Champion & Bultitude, 1994; Bultitude & Garrad, 1997).

Furthermore, the felsic I?-type granites (of the Mission Beach Granite Complex) are similar chemically to Ordovician I-type granites of the Ravenswood Batholith in the Charters Towers region to the south (*e.g.* the Towers Hill Granite and Hogsflesh Creek Granodiorite; table 1, Hutton & Crouch, 1993; Figure 5). Ordovician S-type granites are also thought to be present in the Ravenswood Batholith (*e.g.* Rienks, 1991; Hutton & Crouch, 1993) and possibly also in the Townsville hinterland (Withnall & McLennan, 1991). However, they are all characterised by relatively low K_2O contents and K_2O/Na_2O ratios compared with the felsic S-type granites which intrude the Barnard Metamorphics.

Age

SHRIMP dating of the felsic S- and I?-type granites in the Barnard Metamorphics has yielded emplacement ages of 486±10Ma and 463±7Ma (early and late Ordovician), respectively. The results are consistent with the field relationships.

Age of source rocks

The Tam O'Shanter Granite (S-type) and felsic I-type? granite of the Mission Beach Granite Complex contain inherited zircons (C.M. Fanning, Research School of Earth Sciences, ANU, written communication, 1992). The youngest inherited component detected in the Tam O'Shanter Granite sample using SHRIMP is ~565Ma, implying the metasedimentary source rocks for the granite are very late Neoproterozoic or Cambrian. The felsic I-type? granite, in contrast, has inherited zircon components ranging from ~630Ma to ~3300Ma.

HODGKINSON PROVINCE

Introduction

The early–middle Palaeozoic Hodgkinson Province succession forms the northern part of the Tasman Fold Belt. The province is the most extensive element in the Cairns Region, where it forms a belt ~500km long and up to ~150km

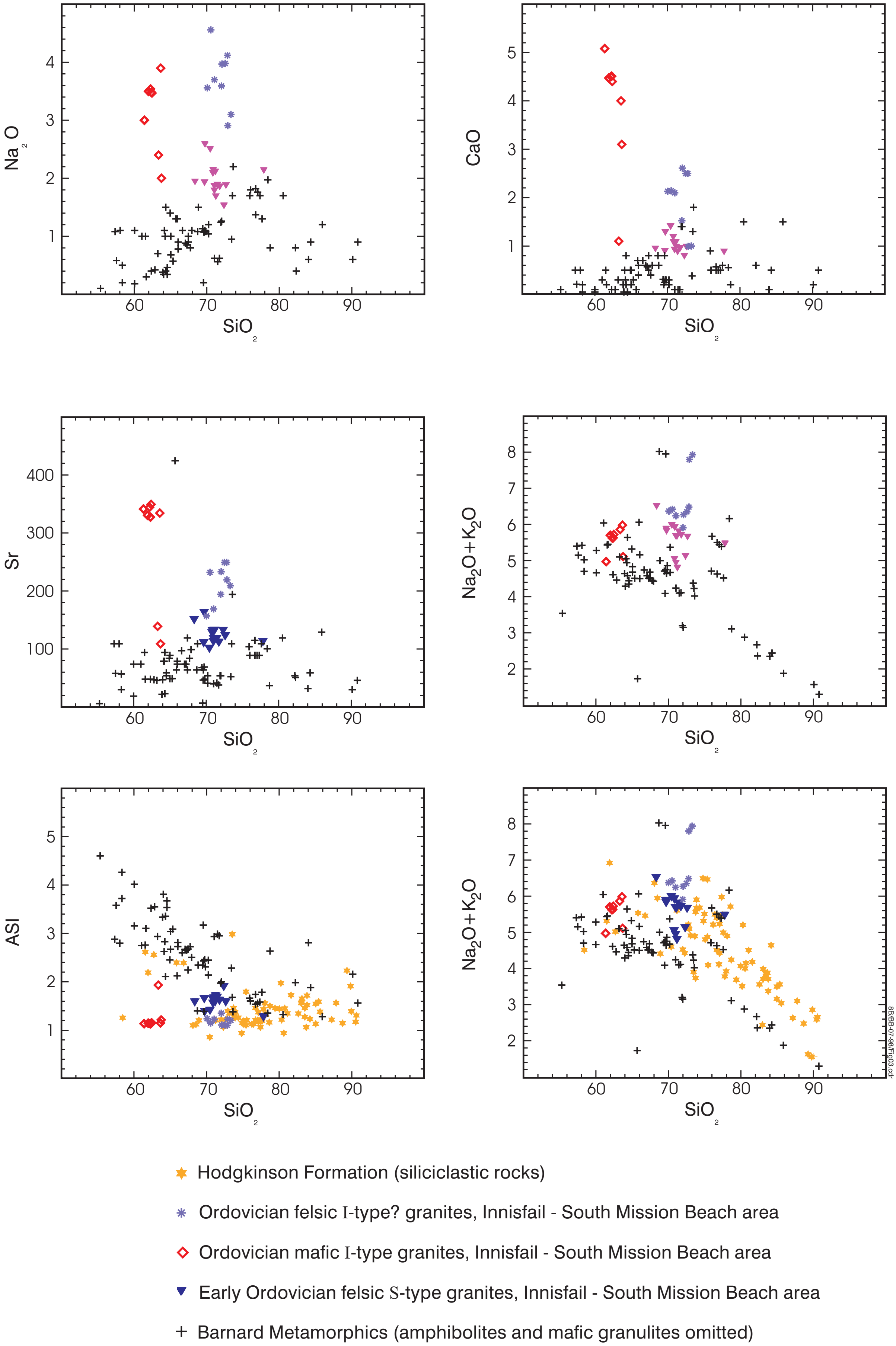


Figure 3. Chemical variation diagrams highlighting the differences between Ordovician granites which intrude the Barnard Metamorphics and between the granites and the enclosing metamorphic rocks. Compositional differences between Hodgkinson Formation rocks and Barnard Metamorphics are also demonstrated on two of the plots.

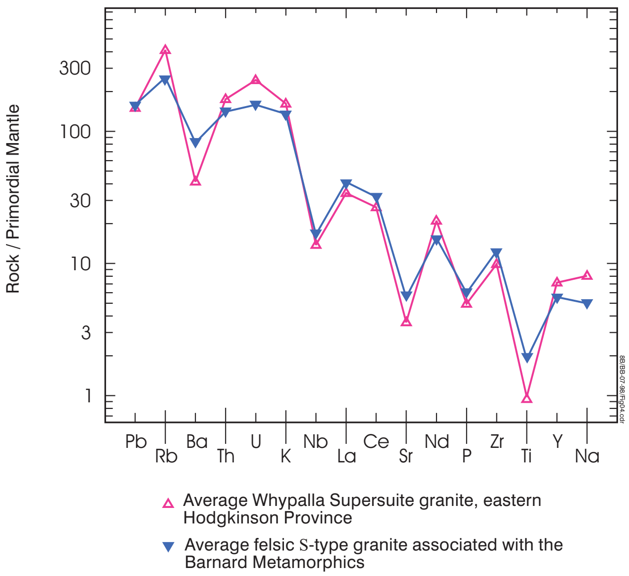


Figure 4. Multi-element variation diagram showing similarities between early Ordovician felsic S-type granites which intrude the Barnard Metamorphics and early Permian granites of the Whypalla Supersuite, eastern Hodgkinson Province.

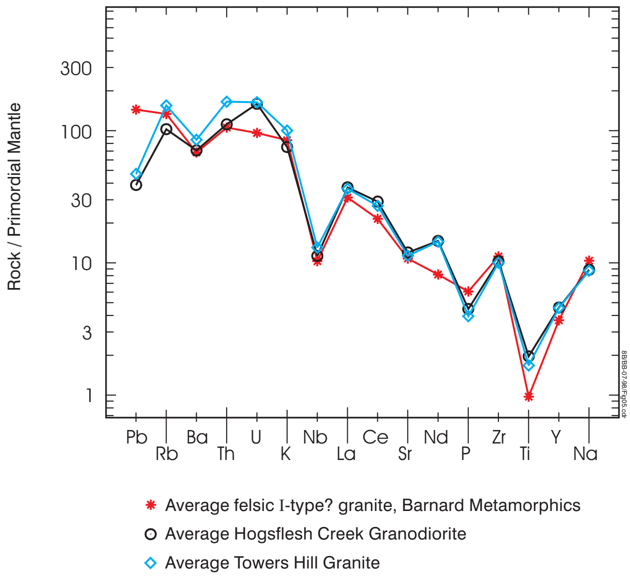


Figure 5. Multi-element variation diagram showing similarities between late Ordovician felsic I-type? granites of the Barnard Metamorphics and selected I-type granites of similar age in the Charters Towers Region.

wide. It is separated from the coeval Broken River Province to the south by Carboniferous–Permian igneous rocks of the Kennedy Province and the north-westerly trending part of the Palmerville Fault of de Keyser (1963).

To the west, the Palmerville Fault defines the boundary with high-grade metamorphic and associated intrusive rocks of the Dargalong and Yambo Inliers (Georgetown and Yambo Province rocks, respectively). In the north and, to a much lesser extent, in the west, the province is overlain by Mesozoic sedimentary rocks of the Laura and Carpentaria Basins. The province extends out to sea for an unknown distance to the north and east.

The dominant rock types in the Hodgkinson Province are quartzofeldspathic arenite and mudstone, which represent deep-water, density current deposits. These are interlayered with subordinate conglomerate, chert, and metabasalt, and minor (on a regional scale) shallow-water limestone. Older siliciclastic rocks (Mulgrave Formation) of probable early Ordovician age, preserved in fault-bounded lenses adjacent to the Palmerville Fault in the far west of the region, have also been included in the Hodgkinson Province.

These rocks are dominated by quartzose arenite rather than quartzofeldspathic arenite (which typifies the younger siliciclastic sequences in the province). They are separated from the younger rocks by a postulated major unconformity and may form part of an older province which extended along much of eastern Australia in the Cambrian–Ordovician. Ordovician quartzose flysch, for example, crops out extensively in the Lachlan Fold Belt of south-eastern Australia.

The recent investigation of the Hodgkinson Province has revealed a much more complex pattern of sedimentation and arrangement of units than that envisaged by previous workers, such as de Keyser & Lucas (1968) or Fawckner (1981); and Ordovician units have been identified for the first time (Bultitude & others, 1990, 1993a, 1995, 1996b). The main formations consist of, from west to east, the Quadroy Conglomerate, Mulgrave Formation, Mountain Creek Conglomerate, Van Dyke Litharenite, Chillagoe Formation, Hodgkinson Formation (containing the Kitoba, OK, and Larramore Metabasalt Members) and Molloy beds. As mapped, these units form distinct, mainly fault-bounded belts most of which are also extensively disrupted internally by numerous thrust faults which trend parallel or subparallel to the strike of the adjacent beds. Most of these fault slices young internally to the west, particularly those in the western part of the province.

Subdivision of the rocks of the province into ‘normal’ stratigraphic units is not practicable because of the complex deformational history, scarcity of stratigraphic markers, scarcity of observable stratigraphic contacts between most

Table 1. Summary of predominantly sedimentary rock units, Cairns Region.

Unit	Constituent Units	Rock Types	Thickness (max.)	Environment of Deposition
MESOZOIC – TRIASSIC				
Kondaparinga Formation		mainly buff, brown, or white claystone, mudstone, siltstone, sandstone; minor granule conglomerate	>200m	fluvial deposits
Pepper Pot Sandstone	two informal subunits	buff, brown, white, pale grey, or purple to red, medium to thick-bedded, cross-bedded, medium to coarse-grained, lithofeldspathic and quartzose sandstone, pebbly sandstone, conglomerate (lower part); argillaceous sandstone, siltstone, mudstone, claystone, conglomeratic sandstone, shale (rare) (upper part)	~800m	fluvial deposits — possibly proximal (lower part) to medial or distal (upper part) braidplain and/or sheet floodplain
PALAEOZOIC – CARBONIFEROUS–PERMIAN				
Little River Coal Measures		medium to thick-bedded, fine to coarse-grained, quartzose to sublabile, feldspathic, lithic sandstone, thin to medium-bedded siltstone, cleaved shale (commonly carbonaceous), mudstone; minor impure coal, siliceous thin-bedded mudstone, impure limestone	probably <1000m; difficult to estimate due to extensive deformation	shallow-water, fluvial and/or lacustrine deposits; sandstones locally display trough cross-bedding and current bedding; locally, the orientations of the cross-beds indicate reversals in current direction, typical of a shallow-water, traction-current environment
Mount Mulligan Coal Measures	four irregularly distributed informal subunits delineated	conglomerate, pebbly sandstone, lithofeldspathic sandstone, siltstone; minor mudstone, shale, (carbonaceous) claystone, coal, silty coal, breccia	~450m	fluvial–lacustrine–estuarine; plant fossils indicate a sub-tropical or tropical climate; presence of coal seams, fossil plants, washouts, channels, current bedding, abrupt lateral facies changes, and local abundance of conglomerate indicate the sediments were deposited in a mature, continental environment
Silver Valley Conglomerate		purplish brown to brown, coarse, polymictic conglomerate, with interbedded tuffaceous sandstone lenses; minor rhyolitic ignimbrite, air-fall tuff, laminated to thin-bedded, tuffaceous and carbonaceous sandstone and siltstone	~90m	siliciclastic sediments probably deposited in an alluvial fan and braided stream system; some of the volcanic detritus probably deposited directly on the alluvial fans as air-fall tuff and pyroclastic flow deposits; thin-bedded to laminated sandstone and siltstone may represent lacustrine deposits
Unit Cs (Featherbed Volcanic Group)		grey to brown, medium to very coarse-grained, feldspathic arenite (commonly pebbly), pebble conglomerate, conglomeratic arenite	~50m	probably a fluviatile or lacustrine deposit

Age and Evidence	Relationships	Distribution (area)	References Comments
mid Triassic; rocks contain fossil plant spores and pollen	conformable on Pepper Pot Sandstone	southern part of Mount Mulligan	McElroy & Bryant, 1981; intersected in hole drilled at GR 2609 81366 (Mount Mulligan 1:100 000 Sheet area)
early–mid Triassic; plant fossils present in places (*e.g.* Geraldine Creek area)	overlies Mount Mulligan Coal Measures, possibly with slight angular discordance; unconformable on Hodgkinson Formation	spectacular cliff-forming unit, which forms Mount Mulligan — a north-westerly oriented, wedge-shaped block, ~18km long and up to ~6.5km wide (Mount Mulligan 1:100 000 Sheet area) (~59km^2 — includes Kondaparinga Formation)	Ball, 1917; de Keyser & Lucas, 1968; McElroy & Bryant, 1981; Oversby & others, 1997
late Permian, J.F. Rigby, personal communication, 1991; finer grained rocks contain abundant plant fossils; *Glossopteris browniana*, *G. indica*, *G. augustifolia*, *Vertebraria indica*, *Schizoneura australia* have been reported	faulted against Yambo Metamorphic Group to the west, and Mulgrave and Chillagoe Formations to the east; locally cut by thin quartz veins	elongate, north-trending lens, up to ~2km wide and >20km long, adjacent to the Palmerville Fault; located north of the Palmer River in the area around Fairlight homestead (~19km^2)	Hann, 1873a,b; Jack, 1882; de Keyser & Lucas, 1968; Bultitude & Donchak, 1992; unit has been extensively folded and faulted by relatively late, mainly vertical movements on the Palmerville Fault
mid–late Permian; indicated by palynofloral and megafloral successions	unconformably overlies Hodgkinson Formation rocks; overlain with slight discordance by the Triassic Pepper Pot Sandstone, according to Ball (1917)	eastern, northern, and western flanks of Mount Mulligan (~10km^2)	de Keyser & Lucas, 1968; Price, 1983; Oversby & others, 1997; Rigby, in press; volcanic debris and/or fragments of Hodgkinson Formation dominant in most of the conglomeratic rocks; individual rock types and associations form mainly lenses which interfinger laterally
late Carboniferous–early Permian?; plant fossils relatively common in upper part of unit	unconformably overlies Hodgkinson Formation rocks; faulted against and overlain, possibly conformably, by Glen Gordon Volcanics	small outlier in the Silver Valley, south-west of Herberton (~6km^2)	Best, 1962; de Keyser & Lucas, 1968; Blake, 1972; Rigby, 1973; clasts range up to ~2m across, but most are <15cm in diameter; clasts consist mainly of Hodgkinson Formation and younger silicic volcanic rocks
late Carboniferous	unconformable on Hodgkinson Formation, and overlain, probably unconformably, by andesite of unit Cad and by Wallaroo rhyolite	small area ~13km north-west of Wolfram Camp; two small outcrops in and adjacent to railway cuttings south-west of Tennyson Mountain (~1.5km^2)	Mackenzie, 1993; Mackenzie & others, 1993

Table 1 (continued)

Unit	Constituent Units	Rock Types	Thickness (max.)	Environment of Deposition
Quadroy Conglomerate		massive, coarse, polymictic conglomerate, with clasts up to ~2m, conglomeratic feldspathic arenite, feldspathic arenite; minor sedimentary breccia	~700m	proximal fan adjacent to an active fault scarp; derived mainly from a source similar to that exposed west of the Palmerville Fault, with minor input from the Hodgkinson Province succession; presence of extensively ferruginised clasts implies a non-marine or marginal-marine environment
Molloy beds		green to dark greenish grey, laminated to thin-bedded, rhythmically interbedded, fine to coarse-grained arenite, siltstone, and dark green or dark grey to black mudstone	maximum exposed thickness of ~150m; unit is more than 235m thick in GSQ Mossman 1	well-developed rhythmic layering implies the rocks represent distal marine or lacustrine turbidity-current deposits; lack of fossils and bioturbation is consistent with a deep-water, marine depositional environment
Hodgkinson Formation	Kitoba Member, OK Member, Larramore Metabasalt Member, several informal subunits	labile arenite, mudstone; minor chert, metabasalt, conglomerate, conglomeratic arenite, quartzose arenite, siltstone, haematitic mudstone, shale, ferruginous chert, (andalusite–) mica schist, phyllite; rare limestone, cordierite-bearing hornfels; talc–carbonate schist	uncertain; probably several thousand metres	mainly deep-water marine (sublittoral or bathyal) turbidity-current deposits; local shallowing resulted in isolated carbonate build-ups; trace fossils indicative of relatively deep water have been found in some of the fine-grained arenites and mudstones; some olistostrome and debris flow deposits reported from scattered localities
Chillagoe Formation	several informal lithological subunits delineated	limestone, chert, metabasalt, quartzofeldspathic arenite; subordinate mudstone, siltstone, conglomerate, conglomeratic arenite, limestone breccia (mainly tectonic); minor calc-silicate rocks; rare quartzose arenite	uncertain; maximum thickness of ~1000m preserved in fault blocks in Mungana area	recent studies indicate the limestones and some cherts most probably formed isolated ramps and mounds, possibly on the upper parts of fault blocks which marked the sites of half-grabens in an extensional basin; tidal and shoreline facies have not been recognised; water depths ranged from relatively deep (sublittoral, below storm-wave base) to very shallow (sublittoral, above fair-weather wave base) during deposition of the limestones in the Mungana area; associated radiolarian cherts and arenites were deposited in relatively deep water (sublittoral or bathyal — below storm-wave base)

Age and Evidence	Relationships	Distribution (area)	References Comments
very late Devonian or early Carboniferous; locally (north-west of Chillagoe) contains boulders of early Devonian limestone	bounded by the Palmerville Fault to the west and the Mulgrave Formation to the east; contact between the Quadroy Conglomerate and Mulgrave Formation is mainly faulted, with discontinuous lenses of melange developed; at GR2269 81025 the former apparently unconformably overlies the latter	discontinuous, mainly fault-bounded lenses, adjacent to the Palmerville Fault, from north-west of Chillagoe almost to the Palmer River ($\sim$6km^2)	Fawckner, 1981; Shaw & others, 1987; Bultitude & others, 1993a; unit is mainly massive with little or no apparent internal stratification
no fossils found; inferred to be most probably late Devonian or early Carboniferous	faulted against the Hodgkinson Formation; sequence south of Mount Molloy intruded subsurface by sills or dykes of dolerite and microgranite	unit forms north-trending belt ($\sim$10km^2), south of Mount Molloy; similar rocks are also poorly exposed at GR3385 81615 (Rumula 1:100 000 Sheet area), near Black Mountain (total area $\sim$16km^2)	Cranfield, 1990; dewatering structures present locally; according to Cranfield (1990) the unit is intruded by the Mount Formartine Granite, but this is now thought to be unlikely
unit is sparsely fossiliferous; corals and conodonts from rare limestone lenses and from clasts in conglomeratic units indicate age range from early Devonian (Lochkovian), or possibly late Silurian, to late Devonian; radiolarians from selected chert lenses imply a late Devonian age (Famennian); meandering trace fossils (including *Dictyodora*, *Helminthoida*, and *Paleodictyon*) of the Nereites ichnofacies locally common	interpreted to conformably overlie the Chillagoe Formation (— the contact is faulted in most places); intruded by numerous Carboniferous–Permian granites, some of which (*e.g.* the Cannibal Creek Granite) have produced well-developed metamorphic aureoles	very extensive unit, up to $\sim$500km long and $\sim$150km wide in the Cairns–Cooktown–Palmer River area; forms most of the northern Tasman Fold Belt, and extends for unknown distances offshore to the east and north ($\sim$16 010km^2)	de Keyser & Lucas, 1968; Bultitude & others, 1990, 1993a, 1995; basic–intermediate and silicic volcanic detritus present in some of the arenites, particularly in the north-east
fossils common in the limestones; conodonts indicate an early Silurian (Llandovery)–early Devonian (Emsian) age range	generally fault bounded; interpreted to be conformably overlain by the Hodgkinson Formation; apparently conformable intervals typical of the Chillagoe and Hodgkinson Formations, respectively, are preserved in several fault slices in Mungana area; transition between such intervals commonly marked by a prominent conglomeratic sequence; unconformably overlain by Featherbed Volcanic Group and Nanyeta Volcanics	forms a north-west to north-striking belt, up to $\sim$10km wide; belt essentially parallels the nearby Palmerville Fault to the west and extends (discontinuously) from near Mount Garnet in the south to the Kennedy River in the north ($\sim$1 015km^2)	Bultitude & others, 1990, 1993a; Bernecker, 1993; Domagala & Fordham, 1997; detailed mapping and conodont biostratigraphy have established numerous thrust repetitions of the sequence in the Mungana area

Table 1 (continued)

Unit	Constituent Units	Rock Types	Thickness (max.)	Environment of Deposition
Mountain Creek Conglomerate		mainly pebble to boulder conglomerate, with subordinate interbedded arenite; minor basal limestone with interbedded quartzose arenite and conglomerate	uncertain because of extensive deformation; probably in the order of hundreds of metres	basal limestone deposited in shallow water; in contrast, the overlying siliciclastic sediments were deposited in relatively deep water (below storm wave base) by density currents
Van Dyke Litharenite		greenish grey to khaki, medium to coarse-grained, lithic arenite (quartz-intermediate greywacke), and dark grey shale and siltstone; minor quartzose arenite, haematitic shale, jasper, feldspathic arenite, conglomeratic feldspathic arenite; rare silicic lava	belts range from ~400m to 1000m in width, but accurate thickness estimates could not be made because of extensive internal folding and faulting	probably deposited by turbidity currents in a deep-water, marine environment
Mulgrave Formation	several informal subunits delineated; western part of formation informally referred to as Palmer River formation by Bultitude & Donchak (1992)	fine to medium-grained, moderately to poorly sorted, quartzose arenite; subordinate interbedded metabasalt, mudstone, siltstone, shale; minor haematitic shale, chert, jasper, pebbly arenite	unit has a maximum width of ~4km (tectonically thickened), but the maximum exposed thickness may be <1000m	arenites formed by rapid deposition (mainly by density currents) in a deep marine environment; presence of basic lava flows may be indicative of rifting; siliciclastic detritus derived from a mature cratonic source of subdued relief, or from recycling of detritus previously derived from such a source
undivided Hodgkinson Province rocks		thin to medium-bedded, quartzose arenite, mudstone; minor massive, recrystallised limestone, chlorite schist	~200m	marine

units, and general lack of age control. Some of these problems were addressed locally, in a limestone-dominated part of the assemblage. A detailed biostratigraphic study (using conodonts) of the Mungana area delineated numerous thrust slices in the Chillagoe Formation (Bultitude & others, 1993a; Fordham, 1994).

Mulgrave Formation

The Mulgrave Formation (Table 1) was first delineated by Fawckner (1981) and subsequently described by Bultitude & Donchak (1992) and Bultitude & others (1993a, 1996b). The unit extends adjacent to the Palmerville Fault from north-west of Chillagoe

Age and Evidence	Relationships	Distribution (area)	References Comments
fossils recovered from basal limestone include tabulate corals, crinoids, algae (*Vermiporella sp.*), gastropods, ostracodes, bryozoans, trilobites, oncolites, conodonts; conodonts have yielded a late Ordovician (Richmondian) age; a dacite clast from the overlying conglomeratic part of unit has yielded a SHRIMP age of 455±5Ma	faulted against the Mulgrave Formation; interpreted to be significantly younger than the Mulgrave Formation and separated from it by a major unconformity — clasts of quartz-veined quartzose arenite similar to that in the Mulgrave Formation are common in the Mountain Creek Conglomerate	forms discontinuous north-striking lenses up to ~7km long and 300m wide, adjacent to the Palmerville Fault in the far northwest of the Hodgkinson Province (mainly in the Mountain Creek area, east of Mount Mulgrave) (~3km^2)	Fawckner, 1981; Bultitude & others, 1990, 1993a; Bultitude & Donchak, 1992; Domagala, 1997b; unit contains mainly eastward younging strata, in marked contrast to nearby units, which are characterised by predominantly westward younging beds
no diagnostic fossils found; may be equivalent to compositionally similar part of the Mountain Creek Conglomerate (late Ordovician) exposed to the north	faulted against and unconformable? on the Mulgrave Formation	two narrow, discontinuous, north-trending belts which extend for ~20km adjacent to the Palmerville Fault, between the Mitchell and Palmer Rivers (in the Little Mitchell River area) (~11km^2)	Fawckner, 1981; Bultitude & Donchak, 1982; Bultitude & others, 1993a; arenites have a mixed provenance; one of the main sources of detritus was a silicic to intermediate volcanic sequence — the other consisted of high-grade metamorphic rocks and granite, similar to those exposed west of the Palmerville Fault
no diagnostic fossils found; regarded as most probably early Ordovician	bounded by the Palmerville Fault or faulted against and locally unconformably overlain by Quadroy Conglomerate to the west; inferred from field evidence to be older than nearby Mountain Creek Conglomerate (late Ordovician) and Van Dyke Litharenite (of uncertain age); faulted against the Chillagoe Formation to east; cut by numerous thin quartz veins	a semi-continuous north-trending belt adjacent to western margin of the Hodgkinson Province, from near Chillagoe to north of the Palmer River — belt ranges from <100m wide in the south to 4km wide between the Mitchell and Palmer Rivers; several smaller belts are also tectonically interleaved with the Chillagoe Formation in the Palmer River area (~215km^2)	Fawckner, 1981; Bultitude & others, 1990, 1993a; Bultitude & Donchak, 1992; formation forms part of a distinctive, extensive lithofacies represented in the Broken River Province, to the south, by lithologically similar arenites of the Judea Formation (early Ordovician)
uncertain; Ordovician?–Devonian?	thin fault-bounded lens enclosed within Yambo Metamorphic Group, west of the Palmerville Fault	north-trending lens, up to ~200m wide, west of the Palmerville Fault, around GR 1886 82129 (Maytown 1:100 000 Sheet area) (~0.4km^2)	Bultitude & Donchak, 1992; Bultitude & others, 1993a; several thin lenses of sheared, banded siliceous rock (chert?) and massive to laminated or brecciated feldspathic arenite exposed farther east in same area may also represent fault slivers of deformed Palaeozoic rocks

to north of the Palmer River, a distance of more than 150km.

Several belts of Mulgrave Formation rocks are also tectonically interleaved with the Chillagoe Formation well to the east of the Palmerville Fault in the Palmer River area. The sequence ranges in width from <100m in the south (Chillagoe–Mungana area) to more than 4km in the north (Mount Mulgrave area). The larger lenses resulted from extensive folding and thrust repetition of the sequence; the unit has a preserved thickness probably only in the order of several hundred metres (Domagala, 1997a). Beds are moderately steeply dipping to subvertical; most young to the west.

The dominant rock type is fine-grained, thin to medium bedded quartz-rich arenite (Table 1). The sequence also contains subordinate chert, jasper, haematitic mudstone, mudstone, and metabasalt. Partial Bouma cycles, horizontal and ripple cross-laminations, and water-escape structures are preserved locally. Chaotic folds in chert and jasper beds are common and are attributed to soft-sediment slumping (Bultitude & others, 1993a; Domagala, 1997a). Radiolarians are common. Reddish-brown, thin bedded, haematitic mudstone forms lenses up to several hundred metres thick. Metabasalt is confined to the northern part of the unit where it crops out in discontinuous lenses over a strike length of ~20km and a width of up to >2km. Pillow structures, flow-margin breccias, and possible hyaloclastite deposits have been identified.

The quartzose arenites which dominate the unit are interpreted as deep-marine density current deposits (mainly turbidites), whereas the chert beds and thick mudstone layers are interpreted as pelagic and hemipelagic deposits (Bultitude & others, 1993a; Domagala, 1997a). The character of the quartz, and the lack of less stable grains such as K-feldspar imply the sediments were derived from a mature source, probably with low relief (Domagala, 1997a). The few palaeocurrent measurements infer sediment transport was directed to the north-north-west (Domagala, 1997a).

The Mulgrave Formation is generally bounded, as well as internally disrupted by well-developed melange zones ranging from ~10m to 500m thick. Many of these zones probably represent major thrust faults which imbricated and upturned the sequence. The unit is also cut by numerous thin quartz veins.

The Mulgrave Formation is thought to be early Ordovician. The juxtaposed late Ordovician (Richmondian) Mountain Creek Conglomerate contains clasts of quartz-veined, quartzose arenite identical to that in the Mulgrave Formation. The field evidence, therefore, implies the two units are separated by a major unconformity. The Mulgrave Formation is correlated with the lithologically similar, early Ordovician Judea Formation in the Broken River Province (Withnall & Lang, 1990, 1993; Withnall, 1997a). The formation may form part of a distinctive lithofacies represented by extensive outcrops of quartz-rich arenite which characterises the Ordovician of the Lachlan Fold Belt (Crook & Powell, 1976; Powell *in* Veevers, 1984, page 293; Fergusson & Colquhoun, 1996).

Mountain Creek Conglomerate

The Mountain Creek Conglomerate (Table 1) was first described by Fawckner (1981) and subsequently, in more detail by Bultitude & Donchak (1992) and Bultitude & others (1993a). The unit is preserved in three north-trending lenses — two of these crop out east of Mount Mulgrave and the third north and south of the Palmer River. The largest lens is ~7km long and up to ~300m wide. The formation contains mainly eastward younging strata in marked contrast to nearby units (including the Mulgrave Formation) which are characterised by predominantly westward younging beds. Contacts with the adjacent Mulgrave Formation are inferred to be faulted.

The unit consists mainly of massive conglomerate and subordinate arenite which overlie and are interlayered (basal part) with discontinuous lenses (up to ~30m thick) of limestone.

The conglomerates are very thick bedded, massive, clast supported, with well-rounded pebble to boulder-size clasts in a matrix of coarse-grained feldspathic and lithofeldspathic arenite. Preserved primary sedimentary structures include ‘a’-axis clast imbrication, scours, and normal and reverse grading. The clasts consist mainly of quartzite, quartzose arenite (commonly cut by thin quartz veins), and felsic to intermediate volcanic rocks; minor rock types represented include granite (some clasts with granophyric textures), chert, quartz, and limestone (Bultitude & others, 1993a; Domagala, 1997b).

The limestone of the Mountain Creek Conglomerate was deposited in shallow water and is thought to form the lower part of the unit (Domagala, 1997b) — boulders of similar limestone are in the overlying conglomerate. In contrast, the conglomeratic rocks and interlayered arenites were deposited by density currents in relatively deep water (below storm-wave base). The clasts in the latter were derived mainly from the Mulgrave Formation, the basal limestone, and from intermediate to silicic volcanic and high-level intrusive sources. A silicic volcanic clast from the conglomerate has yielded a SHRIMP age of 455±5Ma.

A rich conodont fauna in the limestone has yielded a late Ordovician (Richmondian) age (Nicoll, 1988). The presence of oncolites and ooids also distinguish it from younger limestones of the nearby Chillagoe Formation. The basal limestone correlates with limestone of the Carriers Well Formation (Broken River Province) and Fork Lagoons beds (Anakie Inlier) (Fauna 12 ; Palmieri, 1978, 1984). The source of the volcanic clasts may have been a correlative of the Everett Creek Volcanics of the Broken River Province to the south (Withnall & Lang, 1993; Withnall, 1997a).

Deposition of the Mountain Creek Conglomerate is interpreted to have occurred during the last major eustatic episode of the Ordovician (Bultitude & others, 1993a; Domagala, 1997b). This episode commenced in the Richmondian and ceased at the end of the Ordovician (Gorter, 1992). The limestone was deposited in a shallow open-marine environment, probably as a highstand or shelf margin systems tract (Domagala, 1997b).

The conglomerate overlying the limestone has been interpreted as a lowstand systems tract deposited at the end of the eustatic event (Bultitude & others, 1993a; Domagala, 1997b). Several palaeocurrent measurements indicate sediment transport directions to the south and south-west (Domagala, 1997b).

Van Dyke Litharenite

The Van Dyke Litharenite was first described by Fawckner (1981). The unit forms two narrow discontinuous north-trending belts in the Little Mitchell River area, between the Mitchell and Palmer Rivers. The belts range from ~400m to 1000m in width, but accurate thickness estimates could not be made because of extensive internal folding and faulting. Beds are moderately steeply dipping (to the west) to subvertical and most are westward younging (Bultitude & Donchak, 1992; Bultitude & others, 1993a).

The unit is dominated by rhythmically interbedded, thin to medium-bedded arenite and mudstone (Table 1). It also contains minor thick-bedded, grey and haematitic mudstone, haematitic chert (jasper), and rare conglomeratic arkose (Bultitude & Donchak, 1992; Bultitude & others, 1993a).

Two types of arenite are present in the unit, a feldspathic arenite and a less common quartz-rich arenite. The feldspar-rich arenite is thin to medium-bedded, medium to coarse-grained, and locally pebbly (Bultitude & others, 1993a). It consists mainly of quartz, plagioclase, and fragments of felsic and basic volcanic rocks; minor fragments of metamorphic and sedimentary rocks are also commonly present (Domagala, 1997c).

The quartz-rich arenites are very similar to quartzose arenites of the Mulgrave Formation; they form lenses distributed throughout the succession (Bultitude & Donchak, 1992; Bultitude & others, 1993a). Horizontal laminations, normal grading, dewatering structures, and partial Bouma cycles are preserved in the arenites (Bultitude & Donchak, 1992; Bultitude & others, 1993a).

The overall bedding characteristics together with the primary sedimentary structures indicate the arenite beds were deposited by turbidity currents in relatively deep water (below storm-wave base). A dual provenance is implied by the two types of arenite in the succession.

The quartz-rich arenites were derived from sources similar to those which supplied detritus to the older? Mulgrave Formation, whereas the feldspathic arenites were derived from sources similar to those which supplied detritus to the late Ordovician Mountain Creek Conglomerate (Domagala, 1997c). The very thick mudstone beds appear to have been deposited as hemipelagic deposits.

The Van Dyke Litharenite contrasts markedly with the Chillagoe and Hodgkinson Formations to the east, which are characterised by an overall scarcity of volcanic detritus.

The volcanic detritus in the Van Dyke Litharenite may have been derived from either an older sequence or from a (pene-) contemporaneous source. The reported (Fawckner, 1981) presence of thin lenses of silicic volcanic rocks in the unit (Deep Creek area) implies the volcanic activity may have occurred at essentially the same time as the sediments were deposited.

The age of the unit is unknown. However, lithological similarities with the Mountain Creek Conglomerate imply the two formations may be correlatives (Bultitude & Donchak, 1992; Bultitude & others, 1993a; Domagala, 1997c).

SILURIAN TO EARLY DEVONIAN ROCKS

HODGKINSON PROVINCE

Chillagoe Formation

The early Silurian–early Devonian Chillagoe Formation crops out near the western margin of the Hodgkinson Province as a belt of steeply dipping, dominantly westward-younging strata, which trend parallel to the Palmerville Fault. The unit extends over a distance of ~150km and ranges in width from ~10km to less than a few hundred metres. Regional aeromagnetic images indicate the formation extends in a north-north-easterly direction under Mesozoic rocks of the Laura Basin.

The formation is characterised by a diverse range of rock types (Table 1), including limestone, limestone breccia, chert, metabasalt, quartzofeldspathic arenite, mudstone, siltstone, conglomerate, and conglomeratic arenite. The relative proportions of each rock type differ from one locality to another. Although limestone characterises the formation, it is not the dominant rock type everywhere. Limestone, for example, is very rare north of the Palmer River, but is prominent in the area between Chillagoe and the Walsh River. Similarly, metabasalt is rare in the Chillagoe Formation south of the Mitchell River, particularly between the Mitchell and Walsh Rivers. In contrast, metabasalt constitutes up to more than 50% of the area occupied by the formation north of the Mitchell River. Siliciclastic arenite and mudstone dominate in the area between the Mitchell and Walsh Rivers.

The rock types of the Chillagoe Formation, particularly the limestones have been described in detail by Bultitude & others (1985), Bultitude & Domagala (1988), O'Neill (1988), Osborne (1988), Domagala (1991), Bultitude & Donchak (1992), Bernecker (1993), and Bultitude & others (1993a).

Beds in the siliciclastic arenite and mudstone lithofacies range from thin (arenite–siltstone and rhythmically interlayered mudstone sequences) to very thick and massive (arenite and conglomerate). Graded bedding, load casts, parallel and ripple laminations, medium-scale cross-beds (in conglomeratic layers), scours, sole marks, dewatering structures, and partial Bouma cycles are commonly present in the unit. These features are typical of turbidity-current deposits. Carbonate turbidites also form part of the succession south of the Palmer River, reflecting periods of instability, possibly related to basaltic volcanic activity.

The most noteworthy feature of the arenites of the Chillagoe Formation (and the adjacent Hodgkinson Formation) is their quartzofeldspathic rather than volcaniclastic character. Most are quartz-intermediate greywackes (classification of Crook, 1974). Volcanic fragments are generally scarce. Furthermore, what volcanic detritus there is may have been derived from a significantly older assemblage — possibly the same Ordovician source that supplied similar detritus to the older Mountain Creek Conglomerate — rather than from a contemporaneous or penecontemporaneous volcanic arc.

Relationships with adjacent units

Whether or not there was a significant time break between the deposition of the Chillagoe Formation and Mountain Creek Conglomerate is uncertain — the contact between the two formations being faulted. The oldest conodonts recovered from the Chillagoe Formation are late Llandovery (Bultitude & others, 1993a). Bultitude & others (1996b) postulated there may have been an erosional break, corresponding with uplift related to the emplacement of the Nundah Granodiorite in the nearby Etheridge Province to the south-west. The juxtaposition of the east-younging Mountain Creek Conglomerate against west-younging rocks of the Chillagoe Formation is consistent with such an interpretation. The Nundah Granodiorite has yielded a SHRIMP age of 434±10Ma. It, therefore, may predate the Chillagoe Formation and correlate with an unconformity at its base.

The location of the boundary between the Chillagoe and Hodgkinson Formations also poses a problem. At least some siliciclastic-dominated intervals in the Chillagoe Formation (as mapped) appear to conformably overlie limestone-dominated parts. The former closely resemble intervals in the Hodgkinson Formation and may be coeval with them. The biostratigraphic control on the age(s) of the siliciclastic rocks is very poor.

In the Mungana area, the deposition of significant amounts of siliciclastic arenite and mudstone, typical of the rocks found in the Hodgkinson Formation, began in the late Lochkovian (Bultitude & others, 1993a). However, significant limestone deposition, characteristic of the Chillagoe Formation, continued well into the Emsian (Bultitude & others, 1993a; Fordham, 1994). Furthermore, Hodgkinson Formation-like siliciclastic sediments were deposited as early as the Wenlock farther north, in the Mitchell River area (Domagala, 1991). For mapping purposes the boundary between the two formations corresponds to the end of significant carbonate deposition.

Apparently conformable intervals containing rocks typical of the Chillagoe and Hodgkinson Formations are preserved in several fault slices, which, therefore, should contain the stratigraphic contact between the two formations. In the Mungana–Chillagoe area the transition between such intervals is commonly marked by a prominent conglomeratic sequence, mapped as the upper part of the Chillagoe Formation.

Farther north, conglomerate lenses in the Chillagoe Formation south of the Mitchell River, have been tentatively interpreted as facies equivalents of the conglomeratic sequence in the Mungana area (Domagala, 1991; Bultitude & others, 1993a). The lithofacies consists mainly of medium to very thick-bedded and massive limestone conglomerate/breccia, with minor thin to medium-bedded calcarenite. The rounded to angular limestone clasts range from sand to boulder (up to ~5m across) size (Domagala, 1991). Well-rounded pebbles of quartz, chert and arenite, as well as ‘rip-up’ mudstone/shale clasts are also present in places. The presence of graded beds, ‘a’-axis clast imbrication and mixed clast populations indicate this lithofacies was deposited mainly by debris flows and turbidity currents (Domagala, 1991).

North of the Mitchell River the lithofacies is represented by lenses (up to ~10m thick) of massive, pebble to cobble conglomerate, interlayered with mainly medium to coarse-grained, thick-bedded, micaceous quartzofeldspathic arenite. Clasts are matrix supported. They range from subangular to rounded, and consist mainly of limestone, arenite, siltstone, quartzite and quartz, together with minor mudstone and shale and leucogranite (Bultitude & Donchak, 1992). Limestone fragments make up to ~80% of the clasts locally (*e.g.* in the eastern branch of Running Creek, at GR 1978 81802).

Farther north (south of the Palmer River) the lithofacies may be represented by lenses of intensely deformed, stretched boulder conglomerate exposed, for example, around GR 1979 82226. The clasts (up to ~70 cm across) consist mainly of intensely flattened, recrystallised, fossiliferous limestone, mudstone, and quartzofeldspathic arenite. The matrix is coarse-grained quartzofeldspathic arenite. The conglomeratic rocks in this area have been mapped as part of the Hodgkinson Formation.

The lithofacies is thought to represent channel-fill and slope-apron deposits which reflect the transition from the relatively stable conditions of Chillagoe Formation time to the more unstable and significantly deeper water environment of Hodgkinson Formation time.

Environment of limestone deposition

The environment of deposition of the Chillagoe Formation has been the subject of much debate. The presence of numerous, commonly fossiliferous limestone lenses in the type area (Chillagoe–Mungana area) led most earlier workers (*e.g.* de Keyser & Lucas, 1968) to conclude that the Chillagoe Formation was deposited on a shallow-marine shelf. Henderson (1980), Green & others (1988) and Green (1990) subsequently interpreted much of the formation as a shallow-water carbonate shelf which had collapsed into deeper water. A conflicting interpretation has been presented by Webb & others (1989) and Bernecker (1993) who examined the area around Mungana in detail, and Domagala (1991) who studied the limestones south of the Mitchell River. They deduced that most of the limestones in these areas are essentially in-place sequences, not large allochthonous blocks.

The results of these detailed studies indicate the limestones and some cherts in the Chillagoe Formation most probably formed isolated ramps and mounds, possibly on the upper parts of fault blocks which marked the sites of half-grabens in an extensional basin. Tidal and shoreline facies have not been recognised. Water depths ranged from relatively deep (sublittoral, below storm-wave base) to very shallow (sublittoral, above fair-weather wave base) during the deposition of the limestones in the Mungana area (Bernecker, 1993).

The carbonates are mud dominated and accumulated very slowly, mainly in a restricted, relatively stable environment (also indicated by the lack of diversity in the coral faunas and the general scarcity of conodonts; Bultitude & others, 1993a). The Chillagoe Formation in the Mungana area records generally low but locally variable rates of limestone deposition over a period of ~30My (Bultitude & others, 1993a).

Conclusions

Deposition of the Chillagoe Formation began some time prior to the very late Llandovery (late Telychian). The extensive basalt deposits in the northern part of the unit may have been erupted during early rifting of the developing depositional basin. Subsequent shallowing of the substrate encouraged the formation of limestone and the development of carbonate ramps. This carbonate-ramp environment persisted in the Mungana area until the Emsian.

Erosion of the ramp in the Mungana area and deposition of siliciclastic sediments commenced in the late Lochkovian and continued into the Emsian. This erosional episode may have been triggered by uplift in the hinterland, possibly associated with the emplacement of the Cape York Peninsula Batholith. Detritus derived from the hinterland was transported basinwards along numerous distributary channels (representing feeder channels to submarine fans) eroded into the carbonate ramp.

The polymictic and oligomictic (limestone) conglomerate deposits which extend along much of the eastern margin of the Chillagoe Formation may represent extensive channel or slope-apron deposits which formed during this erosional episode. Evidence of similar but less dramatic events in the Wenlock and Ludlow are preserved in the formation in the Mitchell River area (Domagala, 1991).

DEVONIAN TO EARLY CARBONIFEROUS? ROCKS

HODGKINSON PROVINCE

Hodgkinson Formation

The very extensive Hodgkinson Formation is dominated by turbidity-current deposits (Table 1). The formation consists mainly of (meta-) arenite and (meta-) mudstone; it also contains minor (meta-) conglomerate, (meta-) chert, sparse metabasalt, and rare limestone. The siliciclastic rocks display primary sedimentary structures and bedding features diagnostic of high- and low-concentration turbidity-current deposits (Bultitude & others, 1993a; Domagala, 1997d). Palaeocurrent directions are generally perpendicular (east to north-east) and parallel (north-north-west and south-south-east) to the present craton margin, although they show a considerable range in orientations (Domagala, 1997d).

The sediments were deposited mainly in deep water (sublittoral or bathyal), but local shallowing resulted in isolated carbonate build-ups. Fawckner (1981) found that arenites collected from the Chillagoe and Hodgkinson Formations, as well as from the Mount Garnet Formation of de Keyser & Lucas (1968; essentially equivalent to the Kitoba Member of Bultitude & others, 1993a), have no significant textural or compositional differences. Primary sedimentary structures include graded bedding, parallel and ripple laminations, convolute bedding, and load casts.

The framework component of the arenites typically consists of quartz, feldspar (plagioclase and subordinate K-feldspar), lithic fragments, rare muscovite and biotite, and accessory and secondary minerals. Accessory and secondary minerals include zircon, chlorite, garnet, tourmaline, opaque oxides, epidote, pyrite, arsenopyrite, graphite (rare, deformed, detrital? flakes), sericite, siderite, calcite and ankerite. Lithic fragments consist mainly of locally derived mudstone, siltstone, arenite and chert; exotic rock types represented include granite, quartzite, quartz, silicic to basic volcanics and muscovite schist. The matrix (~15%) appears to be a pseudomatrix of quartz, sericite, clays, chlorite, and (locally) Fe oxide (Domagala, 1997d). The arenites have been classified as quartz-intermediate greywackes by Crook (1974).

Whether the volcanic fragments were derived from a significantly older assemblage or from (pene-) contemporaneous sources is uncertain. Locally, for example in the Mitchell River area north of the Featherbed Range, scattered fine-grained, siliceous layers form a minor part of the formation. Some of these contain what may have originally been glass shards (now completely replaced by cryptocrystalline silica). If the fragments are shards their presence would imply essentially contemporaneous volcanic activity in the vicinity of the Hodgkinson Province.

Conversely, a porphyritic dacite clast from a sequence of conglomerate and conglomeratic meta-arenite in the Hodgkinson Formation south of Cooktown has yielded a SHRIMP age of 465±21Ma. The clast is, therefore, significantly older than the Hodgkinson Formation. It is essentially the same age as the source of the dated volcanic clast in the Mountain Creek Conglomerate, exposed adjacent to the western margin of the province.

The most likely sources of the basic volcanic detritus were older units in the Hodgkinson Province.

The formation also contains widely distributed lenses of conglomerate, conglomeratic arenite, quartzose arenite (scarce), metabasalt, chert, and rare limestone. The most common modes of occurrence of the coarse detritus, which contains abundant intraformational clasts (including limestone) is as lenses and thin irregular zones in the basal parts of some of the thicker arenite beds. Intermediate to silicic volcanic detritus is present in a few places, but overall forms a minor component of the succession. Richly fossiliferous limestone clasts, up to ~2m across, have been reported in conglomeratic lenses in the central part of the formation (Cranfield & Hegarty, 1989). Intraformational olistostrome and debris flow deposits (1–8m thick) have been delineated in the Hodgkinson Gold Field (Peters, 1987), as well as elsewhere.

Intraformational clasts ('rip-ups') of mudstone, as well as much scarcer arenite and chert, are widely distributed in the medium to thick-bedded arenites. The mudstone clasts range up to ~3m across and are commonly between 20cm and 1m in length.

The metabasalts in the unit (including those in the OK and Larramore Metabasalt Members) crop out poorly, and are commonly characterised by the development of mantles (of varying thicknesses) of dark reddish brown soil. They are generally fine grained, massive to locally amygdaloidal, brecciated, and rarely pillowed. Results of geochemical studies by Fawckner (1975, 1981) indicate the basalts of the Hodgkinson and Chillagoe Formations are tholeiitic.

Limestone lenses, up to ~5km long and ~1km wide, are sparsely distributed throughout the unit. The larger lenses form prominent bluffs and rocky outcrops. Bedding, where present, is concordant with that in the enclosing sedimentary rocks or, in some cases, the tectonic layering. Contacts are either abrupt or gradational with transitional facies developed (Domagala, 1997d). Some of the limestones are interlayered with minor metabasalt, thereby supporting the interpretation of Fawckner (1981) that they developed on basalt 'highs' and the upper parts of elevated fault blocks. The largest lens (at Melody Rocks, south-west of Cooktown) appears to have developed in place on a base of siliciclastic rocks (Donchak & others, 1992). An alternative interpretation proposed by de Keyser & Lucas (1968) and Henderson (1980) is that these isolated bodies represent allochthonous blocks. Both allochthonous and in-place limestone lenses are probably present in the unit.

The Hodgkinson Formation has been intruded by numerous late Palaeozoic granites which have produced poorly to well-defined contact metamorphic aureoles. Typical effects are induration and recrystallisation in arenite units and the development of (staurolite–garnet–cordierite–andalusite)–quartz–mica hornfels and schist in mudstone units adjacent to the contacts. The aureoles range up to ~2km in width (Cannibal Creek Granite), but most are much narrower.

Age

The available age data indicate the Hodgkinson Formation is generally younger than the Chillagoe Formation, but that some of the older parts of the former may be coeval with younger parts of the latter. The Hodgkinson Formation is sparsely fossiliferous. Lycopod fragments (including *Leptophloem australe*) are scattered throughout the central part of the formation. The reported range of *Leptophloem* *australe* in Australia is early Devonian to early Carboniferous, but it is particularly abundant in late Devonian rocks (Gould, 1976). Conodonts from rare limestone lenses and from clasts in conglomeratic units (also mainly in the central part of the formation) indicate an age range from early Devonian (Lochkovian), or possibly even late Silurian, to late Devonian (Famennian; Cranfield & Hegarty, 1989; Halfpenny & Hegarty, 1991; Donchak & others, 1992; Domagala & others, 1993).

The Hodgkinson Formation in the eastern part of the province is intruded by several plutons of Mount Formartine Granite. A sample from one of these plutons recently yielded a SHRIMP age of 357±6Ma. (Zucchetto & others, 1998), thereby constraining the upper age limit of the formation in the east to pre-late Famennian.

The available data, therefore, imply the central area of Hodgkinson Formation contains the youngest rocks in the unit.

Provenance

The geochemical characteristics of the quartzofeldspathic meta-arenites indicate they were derived from *Quartzose Sedimentary* and *Felsic Igneous* provenances (Domagala, 1997d), using the discrimination diagrams of Roser & Korsch (1988). Samples reflecting a felsic igneous provenance are most common in the east near Cooktown (Domagala, 1997d). The scattered distribution of these samples in the east implies the sediments were deposited intermittently amongst the more typical (background) Hodgkinson Formation arenites and may reflect a dual provenance.

The more felsic sediments may have been derived either from the source of the silicic volcanic clasts in the Mountain Creek Conglomerate, or possibly from a (pene-) contemporaneous volcanic source (to the east?). The source of the detritus in the background quartzofeldspathic arenites, however, was almost certainly on the craton to the west. Such a conclusion is supported by the presence of zircons no younger than 420±14Ma in the matrix of a conglomerate south of Cooktown. The nearest exposed rocks of this age are the Silurian–Devonian granites of the Cape York Peninsula Batholith (Willmott & others, 1973; Black & others, 1992a, b; Mackenzie & Knutson, 1992). A silicic volcanic clast from the same conglomerate yielded a SHRIMP age of 465±21Ma. This clast may have been derived from the source of the volcanic clasts in the Mountain Creek Conglomerate or possibly from a similar-age source (no longer exposed) farther to the east.

Hodgkinson Formation — Kitoba Member

The Kitoba Member (Table 1) includes most of the rocks which were formerly mapped as Mount Garnet Formation (Amos & de Keyser, 1964). It extends along the central-western extremity of the Hodgkinson Formation and is faulted against the Chillagoe Formation. The unit is interpreted as a proximal deposit. Rock types consist mainly of arenite with subordinate mudstone, pebbly arenite and conglomerate, and minor siltstone, chert and metabasalt. The distinguishing characteristic of the member is the predominance of sequences, up to several hundred metres thick, of amalgamated, thick to very thick-bedded, medium to very coarse-grained arenite beds. Locally, most arenite beds in a particular interval have relatively coarse, pebbly, lower parts and normal grading. Elsewhere, the sequences consist of amalgamated, massive, non-graded beds. The arenites are compositionally similar to those in the undivided Hodgkinson Formation (Domagala, 1997d).

The amalgamated arenite sequences are interlayered with much thinner (up to tens of metres thick) sequences of rhythmically interbedded, thin to medium-bedded arenite and mudstone. Bouma cycles are poorly developed.

Conglomeratic rocks are most abundant in the western part of the member, where they are generally associated with amalgamated arenite sequences. Angular to rounded fragments of chert, limestone, quartz, arenite, and mudstone ('rip-ups') predominate. Medium to large-scale planar cross-beds are extensively developed in conglomeratic rocks exposed in the Nolan Creek area (Bellevue 1:100 000 Sheet area). The conglomerates are interpreted as channel-fill and associated slope-apron deposits. They may be time equivalents of thick conglomerate lenses in the upper part of the Chillagoe Formation in the Chillagoe–Mungana area (Bultitude & others, 1993a).

The age of the Kitoba Member is unknown, but its location in the far west of the Hodgkinson Formation assemblage implies it is one of the oldest parts, if not the oldest part of the formation (*i.e.* most probably early Devonian).

The contact with the Chillagoe Formation is inferred to be a fault (westward younging strata predominate in both the Kitoba Member and adjacent Chillagoe Formation rocks).

Hodgkinson Formation — OK Member

The OK Member (Table 1) was previously mapped as the eastern part of the Mount Garnet Formation succession (Amos & de Keyser, 1964). It is characterised by numerous closely spaced chert lenses which form prominent strike ridges. Beds in these lenses are generally thin with shale partings. They are almost invariably characterised by numerous small-scale tight to isoclinal folds, the chaotic nature of which implies they resulted from soft-sediment deformation. Numerous conspicuous radiolarian tests (in the form of spherical to elliptical spheres up to ~100mm in diameter) are present locally (Bultitude & others, 1993a). The radiolarians are commonly restricted to particular beds or concentrated in layers within individual beds, indicating episodic deposition.

The metabasalts are poorly exposed and generally foliated. Contacts with adjacent rock units appear concordant and conformable. The O.K. copper lodes which also produced some gold and silver are in metabasalt of the OK Member. They are thought to represent syngenetic volcanic-hosted massive sulphide deposits which formed in areas of crustal extension in a tectonic environment closely analogous to a marginal sea (Fawckner, 1978).

Hodgkinson Formation — Larramore Metabasalt Member

The Larramore Metabasalt Member (Table 1) crops out in the north-west where it forms a prominent north-west to north-north-west trending belt up to ~3km wide. This belt extends from beneath the Mesozoic sedimentary rocks of the Laura Basin south for ~30km to the abandoned Cannibal Creek tin mine. The member also outlines a structural dome (the Mount Madden Dome) ~25km in circumference farther to the south-west (in the Mount Madden–Stonyville area).

The member consists mainly of metabasalt lava flows with numerous interlayered chert lenses ranging from ~2m to 30m thick. The sequence also reportedly contains minor intercalated tuffaceous metasedimentary rocks containing basic volcanic detritus (McGain, 1981; McLean, 1982; Langmead, 1983). The thickness of the member is uncertain because of extensive deformation and the likelihood of repetition of parts of the sequence by difficult-to-detect bed-parallel or low-angle thrust faults. The member is bounded by a melange zone in the east and is also cut by several prominent melange zones in the north.

Mineralisation

Some of the cherts are vuggy and have a ferruginous, gossany appearance due to the presence of minor but significant amounts of Fe and Mn oxides and, locally, pyrite and other sulphides (McGain, 1981; McLean, 1982).

These ferruginous cherts (now mainly quartzite) are of considerable interest to exploration companies. They locally contain native gold, pyrite, arsenopyrite, scorodite, pyrrhotite, marcasite, and chalcopyrite (McLean, 1982). Lode gold mined at Mount Madden, Buchanans and Jessops Gully in the late 1800s (Jack, 1899) appears to have been mainly in ferruginous chert (McGain, 1981; McLean, 1982). The very fine grainsize and erratic distribution of the gold, combined with low overall grades were the main reasons for the lack of any significant development of the lodes. Gold values up to 14.5g/t have been reported by McConnell & Carver (1985). Wherever metachert crops out in the structural dome south-west of Cannibal Creek tin mine the creeks and gullies draining the area have almost invariably been worked for alluvial/eluvial gold.

The ferruginous cherts have been interpreted by most exploration geologists as chemical (exhalite) deposits related to submarine basaltic volcanism (*e.g.* McGain, 1981). McConnell & Carver (1985) disagreed with this interpretation and postulated the ferruginous cherts represent silicified phyllites or siliceous zones of indeterminate origin.

Copper mineralisation, as stratabound volcanic-hosted massive sulphide deposits, occurs in the sequence at Mount Bennett, south of the Palmer River.

Structure and metamorphism

The sequence commonly shows a weak to prominent tectonic foliation. The foliation is most intensely developed in the Mount Madden–Stonyville area where the rocks are characterised by a prominent platy fabric. The sequence in this area outlines a broad structural dome (the Mount Madden Dome), but on a detailed scale the rocks are intensely folded and faulted. Mesoscopic folds are common in the cherts. A cross-cutting crenulation cleavage is also well developed in this area and foliation planes are generally characterised by a prominent mineral streaking or intersection lineation.

Farther north, the cherts also show a well-developed foliation sub-parallel to bedding and stylolites are locally well developed.

The Larramore Metabasalt Member has been regionally metamorphosed to the lower greenschist facies in most places. Relict igneous textures are poorly preserved in the metabasalts, most of which contain abundant tremolite/actinolite and albite. Fine metamorphic biotite is relatively common in the interlayered siliciclastic sedimentary rocks.

The most extensively recrystallised and highest grade rocks crop out in the Mount Madden Dome south-west of the abandoned Cannibal Creek tin mine. They may indicate the presence of granite at relatively shallow depths. Granite has been intersected in several holes drilled near the abandoned Keddy tungsten mine to the north-east (McConnell & Carver, 1984a). Furthermore, hornfelsed phyllitic rocks containing altered andalusite porphyroblasts have been reported around Buchanans mine (McConnell & Carver, 1985). McConnell & Carver (1985) also reported hornfelsed phyllite near Mount Madden. Several outcrops of very poorly exposed muscovite schist containing scattered chlorite porphyroblasts were also found in the dome during the GSQ survey. The only other known occurrences of schist in the Hodgkinson Formation of the Palmer River area are in the metamorphic aureole surrounding the Cannibal Creek Granite.

Molloy beds

The Molloy beds (Cranfield & Hegarty, 1989) are a distinctive package of rocks (Table 1) exposed mainly in a belt extending for ~5km south of Mount Molloy, in the central part of the region. Some of the best outcrops are in cuttings along the main Mareeba–Cooktown road. Arenite beds are typically 2cm to 10cm thick, whereas most siltstone and mudstone beds are between 2cm and 5cm thick. Noteworthy characteristics of the unit are the presence of numerous graded beds and of upward fining sedimentary cycles (Cranfield, 1990). The latter are characterised by increases in both the thickness of mudstone intervals and the abundance of mudstone relative to arenite. The average thickness of each cycle is ~40m (Cranfield, 1990).

Beds are generally shallowly dipping to subhorizontal (<15°) away from the bounding faults — in contrast to the steeply dipping to subvertical strata of the nearby Hodgkinson Formation assemblage. The unit is more than 230m thick (Cranfield, 1990).

According to Cranfield (1990) the Molloy beds post-date the first regional deformational event (hD_2) which affected the entire Hodgkinson Province (most probably in the Devonian). However, the unit has a well-developed hD_3 axial plane cleavage; mesoscopic hD_3 folds are also present in places (Cranfield, 1990). The presence of shallowly dipping strata away from major faults is consistent with such an interpretation. The lack of abundant volcanic/igneous detritus in the sedimentary rocks implies the sequence is older than late Carboniferous. The available data, therefore, imply the Molloy beds are most probably very late Devonian or early Carboniferous. The sediments were most probably deposited in a deep-marine environment by turbidity currents (Cranfield, 1990).

Cranfield (1990) reported the Molloy beds to be intruded by the Mount Formartine Granite, recently reported to be late Devonian (Zucchetto & others, 1998). This is thought to be unlikely by the writer. The two units have not been mapped as being in contact. Small microgranite bodies (not delineated) which intrude the Molloy beds were presumably equated with the Mount Formartine Granite by Cranfield.

Quadroy Conglomerate

The Quadroy Conglomerate (Fawckner, 1981) crops out as discontinuous lenses along the western margin of the Hodgkinson Province, adjacent to the Palmerville Fault. The formation consists mainly of conglomerate, conglomeratic feldspathic arenite and feldspathic arenite (Table 1). Minor sedimentary breccia is also present in the Quadroy Creek area. The conglomeratic rocks are unsorted to very poorly sorted. Outcrops are mainly massive.

Granite is the dominant clast type in most places. Clasts of amphibolite, quartzofeldspathic gneiss (some with garnet porphyroblasts), quartz mylonite, mylonitised gneiss, quartzite, schist and quartz are also common.

A noteworthy feature is the coarse size of many of the clasts. Some granite boulders are up to ~2m in diameter (Bultitude & others, 1996b), and boulders of gneiss and amphibolite between 50cm and 1m in diameter are common. Most of the granite and high-grade metamorphic clasts are well rounded, whereas fragments of quartz mylonite and mylonitised gneiss tend to be more angular. Highly angular to subrounded amphibolite fragments, up to ~50cm across, are present locally.

Quartz mylonite generally forms a minor but significant proportion of the clasts. The mylonite fragments are highly angular, range up to ~1m in length, and closely resemble — except for the very extensive ferruginisation shown by many — mylonitised middle Proterozoic rocks exposed in and adjacent to the Palmerville Fault.

The massive, immature character of the sedimentary rocks, the almost complete lack of sedimentary structures including bedding, and the presence of numerous large clasts imply extremely rapid deposition under high-energy conditions, probably in a proximal-fan environment. Furthermore, a non-marine or marginal-marine environment is indicated by the dark reddish brown to brick-red colour of many of the metamorphic fragments.

Fawckner (1981) and Shaw & others (1987) interpreted the Quadroy Conglomerate as a synorogenic deposit eroded from the nose of an advancing thrust sheet which developed during the first major deformation to affect late Ordovician–Devonian rocks of the western Hodgkinson Province. The lack of a well-developed foliation in the formation away from the bounding faults implies that, if this had been the case, the unit was most probably deposited during the waning stages of the deformation.

HODGKINSON PROVINCE ROCKS OF UNCERTAIN AGE

Unit Pzu forms a fault-bounded lens west of the Palmerville Fault between the Mitchell and Palmer Rivers (around GR 1886 82129, Maytown 1:100 000 Sheet area). The lens is up to 200m wide and consists mainly of disruptively deformed, extensively recrystallised, thin to medium-bedded quartzose arenite and mudstone (Bultitude & others, 1993a). The mudstone has been extensively converted to fine chloritic schist. Intense bedding disruption has locally produced melange zones.

The western margin of the unit is marked by thin, discontinuous lenses of crudely bedded to massive, recrystallised limestone (Bultitude & Donchak, 1992). The unit is enclosed within porphyroclastic gneiss and amphibolite of the Yambo Metamorphic Group. Several thin lenses of sheared, banded siliceous rock (chert?) and massive to laminated or brecciated feldspathic arenite cut by pegmatite dykes crop out within the Yambo Metamorphic Group farther east (Bultitude & Donchak, 1992). These may also represent fault slivers of deformed Palaeozoic rocks, but are too small to be shown on the maps.

The unit is interpreted to have been tectonically emplaced into its present position during eastward-directed hD_2 thrusting of the Proterozoic rocks over the adjacent Hodgkinson Province sequence to the east (Bultitude & others, 1993a). The presence of limestone within the unit implies it may correlate, at least in part, with the nearby Chillagoe Formation.

Similarly, a small pod of recrystallised limestone which crops out west of the Palmerville Fault farther south (at GR 1126 81129, Mungana 1:100 000 Sheet area) has been tentatively assigned to the Chillagoe Formation (Bultitude & others, 1998b).

STRUCTURE OF THE HODGKINSON PROVINCE

The structural history of the province is complex. It is still largely unknown in detail, primarily as a result of difficulties in correlating deformational events across the entire province. Major problems are the heterogeneous (domainal) nature of most of the deformations, the extensive reactivation and re-use (terminology of Bell, 1986; Davis, 1993, 1994) of older fabrics by subsequent events to produce composite foliations, the apparent localisation of some of the deformational events, and the possibility that some of the deformations were diachronous.

The event which curtailed the deposition of the quartzose flysch of the Mulgrave Formation, probably in the middle Ordovician, is the first significant deformational event known to have affected rocks of the Hodgkinson Province. In some previous reports the event which significantly deformed the *entire* province was considered to be hD_1. This event is currently thought to have occurred in the late Devonian.

An attempt at summarising the main deformational events which affected the Hodgkinson Province is presented in Table 2. However, it is stressed that there is no general agreement amongst structural workers as to the number or timing of events. For more detailed descriptions of aspects of the structure of the province readers are referred to Arnold & Fawckner (1980), Shaw & others (1987), Bultitude & Donchak (1992), Bultitude & others (1993a, 1996b), Davis (1993, 1994), and Donchak (1997).

The recently obtained late Devonian (357±6Ma age for the Mount Formartine Granite and the ensuing interpretation that the unit was emplaced pre- or syn-D_2 (terminology of Zucchetto & others, 1998) provides some constraints on the ages of hD_2 and hD_3 (Table 2). It also provides a link between lithologically similar rocks of the Broken River Province farther south and those of the Hodgkinson Province. The former are intruded in the Camel Creek area by several small plutons of granite and granodiorite, one of which has yielded a K–Ar age of 357Ma (Withnall, 1997b). Withnall (Withnall & Lang, 1993) postulated these plutons were emplaced during the D_2 event which affected the Broken River Province. Zucchetto & others (1998) also pointed out that the structural relationships displayed by these late Devonian granites imply they were emplaced during the first episode of regional-scale orogenesis and the development of penetrative fabrics in the Hodgkinson–Broken River Fold Belt.

TECTONIC MODEL FOR THE HODGKINSON PROVINCE

Introduction

The tectonic setting for the Hodgkinson Province remains controversial. Most interpretations of the evolution of the northern Tasman Orogenic Zone involve the presence of a consuming plate margin for much of the Palaeozoic (*e.g.* Coney & others, 1990). However, there is no general agreement as to the location of the volcanic arc(s) and subduction zone(s) with respect to the Hodgkinson Province.

The Hodgkinson Province is bounded to the west by the Palmerville Fault system, a major structural discontinuity in north Queensland, with a long history of episodic movements. As a consequence, the original relationship between the rocks of the province and the older (middle Proterozoic) high-grade metamorphic rocks of the Dargalong, Yambo, and Coen Inliers is conjectural. Furthermore, relationships between most units of the Hodgkinson Province are also uncertain. Virtually all, in fact, represent belts of distinctive rock types bounded, as well as internally disrupted by numerous thrust faults.

Previous tectonic models for the Hodgkinson Province

Most previous workers (*e.g.* Arnold, 1975; Cooper & others, 1975; Henderson, 1980) interpreted the Hodgkinson Province succession as having accumulated in a fore-arc–accretionary prism setting located to the east of an active continental magmatic arc. In at least some of these interpretations the Chillagoe Formation was regarded as a fore-arc assemblage and the Hodgkinson Formation as an accretionary prism/subduction complex. White (1978) also accepted this model in principle, but was the first to postulate most of the Chillagoe Formation to be an island-arc sequence. Henderson (1987) subsequently modified his earlier model and rationalised the formation of the Hodgkinson Province in terms of oblique subduction and strike-slip faulting.

The Hodgkinson Province succession, especially the Hodgkinson Formation, does show many features that are typical of accretionary prisms or subduction complexes, in particular:

- the abundance of relatively deep-water, density-current deposits in the Hodgkinson Formation with intercalated lenses of submarine basalt and chert;

- the imbricate stacking of steeply dipping thrust slices, internally younging towards the continent/craton but overall younging away from it — at least as far as the central parts of the province;

- the abundant evidence of soft-sediment deformation in the Hodgkinson Formation; and

- the widespread distribution of melange zones (particularly in the Hodgkinson Formation), interpreted by many workers to result from deformation of incompletely lithified and dewatered sediments within subduction complexes.

Nevertheless, not all of the features of the Hodgkinson Province can be readily rationalised by subduction. Fawckner (1981) postulated that the tholeiitic rather than calc-alkaline character of the basic lavas which are widespread throughout the province, and the overall scarcity of penecontemporaneous intermediate to silicic volcanic detritus, indicated a model involving the development of a rifted continental margin rather than a fore-arc/accretionary prism complex (*i.e.* overall extension rather than compression).

Hammond (1986) proposed an intracontinental thrust (foreland basin) model for the Hodgkinson Province. This model involved shedding of intraformational and basement detritus from a series of eastward-advancing thrust sheets into an adjacent basin created by crustal downwarping ahead of a propagating thrust front. The sedimentary pile was successively overridden by the advancing thrust sheet(s), resulting in deformation of the incompletely dewatered sediments to produce zones of melange. Hammond did not propose a mechanism for such intracratonic thrusting; nor did he attempt to explain the belts of basic lava and chert which are present throughout the Hodgkinson Province. The model also did not adequately explain the emplacement of the late Silurian–early Devonian granites of the Cape York Peninsula Batholith west of the Palmerville Fault at about the same time as the commencement of significant siliciclastic sedimentation in the Hodgkinson Province.

A possible model

The results of recent investigations of the Hodgkinson Province by GSQ favour an extensional rather than a compressional regime for the evolution of the Hodgkinson Province. Whether a rifted continental margin as suggested by Fawckner (1981) is a more appropriate setting than a back-arc basin depends essentially on whether the relatively common volcanic detritus in the north-eastern part of the province, as well as minor amounts elsewhere, was derived from a contemporaneous magmatic arc or from an older sequence.

However, it should be pointed out that much of the work is of a preliminary, reconnaissance nature. More detailed studies, such as SHRIMP dating of zircon grains from selected sedimentary and tuffaceous layers to determine whether or not there was nearby intermediate–felsic volcanic activity during the deposition of the Hodgkinson Formation could have a significant influence on interpretations of the tectonic setting for the Hodgkinson Province. Similarly, SHRIMP dating of zircons from the S-type granites which intrude the Hodgkinson Formation, in particular zircons from the ~357My old Mount Formartine Granite, should be carried out to determine the presence or otherwise of inheritance. Such a procedure has the potential to indicate whether or not the Hodgkinson Formation was involved in the generation of the S-type granites of the eastern Hodgkinson Province. Researchers at James Cook University are currently carrying out studies along these lines but the results had not been published when this report was written.

Table 2. Summary of the main deformational events in the Hodgkinson Province.

Deformation	Character	Fabric	Extent
hD_1	E–W shortening	slaty cleavage	confined to the Mulgrave Formation in far west
hD_2	easterly or north-easterly directed thrusting	slaty cleavage parallel or subparallel to bedding; stack of numerous westward-dipping imbricate thrust slices (mainly in west); tight to open outcrop- and map-scale folds (mainly in central part); melange zones	throughout province
hD_3	broad NNW trending, steeply dipping (transpressive?) shear zone (Big Watson Shear Zone and Mitchell Fault Zone); pervasive steeply dipping cleavage in east	bed-parallel slaty and/or spaced solution cleavage; mylonitic foliation locally developed in north; melange zones common in south; prominent NNW-trending lineaments; macroscopic folds in places	very well developed in belt a few kilometres wide in west; widespread in east
hD_4	E–W shortening and associated folding and cleavage development	distinctive N-trending, outcrop- and map-scale upright folds and associated axial-plane cleavage; folds generally have steeply dipping axial planes and moderate to steep plunges	most of province east of Big Watson Shear and Mitchell Fault Zones; best preserved in central part
hD_5	shallow to moderately dipping beds and local doming of strata	open to closed folds with shallow axial planes; overturned hD_4 folds; regionally developed differentiation cleavage, north and west of Cannibal Creek Granite	widespread in central part of region, especially in the Cannibal Creek–Maytown area
hD_6	N–S compression	E–W trending crenulations and small-scale folds with moderately to shallowly dipping (to the south) axial planes; according to Donchak (1997) ~E–W trending map-scale folds in the O.K. mine area are also probable hD_6 structures	O.K. mine–Saint George River area, in central part of province
hD_7	E–W compression; probably associated locally with forceful intrusion of granite which resulted in extensive areas of anomalously high (greenschist facies) metamorphic grades	weakly to intensely developed crenulations (commonly differentiated) and kinks; well-developed slaty cleavage in places; mesoscopic folds with steeply dipping, NNW–NW trending axes and shallow to moderately steep plunges; scarce open mesoscopic folds with steep axial planes and shallowly plunging N–S axes	widespread, especially in the central, north-western and north-eastern parts of the province
hD_8	NNW–NW trending structures possibly associated with oblique compression; transpressional? movements along Palmerville Fault system	extensive shear zones (*e.g.* Russell–Mulgrave Shear Zone, Daintree Fault); widespread recrystallisation and development of mylonitic fabrics (especially in granitic rocks), mainly in eastern part of province; intense slaty cleavage developed in metasedimentary rocks	most intensely developed in eastern part of province; also well developed in relatively high-grade (greenschist facies) rocks of the Cannibal Creek–Maytown area

Age	Comments
middle? Ordovician	deposition of quartzose flysch may have been halted by subduction-related compression — the postulated subduction zone being located to the east (Donchak, 1997)
late Devonian	first regional deformational event to affect entire province; thrusting may have reversed movement along westward-dipping extensional structures formed during development of the Hodgkinson Basin
late Devonian	zone of extensive shearing up to ~5km wide in west; zone separates steeply east-dipping strata in west from steeply west-dipping strata to the east; evidence of significant vertical extension with possible flower-structure geometry; may be related to localised backthrusting during final stages of hD_2, or may have resulted from subsequent compression; Bultitude & Donchak (1992), Bultitude & others (1993a, 1996b), Donchak (1997), Zucchetto & others(1998)
early-middle Carboniferous	very widespread and involved significant basin-wide shortening; most older, dipping hD_2 structures steepened during this event; pre-dates the late Carboniferous magmatic activity in region
early Permian?	accompanied by increase in metamorphic grade (greenschist facies), with widespread recrystallisation and development of phyllitic rocks, as well as rare schists in the Mount Madden Dome area; most probably due to emplacement of granite (not exposed); in which case the event probably occurred in the early Permian — exposed early Permian granites are common in the central parts of the province; may be equivalent to the D_3 event of Davis (1993, 1994), who associated it with the forceful emplacement of the older pluton of Cannibal Creek Granite
early Permian?	relatively local event; according to Donchak (1997) this event post-dated hD_5 — in which case it most probably occurred in the early Permian (see comments above); alternatively, if the event pre-dated hD_5 it may have occurred during the Alice Springs Orogeny (which was characterised by N–S compression), in the middle Carboniferous (Powell & others, 1985)
early Permian?	D_4 of Davis (1993, 1994), who interpreted the deformation to be a major event which caused extensive modification and reorientation of pre-existing structures and foliations in the aureole of the Cannibal Creek Granite, as well as elsewhere (*e.g.* Zucchetto & others, 1998); in contrast, Bateman (1985a,b) and Donchak (1997) argued that the emplacement of the Cannibal Creek Granite was associated with only localised aureole cleavage development; Donchak postulated Davis' D_4 event probably represented part of the Hunter–Bowen Orogeny
late Permian–Triassic	reset K–Ar biotite ages yielded by extensively deformed and recrystallised late Carboniferous–early Permian granites of the eastern Hodgkinson Province are mainly in the 245Ma–255Ma range; east-block-up sense of movement on several shear zones (including Russell–Mulgrave Shear Zone) indicated at several widely scattered localities in eastern part of province; movements along Palmerville Fault and other major faults during the middle Permian–Triassic produced rift basins and grabens in places

Some of the reasons for favouring an extensional environment are summarised below.

1. The Silurian–Devonian sedimentary rocks which make up most of the province are, on the whole, notably poor in volcanic detritus. Furthermore, any volcanic detritus present in rocks of this age in the western part of the province at least may have had the same source as the abundant volcanic debris in the significantly older (late Ordovician) Mountain Creek Conglomerate and Van Dyke Litharenite (a probable correlative; Bultitude & others, 1993a).

2. Although volcanic detritus is overall very scarce, it is relatively abundant in some of the arenites of the Hodgkinson Formation in the north-eastern part of the province (especially in the Cooktown area; *e.g.* Donchak & others, 1992; Domagala & others, 1993). The episodic influx of intermediate to silicic volcanic detritus in this part of the province may indicate the presence of a contemporaneous magmatic arc or older volcanic rocks (farther to the north-east rather than the west) in the Silurian–Devonian. Results of SHRIMP dating of zircons from a porphyritic dacite clast (with phenocrysts of plagioclase and K-feldspar) from the north-eastern part of the province can be interpreted as supporting the latter alternative. The clast was obtained from a sequence of conglomerate and conglomeratic meta-arenite in the Hodgkinson Formation south of Cooktown (at GR 3134 82543, in the Helenvale 1:100 000 Sheet area). These results indicate the source of the clasts most probably crystallised at 465±21Ma — *i.e.* at or about the same time as the source of the silicic volcanic clasts in the Mountain Creek Conglomerate (exposed adjacent to the western margin of the province). Furthermore, none of the detrital zircons analysed from the enclosing meta-arenite are younger than 420±14Ma, consistent with the interpretation of the Hodgkinson Formation as being mainly early–late Devonian. The results support the observation concerning the overall scarcity of contemporaneous intermediate to felsic volcanic deposits in the formation.

3. Field relationships imply that many of the basic volcanic rocks in the province were erupted more or less at the same time as the adjacent sediments were deposited — *i.e.* the basic volcanics do not represent fault slivers of underlying oceanic crust. Basalt is relatively abundant in the Chillagoe Formation in the north, where it locally makes up >50% of the unit.

4. The Hodgkinson Formation in the far north-east of the province contains rocks that are significantly older than those in the central parts of the province — a feature inconsistent with the progressive trenchward younging of accretionary prism rocks in normal subduction models. Early Devonian and possibly late Silurian ages have been obtained from reportedly in-place limestones of the Hodgkinson Formation south-west of Cooktown (Donchak & others, 1992; Domagala & others, 1993).

   Similarly, Hodgkinson Formation rocks farther south (in the Macalister Range area) are intruded by the Mount Formartine Granite. A sample from one of the plutons has recently yielded a SHRIMP age of 357±6Ma (*i.e.* Fammenian; Zucchetto & others, 1998). The available data, therefore, strongly imply the youngest rocks of the formation are in the central parts of the province. There, Fammenian and Frasnian conodonts have been recovered from limestone clasts in conglomerate lenses, and lycopod fragments are scattered throughout the sequence.

5. Most of the late Silurian–early Devonian granites exposed west of the Palmerville Fault in the Yambo and Coen Inliers do not have the chemical characteristics one might expect if they represent the root zones of a continental magmatic arc, as postulated by Henderson (1987). Volcanic arc sequences are typically dominated by calc-alkaline I-type igneous rocks of intermediate (tonalitic-granodioritic) composition, whereas most of the granites in the Coen and Yambo Inliers are highly felsic, biotite–muscovite bearing S-types containing >70% SiO_2.

6. The geochemical and isotopic characteristics of the numerous Permian S-type granites in the central and eastern parts of the Hodgkinson Province indicate they were derived from supracrustal rocks which are more immature and isotopically more primitive than the analysed metasedimentary rocks of the enclosing Hodgkinson Formation (Champion, 1991; Champion & Bultitude, 1994). The analysed

Hodgkinson Province metasedimentary rocks are too poor in Al, Ca (figure 20 in Bultitude & others, 1996b), P and Sr, to name a few elements, and too isotopically evolved to have been the sole source of the granites. The inference, therefore, is that more immature and isotopically primitive metasedimentary rocks (with a volcanic provenance?) either underlie the Hodgkinson Formation, or are present within the formation but have not been recognised.

7. Regional Bouguer anomalies and seismic evidence imply continental crust with similar characteristics to those of the metamorphic basement west of the Palmerville Fault extends east of the fault beneath the Hodgkinson Province (Finlayson, 1968; Fraser & others, 1977; Shirley, 1979). The negligible difference in the regional gravity across the fault is also consistent with the hypothesis that the fault is a relatively shallow feature, confined to the upper crust (Fraser & others, 1977). Furthermore, current models for the petrogenesis of the late Carboniferous granites which crop out extensively in the western part of the Hodgkinson Province require the involvement of a long-lived and isotopically homogeneous crustal protolith that most probably underplated the crust in the early Mesoproterozoic (~1550Ma; *e.g.* Champion, 1991; Champion & Chappell, 1992).

8. Granites of the Barnard Province, on the south-eastern margin of the Hodgkinson Province, have yielded Ordovician SHRIMP ages, indicating the enclosing metamorphic rocks are older than early Ordovician and, therefore, significantly older than the nearby Hodgkinson Province succession (most probably Devonian). The Barnard Metamorphics are tectonically juxtaposed against the Hodgkinson Formation along the Russell–Mulgrave Shear Zone and may represent uplifted basement rocks on the south-eastern margin of the Hodgkinson Province.

9. Many of the granites of the eastern Hodgkinson Province contain sparse inclusions of high-grade (at least middle-upper amphibolite grade) metasedimentary rocks (Bultitude & Champion, 1992; Bultitude, 1993). These inclusions contrast markedly with and are distinct from the enclosing low-grade metasedimentary rocks of the Hodgkinson Formation. The presence of high-grade crustal inclusions implies the Hodgkinson Province succession was underlain by cratonic (continental) crust of significant thickness by at least the late Palaeozoic. In addition volcanic rocks of the Cainozoic Atherton Basalt Province contain scarce inclusions of schist and lower-crust granulites (Stephenson, 1989). Sparse to locally common fragments of mafic granulite and more felsic gneiss containing abundant garnet and with a very well-developed mineralogical layering are present is lava flows and fragmental deposits from some vents in the Cainozoic McLean Basalt Province (Stephenson, 1989; Domagala & others, 1993).

For a more detailed interpretation of the geological and tectonic history of the Hodgkinson Province the reader is referred to accounts by Bultitude & Donchak (1992), Bultitude & others (1993a, 1996b) and Donchak (1997).

LATE DEVONIAN INTRUSIVE ROCKS

Mount Formartine Supersuite

The S-type Mount Formartine Supersuite (Champion, 1991; Champion & Bultitude, 1994) comprises one unit — the Mount Formartine Granite of Willmott & others (1988). The Mount Formartine Granite (Table 4) consists of several, small, generally elongate intrusions in the east of the region. The few plutons that had been recognised prior to the recent mapping of Willmott & others (1988) and Cranfield & Hegarty (1989) had been mapped as part of the Mareeba Granite (de Keyser & Lucas, 1968).

Willmott & others (1988) reported muscovite to be the dominant mica at a few localities, but in the outcrops examined by the writer biotite predominates. The unit is commonly very extensively deformed and recrystallised. It is also characterised by the presence of a widespread, locally intensely developed (mylonitic) foliation with the same orientation as the main regional north-north-westerly striking cleavage in the enclosing Hodgkinson Formation rocks.

The larger intrusions are surrounded by narrow hornfels zones in the enclosing Hodgkinson Formation metasedimentary rocks

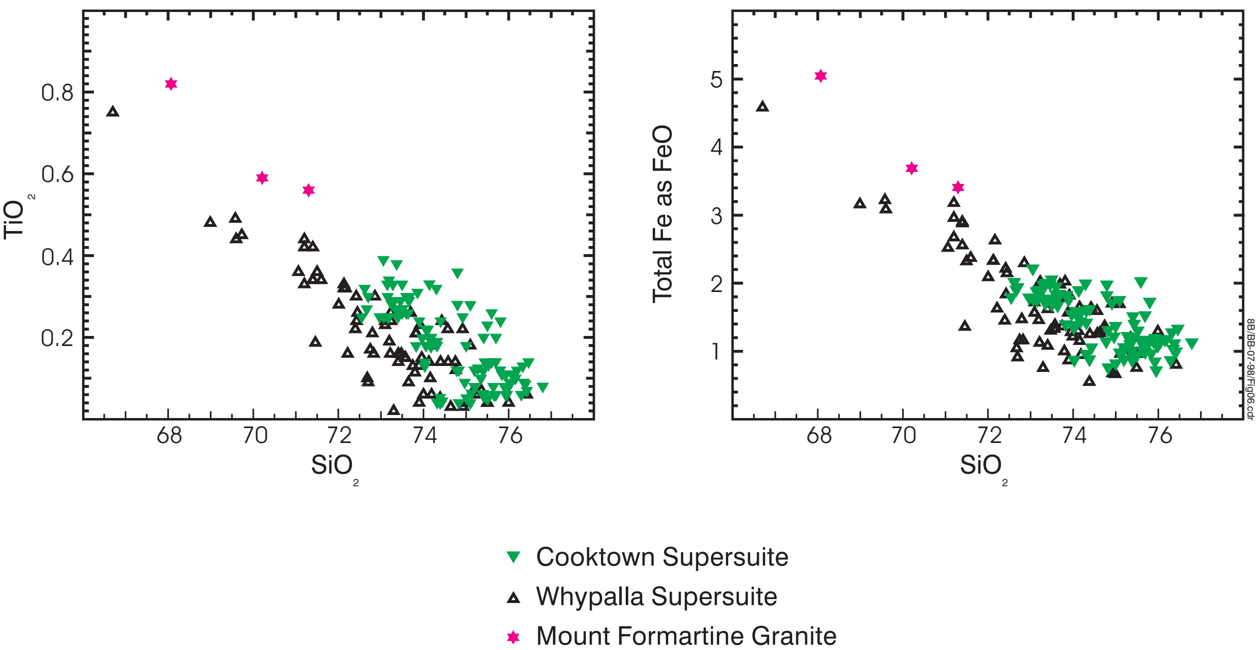


Figure 6. Selected major element (wt%) plots showing the relatively mafic, TiO_2 and FeO-rich character of the Mount Formartine Granite compared with the two main S-type supersuites (Permian) in the eastern part of the Cairns Region.*

(Cranfield & Hegarty, 1989). Willmott & others (1988) reported andalusite porphyroblasts in argillite near the contact with a pluton of Mount Formartine Granite.

Extensively recrystallised and intensely foliated granite from the northern end of Trinity Beach (GR 3162 81439; Cairns 1:100 000 Sheet area) has yielded a K–Ar biotite age of 247±2Ma (Willmott & others, 1988). This date was interpreted by the writer as a reset, metamorphic age rather than the age of crystallisation of the granite (*e.g.* Bultitude & Champion, 1992). Significantly, it is similar to ages obtained from extensively deformed granites of the Cooktown and Whypalla Supersuites farther north and west, some of which have yielded early Permian SHRIMP ages (interpreted to be crystallisation ages; Bultitude & Champion, 1992).

Consequently, the emplacement age of the Mount Formartine Granite was uncertain. The unit was inferred to be early Permian (Bultitude & Champion, 1992; Bultitude & others, 1996b), mainly because of its association with other granites of that age in the central and eastern parts of the Cairns Region.

However, Zucchetto & others (1998) have recently reported the emplacement age of the unit to be 357±6Ma (using the U–Pb zircon, SHRIMP technique). This date is particularly significant because it identifies the oldest episode of plutonism known to have occurred in the Hodgkinson Province. Furthermore, it constrains the younger age limit of the Hodgkinson Formation in the eastern part of the province, as well as at least the earliest deformational event to affect the eastern Hodgkinson Formation. In addition it provides a link with the Broken River Province farther south. Rocks of the latter are intruded in the Camel Creek area by several small plutons of granite and granodiorite, one of which has yielded a K–Ar age of 357Ma (Withnall, 1997b).

The Mount Formartine Granite is one of the most mafic granites in the eastern Hodgkinson Province. Analysed samples are characterised by relatively high TiO_2, FeO* and Y, and low SiO_2, CaO, K_2O, Ce, La, Pb, Rb, Th and Zr contents compared with most Permian S-type granites of similar SiO_2 or FeO* content in the eastern Hodgkinson Province (Figure 6, Table 4; Champion, 1991; Champion & Bultitude, 1994).

LATE PALAEOZOIC SEDIMENTARY AND MINOR TO SUBORDINATE VOLCANIC ROCKS

KENNEDY PROVINCE

The Cairns Region had undergone at least one major orogeny and had been effectively cratonised by about the middle Carboniferous. Late Carboniferous–early Cretaceous times were characterised by extensive sedimentation in north Queensland. Most of the major depositional sites are located west, north, and south of the Cairns Region. However, late Carboniferous–middle Triassic, post-orogenic strata (deposited in mainly fluviatile and lacustrine environments) crop out in several parts of the region (Table 1). The sedimentary rocks are preserved mainly in elongate down-faulted depressions or grabens. The depressions probably developed as a result of structural instabilities associated with the extensive late Palaeozoic magmatic activity in the region.

Silver Valley Conglomerate

The Silver Valley Conglomerate (Table 1; see Blake, 1972, for a summary of the nomenclature used by early workers) is preserved as a mainly fault-bounded lens (~6km^2). The unit consists mainly of coarse, polymictic conglomerate, and subordinate medium to coarse-grained volcanic sandstone and mudstone containing numerous glass shards. Lenses of rhyolitic ignimbrite and air-fall tuff, and carbonaceous sandstone and siltstone are scattered throughout the sequence. The epiclastic detritus was derived from the local basement rocks, with significant input from outcrops of volcanic rocks in all but the lower part of the formation (de Keyser & Lucas, 1968). Beds are mainly gently dipping, except adjacent to the bounding faults. Oversby (1985) postulated that accumulation of the Silver Valley Conglomerate was significantly influenced by volcanism, possibly to the extent of being initiated by extrusive (± intrusive)-related (synvolcanic) structural instability.

Pebble to cobble-size clasts predominate in the conglomeratic rocks, although boulders up to ~2m in diameter are not rare. The clasts consist mainly of arenite, mudstone and chert derived from the Hodgkinson Formation, and a range of silicic volcanic rocks. Grey quartzite clasts (source unknown, but possibly representing fragments of recrystallised chert from the Hodgkinson Formation) are also common.

Fossil plant fragments have been recorded from several localities near the top of the formation. They include a form generally referred to as *Aneimites ovata* (Blake, 1972; Arnold & Fawckner, 1980), but assigned by Rigby (1973) to *Botrychiopsis* (ex *Gondwanidium*) *plantianum* of minimum latest Carboniferous age — in contrast to the middle Carboniferous age inferred previously (Blake, 1972).

Mount Mulligan Coal Measures

The Mesozoic rocks forming the spectacular cliffs of Mount Mulligan (Ngarrabullgan) are underlain by the middle to late Permian (Price, in Whitby, 1975; Price, 1983; Rigby, in press) Mount Mulligan Coal Measures (Table 1) containing several coal seams. The Mount Mulligan Coal Measures attain a maximum thickness of ~450m in the north-east, but thin markedly to the south and wedge out completely ~700m south of the King Cole mine (de Keyser & Lucas, 1968; Oversby & others, 1997). Most of the coarse detritus in the succession appears to have been derived locally — volcanic debris or fragments of Hodgkinson Formation rocks are dominant in the conglomeratic rocks. Individual rock types and associations form mainly lenses which interfinger laterally (Oversby & others, 1997). Four irregularly distributed subunits have been delineated in the formation (Mackenzie & others, 1993; Oversby & others, 1997).

The main rock types in the basal part (subunit 1 of Mackenzie & others, 1993; Oversby & others, 1997) of the formation have a very irregular distribution. Some are very similar to and difficult to distinguish from non-welded ignimbrite of the underlying Breccia Creek Rhyolite according to Oversby & others (1997). The deposits contain carbonaceous fragments, which have not been found in the otherwise lithologically similar Breccia Creek Rhyolite (Oversby & others, 1997). The observed features of the rocks assigned to the lowermost Mount Mulligan Coal Measures, as developed in the Breccia Creek area, imply they represent little reworked Breccia Creek Rhyolite. The detritus may have accumulated as small-scale alluvial fans with sporadic small debris flows in palaeotopographic depressions (Oversby & others, 1997). These relatively coarse deposits are overlain locally, in the north, by up to ~50m of mainly laminated to thin-bedded, fine to medium-grained, carbonaceous siltstone containing fossil plant fragments (subunit 2; Oversby & others, 1997).

The third subunit delineated by Mackenzie & others (1993) and Oversby & others (1997) crops out in the north-east and south-east. It commonly directly overlies Hodgkinson Formation rocks and is the only subunit represented in the area around the State and King Cole mines. The sequence is dominated by thin-bedded to laminated carbonaceous claystone, siltstone and fine-grained sandstone, with up to four interlayered, coal-dominated intervals. Three of the four coal-rich intervals have been mined (Shepherd, 1945). The combined thickness of the productive coal seams is only ~6m at the King Cole mine but increases to ~35m in the State mine farther north. The number of coal seams also decreases to the south. The coal seams in the State mine range in thickness from 0.4m to ~1.7m (Matheson, 1995). The No. 3 seam averaged only 0.6m, but comprised clean coal and was the most extensively worked. Only the upper seam, with an average thickness of 1.2m, was worked in the King Cole mine ~1.7km to the south (Matheson, 1995).

The uppermost part of the Mount Mulligan Coal Measures (subunit 4) crops out around the north-eastern, northern and north-western margins of Mount Mulligan (Mackenzie & others, 1993). The sequence is up to ~400m thick (in the north-east) and consists mainly of interdigitating pebble to small cobble conglomerate and flaggy to massive lithofeldspathic sandstone and conglomeratic sandstone (Oversby & others, 1997). The conglomeratic rocks contain numerous subangular to rounded clasts of rhyolite.

The presence of coal seams, fossil plants, washouts, channels, current-bedding, abrupt lateral facies changes, and the local abundance of conglomerate are interpreted to indicate the sediments were deposited in a mature, continental (lacustrine/meandering alluvial complex/piedmont plain/estuarine) environment (de Keyser & Lucas, 1968; Oversby & others, 1997; Rigby, in press).

The coal measures are overlain by conglomerate and sandstone forming the cliffs of Mount Mulligan. The latter rock types are generally regarded as early?–middle Triassic. However, de Keyser & Lucas (1968) postulated the lowermost conglomerate (9–21m thick) directly overlying the coal measures is probably late Permian. They pointed out that this conglomerate closely resembles the basal conglomerate of the coal measures — in particular, the clasts consist mainly of rhyolite apparently derived from the Featherbed Volcanic Group.

Little River Coal Measures

The Little River Coal Measures are preserved as a fault-bounded lens within a narrow graben, up to ~2km wide and >20km long. The graben developed adjacent to the Palmerville Fault, in the north-west of the region.

The formation consists mainly of sandstone and siltstone, interbedded with shale (generally highly cleaved and commonly carbonaceous) and more massive mudstone (Table 1). The unit also contains minor impure coal and siliceous, thin-bedded mudstone (de Keyser & Lucas, 1968; Bultitude & Donchak, 1992). De Keyser & Lucas (1968) reported coal seams up to ~6m thick, but they are steeply dipping and extensively faulted. Lenses of impure limestone were also recorded by de Keyser & Lucas.

The sandstones are commonly characterised by irregular bedding planes (Bultitude & Donchak, 1992). The siltstones display trough cross bedding and current bedding in places (Bultitude & Donchak, 1992). The orientations of some cross-beds indicate reversals in current direction, typical of a shallow-water depositional environment. The mudstones, as well as some of the finer grained sandstones, contain abundant fossil plant fragments.

Post-Permian movements along the Palmerville Fault produced chaotic folds and extensive disruption of the sequence. They were also responsible for the steep dips and numerous younging reversals.

Age

White (1961) identified *Schizoneura australis*, *Glossopteris indica*, *G. augustifolia*, and *Vertebraria indica* from shales in the formation. The presence of *Schizoneura australis* indicates a probable late Permian age (White, *in* de Keyser & Lucas, 1968). J.F. Rigby (Department of

Natural Resource Sciences, Queensland University of Technology, personal communication, 1995) is also of the opinion that the flora is late Permian and that the sequence correlates with fossil plant-bearing strata in the Mitchell River Volcanics (Coen Region), farther south.

Normanby Formation

The formation was first described by Jack (1879a, b) who found *Glossopteris*-bearing shale and coal in the Oaky Creek area, south-west of Cooktown. The unit is mainly preserved as small outliers in narrow (<2km wide), elongate, north-north-west and north-north-east trending fault blocks, west and south-west of Cooktown.

The formation contains a diverse range of rock types (Table 1) including massive rhyolite (lava and ignimbrite), rhyolitic tuff, lapilli tuff, volcanic breccia, andesite, andesitic tuff, basalt, conglomerate, sandstone, volcanic sandstone, siltstone, and mudstone, carbonaceous mudstone, shale, coal, and impure limestone (de Keyser & Lucas, 1968; Bultitude & others, 1991; Donchak & others, 1992; Domagala & others, 1993). The relative proportions of the major rock types commonly differ markedly from one outlier to another. The coal deposits have never been worked.

The formation locally contains relatively thick zones of thick-bedded to massive, mainly clast-supported, polymictic, pebble to boulder conglomerate. Clasts consist mainly of arenite, siltstone, mudstone, chert, rhyolite, quartz, quartzite and rare limestone (Bultitude & others, 1991; Donchak & others, 1992). Most were derived from the nearby Hodgkinson Formation and volcanic rocks of the Normanby Formation. The conglomeratic rocks commonly interfinger with and grade laterally into medium to thick-bedded pebbly sandstone and medium to coarse-grained labile sandstone.

The Normanby Formation is cut by steeply dipping, north-north-westerly to north-north-easterly trending faults. Beds are folded and commonly characterised by a well-developed foliation, particularly adjacent to the bounding faults. They are generally steeply dipping and locally brecciated in these areas; as well as silicified and cut by networks of thin (<10cm) quartz veins. In contrast, beds commonly dip between 20° and 30° in the central parts of the larger outliers, away from the faulted margins. The local presence of numerous folds with northerly trending axial planes and gently plunging axes (Amos, 1962) also results in steeply dipping beds.

Age

Permian plant fossils have been found in several parts of the unit (Jack, 1879a,b; Bultitude & others, 1991). De Keyser & Lucas (1968) regarded the formation as late Permian. Preliminary studies of plant fossils in drill core from GSQ Cooktown 1, 1–3R, and 2R indicate they resemble some found in the Mitchell River Volcanics (late Permian) and the Mount Mulligan Coal Measures (middle to late Permian) (J.F. Rigby, Department of Natural Resource Sciences, Queensland University of Technology, personal communication, 1995).

Environment of deposition

The formation mainly accumulated in narrow grabens produced by regional extension during the Permian. The bimodal character of the volcanic activity (Donchak & others, 1992; Domagala & others, 1993) is typical of extensional regimes, with relatively high geothermal gradients. The conglomerates are interpreted as alluvial-fan deposits; the coal beds and interbedded mudstones and shales as closely associated lacustrine deposits. Most of the sediments and interlayered volcanic rocks accumulated in fluviatile or lacustrine environments. Shallow marine or marginal marine conditions may have prevailed locally (de Keyser & Lucas, 1968).

LATE PALAEOZOIC IGNEOUS AND MINOR SEDIMENTARY ROCKS

KENNEDY PROVINCE

Introduction

Extensive granite emplacement occurred in the Cairns Region in the late Carboniferous–Permian and, to a much lesser extent, in the early–middle Carboniferous. The late Carboniferous–Permian igneous activity also involved widespread subaerial volcanism. Most volcanic sequences are dominated by rocks of silicic composition — mainly rhyolitic ignimbrites (Table 3). Basic and intermediate volcanic rocks are rare by comparison and tend to be concentrated in the older (lower) parts of individual sequences.

The widespread distribution of Permian rocks with A-type geochemical affinities is noteworthy (Bultitude & others, 1993a). The rocks form lava flows, pyroclastic flow deposits, high-level resurgent-type intrusions, ring dykes, and discrete plutons.

Cairns is also the only region in north Queensland where there has been extensive intrusion of late Palaeozoic S-type granites. The S-type granites are concentrated in the central and eastern parts of the Hodgkinson Province and are mainly Permian. Most units belong to the Cooktown or Whypalla Supersuites.

KENNEDY PROVINCE — VOLCANIC ROCKS, CHILLAGOE–RAVENSHOE AREA

Pratt Volcanics

The Pratt Volcanics were briefly described by Morgan (1961, 1964a, 1974) who, together with Best (1962), Amos & de Keyser (1964), and de Keyser & Lucas (1968), included them as part of the Nychum Volcanics. They were delineated as a discrete sequence during the GSQ survey (Bultitude & Domagala, 1988; Bultitude & others, 1995). The formation crops out extensively in the adjacent Coen Region, but only a very small part of the sequence extends east of the Palmerville Fault (south of the Walsh River) into the Cairns Region.

The sequence in the Cairns Region consists of rhyodacitic to rhyolitic ignimbrite (I-type), minor amygdaloidal basalt (at base), and rare outcrops of rhyolite lava (Table 3). Plagioclase is the more abundant feldspar in the ignimbrites. The formation west of the Palmerville Fault contains dacitic to rhyolitic lava flows with A-type chemical affinities (Bultitude & others, 1995).

The unit in the adjacent Coen Region is intruded by the late Carboniferous? Almac Granodiorite (Almaden Supersuite), as well as by very high-level plugs of andesite and dacite. The plugs are lithologically and chemically similar to the nearby early Permian Nychum Volcanics (Bultitude & others, 1995). The Pratt Volcanics are therefore most probably late Carboniferous.

The Pratt Volcanics are characterised by a scarcity of pyroclastic airfall and epiclastic deposits, and the presence of abundant rhyodacitic–rhyolitic ignimbrite rather than lava. The unit differs in these respects (as well as many others) from the nearby Nychum Volcanics. The pyroclastic flow deposits were erupted from relatively deep-level magma chambers and are preserved in an irregular, basin-like subsidence structure with inward dips around its periphery. The unconformity with the underlying rocks of the Hodgkinson Province is commonly exposed. Lenses of sandstone and conglomerate are present at the base of the sequence farther west, in the Coen Region.

Claret Creek Volcanics

The late Carboniferous Claret Creek Volcanics (Bailey, 1977; Black, 1980) crop out around the margins of the Claret Creek Ring Complex, one of several extensively eroded volcanic centres in the south-western part of the Cairns Region. The volcanic rocks are steeply dipping (~70°) and outline a saucer-shaped structure. The depression formed as a result of collapse of the volcanic pile into the partly evacuated magma chamber.

The formation consists mainly of rhyolitic ignimbrite and intercalated lenses of volcanic breccia. The eruptive centres were probably located on the outer ring fracture of the

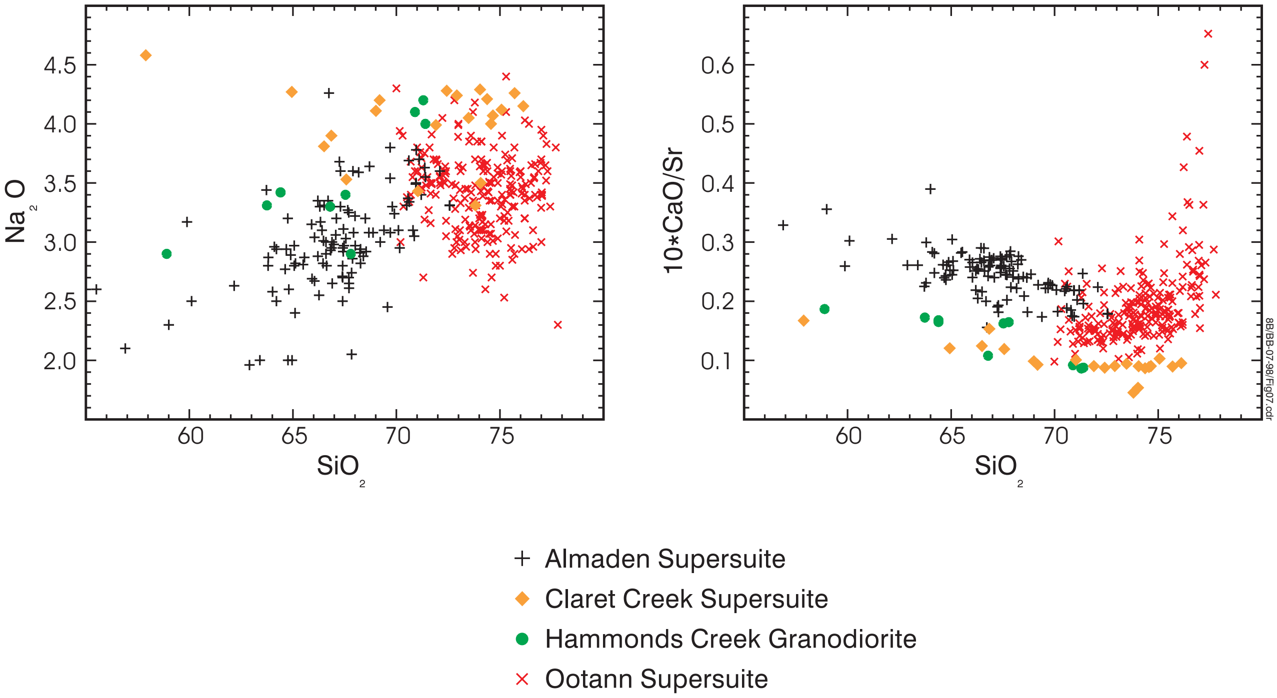


Figure 7. Na_2O and CaO/Sr versus SiO_2 plots for the Claret Creek Supersuite (extrusive and intrusive rocks). Also shown for comparison are the Almaden and Ootann Supersuites and Hammonds Creek Granodiorite. Oxides are in weight per cent, trace elements in parts per million. Plots include data from Bailey (1969, 1977), Sheraton (1974), Richards (1981), and Champion (1991).

complex (Bailey, 1977). The pyroclastic flow deposits contain crystals of zoned plagioclase ($An_{52–33}$), as well as subordinate quartz, biotite, K-feldspar and opaque minerals.

The Claret Creek Volcanics and comagmatic intrusive rocks which form the complex have been assigned to the Claret Creek Supersuite (Champion, 1991; Champion & Chappell, 1992). They are characterised by relatively low K_2O, Nd, Rb, Th, U and Y contents, as well as Ca/Sr, K/Na, Rb/Sr and Th/K ratios, and high Na_2O and Sr contents (Figure 7; Bailey, 1977). The presence of relatively abundant plagioclase and scarce K-feldspar phenocrysts reflect the Na-rich and K-poor character of the volcanic rocks.

Bailey's investigations indicated the rocks of the Claret Creek Ring Complex are chemically distinct and genetically unrelated to the other igneous rocks in the region. He postulated the dacitic and rhyolitic rocks of the complex were produced by progressive partial melting of source rocks with the composition of low K/Na basaltic andesite — the tonalitic-granodioritic rocks formed subsequently by the mechanical dispersion of cognate mafic enclaves within magma of dacitic composition.

Gurrumba Volcanics

The Gurrumba Volcanics (Blake, 1972) crop out in the central part of the Gurrumba Ring Complex. The volcanic rocks are confined to two small areas. They consist of flow-banded and autobrecciated rhyolite lava containing white feldspar phenocrysts. The rhyolite is extensively altered (Blake, 1972). Sericite and pyrite are common.

Contacts between the volcanic rocks and adjacent Hodgkinson Formation are generally faulted. They are marked by breccia zones containing angular fragments derived from both rock units. The extrusive rocks are interpreted, mainly from the distribution of units, to pre-date the intrusive rocks of the ring complex.

The age of the Gurrumba Volcanics is uncertain. They are most probably late Carboniferous. Black (1978, 1980) reported isotopic (Rb–Sr biotite) ages of 314Ma (calculated using the 'old' ^{87}Rb decay constant) and 303Ma for gabbro in the ring complex (Table 4).

Other late Palaeozoic volcanic units in south-west of region

The *Nanyeta*, *Slaughter Yard Creek* and *Walsh Bluff Volcanics* crop out over relatively restricted areas in the south-west of the region. The units consist mainly of rhyolitic ignimbrite. Basic and intermediate rocks are rare and, where present (*e.g.* in the Nanyeta Volcanics),

Table 3. Summary of volcanic units, Cairns Region.

Group/ Subgroup/ Unit	Constituent units	Rock types	Distribution (area)	Thickness (max.)	Age and evidence
CAINOZOIC					
Atherton Basalt	Adler Hill Basalt, Meringa Basalt, The Fisheries Basalt, Twiddler Hill Basalt	alkali basalt, basanite, hawaiite, *ne*-hawaiite, transitional basalt; minor tholeiitic basalt, scoria, and sandstone, shale, lignite, oil shale, alluvium (mainly at base; stanniferous in places)	extensive areas of the Atherton Tableland; also forms scattered outcrops in coastal lowlands from south of Cairns to South Mission Beach area; Stephens and Sisters Islands (~1760km^2)	~300m	7.1Ma–10 000BP (K–Ar, C^{14})
Culgar Basalt		olivine basalt	valley of Oaky Creek, north-west of Atherton (~5km^2)	?	Cainozoic
McIvor River Basalt		basanite, hawaiite, mugearite, nephelinite; minor scoria, lapilli tuff	small areas at the head of the Starcke River, and in the valleys of the Morgan and McIvor Rivers (~77km^2)	~30m?	Pliocene?–Pleistocene
McLean Basalt		(olivine-) nepheline analcimite, leucitite, transitional basalt, *ne*-hawaiite, hawaiite, alkali basalt, melanephelinite, mugearite, basanite; minor quartz tholeiite, gravel (at base), sandstone, siltstone, tuff, lapilli tuff, scoria, diatomite	scattered isolated lava fields and remnants; mainly around Lakeland Downs; also forms erosional remnants in the catchments of the Annan, Palmer, North Palmer, East Normanby and West Normanby Rivers (~240km^2)	~60m	~9Ma–0.5Ma (K–Ar)
Piebald Basalt		alkali basalt, transitional basalt, olivine tholeiite, hawaiite, mugearite, scoria; minor alluvium (at base)	relatively restricted areas north and north-west of Cooktown (~36km^2)	~50m?	~3–1.2Ma (K–Ar)
PALAEOZOIC — CARBONIFEROUS–PERMIAN					
Normanby Formation	four informal subunits	pale green to cream, fine to coarse-grained, thin to thick-bedded and massive, quartzose arenite; very thick-bedded and massive, pebble to cobble polymictic conglomerate; cream, pale green, purple or pink, aphyric to slightly porphyritic rhyolite; grey-green andesite and andesitic tuff; subordinate basalt, rhyolitic tuff, lapilli tuff, volcanic breccia, siltstone, mudstone, volcanic sandstone and mudstone, coal, carbonaceous mudstone, impure limestone	forms several elongate, narrow (up to ~2km wide), fault-controlled belts extending for ~20km from Kings Plains to the valley of the East Normanby River; also forms scattered outcrops ~4km south-west of Dingo Hill, in the Mount Barnett area, and west of Cooktown (~46km^2)	<1000m	mid–late Permian (J.F. Rigby, personal communication, 1996); plant fossils including *Glossopteris spp.* and *Gangamopteris spp.* common

Relationships	Environment of deposition	References Comments
unconformably overlies Barnard Metamorphics, Hodgkinson Formation rocks, and Carboniferous–Permian granites and volcanic rocks; younger flows separated from older flows in places by Tertiary sediments; basaltic rocks also locally overlie Tertiary sediments (up to ~85m thick) and alluvium	subaerial eruptions; older flows erupted from several shield volcanoes; relatively recent activity included the formation of scoria cones and maars; sedimentary rocks probably formed in fluvial and lacustrine environments	Best, 1960; Morgan, 1961, 1968a; Blake, 1972; Stephenson & Griffin, 1976; Stephenson & others, 1980; >50 known eruptive centres; has a range of volcano types, including lava shields, cinder cones, maars, and one diatreme; basalts south and west of Cairns delineated as separate formations by Willmott & others (1988)
unconformable on Hodgkinson Formation	subaerial	Best, 1962; currently mapped as part of the Atherton Basalt
unconformable on Hodgkinson Formation and Laura Basin rocks	subaerial; most of the basalt emanated from 2 small shield volcanoes (Mount Webb, Mount Ray)	Morgan, 1968b; Bultitude & others, 1991; may span a greater time range than the Piebald Basalt; pyroclastic deposits much scarcer than in the Piebald Basalt
unconformable on Hodgkinson Formation rocks; volcanic rocks in upper reaches of the Annan River overlie Cainozoic stanniferous gravels (up to ~6m thick) and finer grained sediments containing fossil wood	subaerial eruptions; thin, fossil-plant bearing siltstone beneath basalt near Springvale homestead, as well as intercalated sedimentary rocks elsewhere, may have been deposited in lava-dammed lakes	Lucas & de Keyser, 1965b; Stephenson & others, 1980; Stephenson, 1989; Robertson, 1993; 18 eruptive centres and 2 maars have been identified in the Butchers Hill 1:100 000 Sheet area; xenoliths and megacrysts are common in the lavas and pyroclastic deposits
unconformable on Hodgkinson Formation rocks, and Mesozoic sandstone of the Laura Basin	subaerial; characterised by numerous pyroclastic and composite vent-type eruptions	Morgan, 1968b; Stephenson & others, 1980; Ewart & others, 1988; Stephenson, 1989; Bultitude & others, 1991; 5 major eruptive centres known (some with more than one vent)
unconformably overlies or faulted against Hodgkinson Formation rocks; unconformably overlain by Dalrymple Sandstone (Laura Basin) and by basalt lava flows of the Cainozoic McLean Basalt; locally cut by dolerite dykes or sills	mainly deposited in narrow, elongate grabens; the sediments were probably deposited mainly in fluviatile to lacustrine and possibly (locally) shallow marine environments; the primary volcanic subunits were erupted (and mainly deposited) subaerially	de Keyser & Lucas, 1968; Jorgensen, 1990; Bultitude & others, 1991; Donchak & others, 1992; Domagala & others, 1993; diverse unit preserved mainly in fault-bounded rift basins; the siliciclastic part of the unit was derived from erosion of penecontemporaneous volcanic rocks, as well as the arenites, cherts, and limestones of the older Hodgkinson Formation; both rhyolitic lavas and ignimbrites have been reported; rhyolite lavas commonly flow banded; the facies association is typical of a graben setting, the conglomerates representing alluvial fan deposits associated with fault scarps and the coal closely associated with lacustrine deposits

Table 3 (continued)

Group/ Subgroup/ Unit	Constituent units	Rock types	Distribution (area)	Thickness (max.)	Age and Evidence
Nychum Volcanics	30 informal subunits delineated on Bellevue Region map — many more delineated on the photo-scale compilation sheets	aphyric to slightly porphyritic rhyolite; rhyolitic ignimbrite; rhyolitic tuff, lapilli tuff; volcanic breccia; volcanic conglomerate, sandstone and mudstone; massive to moderately amygdaloidal, equigranular to highly porphyritic basalt, andesite and dacite; minor obsidian, vitrophyre	unit mainly occupies area N and NW of Nychum homestead, in the area around Elizabeth Creek (~306km^2)	~250m	277±4Ma (SHRIMP); plant fossils also locally common
Slaughter Yard Creek Volcanics	two informal subunits	pink to pale grey, slightly porphyritic, rhyolitic lava, highly porphyritic microgranite, and intrusive rhyolite; minor volcanic conglomerate/breccia	elliptical area between Herberton and Watsonville (~50km^2)	>100m	~275±3Ma (Rb–Sr)
Walsh Bluff Volcanics	two informal subunits recognised	buff, greenish grey, or dark grey, welded, rhyolitic ignimbrite; minor rhyolitic lava (commonly flow banded, autobrecciated), quartzose sandstone (below main, uppermost ignimbrite sheet), volcanic breccia, tuff	prominent outcrops) between Atherton and Collins Weir (on the Walsh River) to the west (~156km^2)	600m?	~275±23Ma ~282±9Ma (Rb–Sr)
Wakara Volcanic Subgroup (Featherbed Volcanic Group)	Rackarock Rhyolite (with 3 informal subunits), Ticklehim Rhyolite, unit Pwh, unit Plh, unit Pwt, unit Pwg, unit Pwf, Gavin Rhyolite (with 3 informal subunits), unit Pwx, unit Pwd, Stuarts Rhyolite, unit Pwb_2, unit Pwb_1, Wollenden Rhyolite (with 3 informal subunits), unnamed rhyolite–dacite lavas, domes, and intrusions	mainly unwelded to intensely welded, very lithics-poor to very lithics-rich, moderately crystal-rich to very crystal-rich, rhyolitic ignimbrite; partly intrusive (subunits Pwd, Pwx); minor volcanic breccia, vitrophyre, partly flow-banded and autobrecciated aphyric to slightly porphyritic rhyolite to dacite, very fine-ash vitric tuff, volcanic sandstone and siltstone	forms the northwestern lobe of the Featherbed Range (~300km^2)	~1500m–2000m?	278±3Ma, Ticklehim Rhyolite (Rb–Sr)

Relationships	Environment of deposition	References Comments
unconformable on the Hodgkinson and Chillagoe Formations, the Wotan Granodiorite, the Nightflower Dacite, and lavas of the Wakara Volcanic Subgroup; cut by numerous dykes of rhyolite to andesite (rare)	volcanic rocks erupted subaerially, in a terrestrial environment; sediments probably deposited in fluviatile and/or lacustrine environments	Morgan, 1974; Bailey & others, 1982; Bultitude & Domagala, 1988; Bultitude & others, 1995; individual rhyolite lava flows commonly extensive, with well-developed obsidian or perlite zones; vitric zones in the silicic units have complex mineralogy, with fayalite, Fe-rich pyroxenes, garnet, and cristobalite (rare), as well as rare fragments of carbonised wood
unconformable on and/or intrudes the Jumna and Herberton Hill Granites and Kalunga Granodiorite	volcanic rocks erupted in a subaerial/terrestrial environment	Best, 1962; Branch, 1966; Blake, 1972; Sheraton, 1974; Black, 1974, 1978; Sheraton & Labonne, 1978; Clarke, 1990; Blake postulated that the numerous small high-level intrusives in the Herberton area were contemporaneous with nearby volcanic rocks and included them in the same formation
unconformable on or faulted against Atlanta and Lass O'Gowrie Granites and Hodgkinson Formation; cut by the Parada Dyke Swarm and the early Permian Cherry Tree and Watsonville Granites; unconformably overlain by Atherton Basalt	volcanic rocks erupted in a subaerial, terrestrial environment	Branch, 1966; Blake, 1972; Sheraton, 1974; Black, 1978; Sheraton & Labonne, 1978; Clarke, 1990; well-developed columnar jointing present in densely welded ignimbrite near top of succession; volcanic breccia with fragments of rhyolite and sedimentary rocks present in basal part of unit north of Walsh Bluff
mainly ring-dyke/fault bounded; Gavin Rhyolite (subunit Pwb_1) locally overlies Djungan Volcanic Subgroup; overlies Arringunna Rhyolite (Yongala Volcanic Subgroup) paraconformably; oldest part of subgroup unconformably overlain by Nychum Volcanics; intruded by Bustlem and Yokas Microgranites and unit Pmg	mainly massive, subaerial, pyroclastic flow and associated deposits; erupted in a terrestrial environment; rare sediments probably deposited in fluviatile and/or lacustrine environment(s)	Mackenzie, 1993; Mackenzie & others, 1993; Bultitude & others, 1995, 1996b; coarse, partly intrusive breccias of units Pwd and Pwx may represent vent-fill and proximal deposits

Table 3 (continued)

Group/ Subgroup/ Unit	Constituent units	Rock types	Distribution (area)	Thickness (max.)	Age and Evidence
Djungan Volcanic Subgroup (Featherbed Volcanic Group)	Lumma Rhyolite, Lightning Creek Rhyolite, unit Pdd, unit Pdc, Aroonbeta Rhyolite, Scrufflem Rhyolite, unit Pd	lithics-free to lithics-rich, moderately crystal-poor to very crystal-rich, rhyolitic ignimbrite; minor vitrophyre, tuffisite, rhyolite and dacite? lava, polymictic volcanic breccia	forms northeastern part of the Featherbed Range (~350km^2)	>750m	281±2Ma, ~280Ma (Rb–Sr)
Yongala Volcanic Subgroup (Featherbed Volcanic Group)	Arringunna Rhyolite (with two informal subunits), Combella Rhyolite, Fisherman Rhyolite (with two informal subunits)	unwelded to intensely welded, crystal-poor to very crystal-rich, rhyolitic ignimbrite; subordinate rhyolite lava, vitrophyre; rare rhyolitic tuff, lapilli tuff, volcanic sandstone and siltstone	main component of the Featherbed Range — a belt of rough, hilly to mountainous country between Dimbulah and Chillagoe (~995km^2)	>2000m	288±17Ma, 290±12Ma, Arringunna Rhyolite; 284±4Ma, Combella Rhyolite (Rb–Sr)
Timber Top Volcanic Subgroup (Featherbed Volcanic Group)	Breccia Creek Rhyolite, Controversy Hill Rhyolite, and six unnamed, informal units	slightly to moderately porphyritic, rhyolite to dacite lava (commonly with well-developed, fine flow lamination); non-welded to intensely welded, rhyolitic ignimbrite (rheomorphic textures in places); minor vitrophyre, tuff, andesite, intrusive rhyolite to dacite and microgranite to microgranodiorite, volcanic breccia, sandstone and siltstone	irregular area (Mount Mulligan Cauldron) on the northeastern margin of the Featherbed Range (~25km^2)	~50m–200m	A-type rhyolitic–dacitic rocks most probably early Permian; andesite south of Contro-versy Hill may be late Carbon-iferous
Unit Cad (Featherbed Volcanic Group)		very dark grey, fine-grained, slightly porphyritic, pyroxene-biotite-horn-blende andesite	thin lenses ~13km NW of Wolfram Camp (abandoned site), and ~13km east-south-east of Chillagoe (~1.3km^2)	?	late Carbonif-erous or early Permian
Boxwood Volcanics (Featherbed Volcanic Group)		grey to dark grey, welded, lithics-poor to lithics-free, crystal-rich, dacitic to rhyodacitic ignimbrite; subordinate porphyritic dacite–rhyolite? lava; minor medium-ash crystal tuff	circular area (Boxwood Cauldron), ~20–28km south-east of Almaden (~28km^2)	~100m	~301Ma (Rb–Sr)
Tennyson Volcanic Subgroup (Featherbed Volcanic Group)	Lappa Rhyolite, Allsorts Rhyolite, (with three informal subunits), Dalnotter Dacite	buff, brown, pale to dark grey, and greenish grey, non-welded to welded, crystal-poor to very crystal-rich, dacitic to rhyolitic ignimbrite; minor andesite and rhyolite lava, vitric tuff, volcanic sandstone and siltstone	elliptical area ~15km south-east of Almaden (~43km^2)	~430m	late Carbon-iferous

Relationships	Environment of deposition	References Comments
mainly ring-dyke/fault bounded; apparently unconformably overlies Fisherman Rhyolite; locally overlain by subunit Pwb_1 (Gavin Rhyolite) of the Wakara Volcanic Subgroup; intruded by the Bustlem Microgranite, unit Pmg	mainly massive, subaerial, pyroclastic flow deposits	Mackenzie, 1993; Mackenzie & others, 1993
mainly ring-dyke/fault bounded; overlain unconformably by Wollenden Rhyolite (Wakara Volcanic Subgroup); cut by Saint Helena Monzogranite and Yokas Microgranite	volcanic rocks erupted subaerially (mainly as pyroclastic flows and numerous lava flows in basal part) in a terrestrial environment; rare sediments probably deposited in a fluviatile and/or lacustrine environment(s)	Mackenzie, 1993; Mackenzie & others, 1993; igneous rocks have A-type chemical characteristics; rocks equated with the Fisherman Rhyolite have been mapped around the northern and eastern sides of the Djungan Cauldron; evidence of rheomorphism common
unconformable on Hodgkinson Formation and Wallaroo rhyolite; overlain disconformably by Fisherman Rhyolite?; overlain with slight angular discordance by Mount Mulligan Coal Measures; cut by Maneater Granodiorite and other rhyolitic–dacitic intrusive rocks	volcanic rocks erupted in a subaerial, terrestrial environment;	Branch, 1966; Mackenzie, 1993; Oversby & others, 1997; rhyolitic–dacitic volcanic and intrusive rocks have A-type characteristics, implying they are probably Permian; rare andesites at base of sequence exposed south of Controversy Hill have I-type characteristics and are similar chemically to late Carboniferous units found elsewhere in the group
at least partly intrusive (into Hodgkinson Formation, Wallaroo rhyolite, and possibly unit Cs) — unit is continuous with a vertical, north-east-trending dyke of generally coarser grained andesite		Mackenzie, 1993; Mackenzie & others, 1993; rocks exposed north-west of Wolfram Camp have A-type affinities implying they may be Permian — they are similar chemically to A-type rocks of the Timber Top Volcanic Subgroup
unit crops out within the Boxwood Ring Complex of Branch (1966), and the Boxwood Cauldron of Mackenzie & others, 1993; unconformable on Hodgkinson Formation, and cut by the Sunnymount Granodiorite, Indicator Granite and rhyolite dykes	subaerial deposits	de Keyser & Wolff, 1964; Branch, 1966; Sheraton & Labonne, 1978; Black, 1980; Mackenzie, 1993; Mackenzie & others, 1993; hornblende and allanite reported in some samples
unconformable on Hodgkinson Formation rocks; also overlies Boonmoo Volcanic Subgroup in places; overlain locally by Fisherman Rhyolite; intruded by Lags Microgranite, Petford Granite, rare rhyolite dykes, and plug of olivine basalt (Cainozoic)	subaerial/ terrestrial	Mackenzie, 1993; Mackenzie & others, 1993; most volcanic units and subunits contain hornblende

Table 3 (continued)

Group/ Subgroup/ Unit	Constituent units	Rock types	Distribution (area)	Thickness (max.)	Age and Evidence
Jamtin Rhyolite (Featherbed Volcanic Group)	six informal subunits delineated	pink, pinkish grey, or pale to dark grey, welded, crystal-poor to crystal-rich dacitic to rhyolitic ignimbrite	north-westerly trending belt adjacent to western margin of Featherbed Cauldron; also forms a small lens at Chillagoe (~40km^2)	~3000m	301±11Ma (Rb–Sr)
Wallaroo rhyolite (Featherbed Volcanic Group)	three informal subunits	white, buff, brownish grey, or pale grey, non-welded to welded, lithics-free to -rich, crystal-poor to -rich, rhyolitic ignimbrite; minor slightly porphyritic rhyolitic lava, rhyolitic tuff, volcanic breccia	small area ~14km north-west of Wolfram Camp (abandoned site) (~5km^2)	~250m	late Carbon-iferous
Redcap Dacite (Featherbed Volcanic Group)	four informal subunits	medium to very dark grey, welded, moderately crystal-poor to very crystal-rich, rhyolitic to andesitic ignimbrite	triangular area ~10km NW of Chillagoe (~18km^2)	~3600m	late Carbon-iferous
Beapeo Rhyolite (Featherbed Volcanic Group)	relatively silicic lower part and a more basic upper part	pale to dark grey, lithics-poor to -free, moderately crystal-rich to very crystal-rich, dacitic to rhyolitic ignimbrite	scattered outcrops between Wolfram Camp mine and the Little River to the north-west (~12km^2)	~300m	late Carbon-iferous
Doolan Creek Rhyolite (Featherbed Volcanic Group)	relatively silicic lower part and a more basic upper part, which have been delineated as informal subunits	grey to dark greenish grey, and dark grey, moderately crystal-rich to very crystal-rich, lithics-poor, dacitic? to rhyolitic ignimbrite; extensively recrystallised	two small, irregularly shaped areas in the Walsh River area, ~16km NW of Chillagoe (~16km^2)	~200m?	late Carbon-iferous
Boonmoo Volcanic Subgroup (Featherbed Volcanic Group)	Rock Hole Rhyolite, Theodolite Rhyolite, Verdure Andesite, Adder Dacite, Hopscotch Rhyolite, Muirson Rhyolite, Eureka Rhyolite, Bluewater Rhyolite, Cummings Rhyolite, Orient Rhyolite, Bedlog Rhyolite	moderately crystal-poor to very crystal-rich, poorly to densely welded, andesitic to rhyolitic ignimbrite; minor rhyolite lava, airfall tuff, reworked pyroclastic deposits, volcanic conglomerate or breccia, sandstone, siltstone, and shale	elliptical area (Boonmoo Cauldron), between Irvinebank and Almaden; forms southeastern part of the Featherbed Range (~426km^2)	~2950m (in west) and ~2000m (in east)	304±4Ma (Rock Hole Rhyolite); 306±3Ma, (Bluewater Rhyolite) (Rb–Sr)
Nightflower Dacite (Featherbed Volcanic Group)	four informal subunits	pale to dark grey, or greenish grey, poorly to moderately welded, lithics-free to -rich, crystal-poor to very crystal-rich, dacitic to rhyolitic ignimbrite; minor porphyritic dacite lava?, volcanic breccia and sandstone	approximately rectangular area 1–12km south-east of Nychum homestead (~47km^2)	~300m?	308±4Ma (Rb–Sr)

Relationships	Environment of deposition	References Comments
unconformable on Chillagoe Formation; extensively intruded by granites of the Almaden and Ootann Supersuites and by rhyolite dykes	sequence of subaerial pyroclastic flow deposits	Mackenzie, 1993; Mackenzie & others, 1993; extensively recrystallised and/or altered in places
overlies epiclastic sedimentary rocks (unit Cs) of the Featherbed Volcanic Group, either conformably or disconformably; unconformable on Hodgkinson Formation rocks; intruded by rhyolite dykes, and probably by andesite of unit Cad	subaerial / terrestrial	Mackenzie, 1993; Mackenzie & others, 1993; moderately to intensely altered
faulted against and apparently unconformable on Hodgkinson Formation rocks; intruded by the Ruddygore and Belgravia Granodiorites	subaerial pyroclastic flow deposits	Branch, 1966; Mackenzie, 1993; Mackenzie & others, 1993; contains hornblende
unconformable on Hodgkinson Formation; cut by the Worcester Granite and Bulluburrah Granodiorite; probably also predates the James Creek Granite	mainly subaerial, pyroclastic flow deposits	Mackenzie, 1993; Mackenzie & others, 1993; both informal subunits contain hornblende; upper subunit also contains augite
unconformable on Hodgkinson Formation rocks; extensively intruded by the Ruddygore Granodiorite and Bungabilly Granite, and by dykes and pods of rhyolite and 'diorite'	mainly subaerial pyroclastic flow deposits	Branch, 1966; Bultitude & Domagala, 1988; Mackenzie, 1993; Mackenzie & others, 1993; may represent a deeply eroded cauldron subsidence structure (Doolan Creek Cauldron of Mackenzie, 1993); both informal subunits contain hornblende
unconformity with Hodgkinson Formation well exposed around margins; intruded by Atlanta, Bamford, Borneo, Gibbs, Hales Siding, Halpin, Lass O'Gowrie, and Petford Granites, Retire Monzodiorite, Bock and Solanum Granodiorites, Cottell Rhyolite	mainly subaerial pyroclastic flows	Mackenzie, 1993; Mackenzie & others, 1993; most volcanic subunits contain hornblende
unconformably overlies Hodgkinson Formation, and is overlain disconformably or unconformably by early Permian Nychum Volcanics; faulted against Wakara and Djungan Volcanic Subgroups, and is cut by the Bilch Creek Granodiorite, Wabaredory Granite, granite of units Clgn and Pmg, and by rare rhyolite dykes	subaerial / terrestrial	Mackenzie, 1993; Mackenzie & others, 1993; Bultitude & others, 1995; characterised by presence of biotite, common hornblende, minor pyroxene (augite?), and rare garnet; radiating, acicular grains of secondary stilbite (pink) present locally

Table 3 (continued)

Group/ Subgroup/ Unit	Constituent units	Rock types	Distribution (area)	Thickness (max.)	Age and Evidence
Wallaman Falls Volcanics		dacitic to rhyolitic ignimbrite and lava; minor andesite, trachyte?, tuff, volcanic breccia, porphyritic microgranite	scattered outcrops in the Abergowrie– Halifax–Kennedy area, and on Hinchinbrook and Palm Islands, in far south of region (~880km^2)	>450m?	279±5Ma, 326±6Ma (SHRIMP)
Glen Gordon Volcanics	two informal, unnamed subunits delineated — one lava dominated, the other ignimbrite dominated	dacitic to rhyolitic ignimbrite, and rhyolitic to dacitic lava; minor andesite, tuff, volcanic breccia (locally very coarse), trachyte?, and volcanic breccia, conglomerate, sandstone, siltstone, and shale	north-trending belt in south-east of region, in the Ravenshoe–Kirrama area (~1055km^2)	>300m	late Carbon-iferous–early Permian
Little Forks Volcanics		fine-grained, porphyritic rhyolite and microgranite	small area near the junction of Parrot Creek and the Annan River (~1km^2)	?	most probably late Carbon-iferous or early Permian
Unit Cv		volcanic breccia, dacitic to andesitic tuff, argillaceous siltstone	forms ridge extending west from Cape Tribulation to the Mount Sorrow Tableland (~6km^2)	>100m?	probably late Carbon-iferous or early Permian
Obree Point Volcanics		dark grey, moderately to highly porphyritic, dacite lava — commonly flow banded and locally autobrecciated; subordinate andesite lava, boulder conglomerate, andesitic to dacitic tuff, lapilli tuff, volcanic breccia	scattered headlands and rocky outcrops in the Obree Point–Whalebone Beach area, north of Cedar Bay; also forms a northeasterly-trending belt in the upper reaches of Slaty Creek (~17km^2)	>250m?	299±6Ma (SHRIMP)
Claret Creek Volcanics	Ballast Creek Dacite, The Gorge Rhyolite	pink to pinkish grey, and grey, lithics-poor to -rich, welded, dacitic to rhyolitic ignimbrite, volcanic breccia; minor pale grey intrusive dacite, rhyodacite	semi-circular belt (Claret Creek Ring Complex) ~25km north-west of Mount Garnet (~36km^2)	~430m	300±5Ma (Rb–Sr)
Gurrumba Volcanics		pale grey, autobrecciated and flow-banded slightly porphyritic rhyolite lava; extensively altered	two small outcrops near abandoned township of Gurrumba (~1km^2)	~150m	late Carbon-iferous?
Nanyeta Volcanics		cream, buff, pink, red, purple, brown, green or grey, rhyolitic ignimbrite and lava; minor dacite, andesite, airfall tuff, volcanic breccia, tuffaceous sedimentary rocks	north-westerly trending belt, ~19km long and up to ~7km wide, north of Mount Garnet (~76km^2)	>150m	~289±10Ma
Pratt Volcanics	several subunits, only two of which crop out east of the Palmer-ville Fault, in the Cairns Region	dark grey, lithics-poor, crystal-rich to moderately crystal-rich (locally), rhyolitic to rhyodacitic ignimbrite; buff to brown, slightly porphyritic, rhyolite lava (locally flow banded)	scattered outcrops in Walsh River area, in far west of region, ~25–40km north-west of Chillagoe (~4km^2)	<~250	late Car-boniferous

Relationships	Environment of deposition	References Comments
extensively intruded by late Carboniferous–early Permian granites of the Ingham Batholith and, in places, by mafic to felsic dykes	volcanic rocks erupted subaerially in a terrestrial environment	de Keyser & others, 1965; Branch, 1966; Champion & Heinemann, 1994; Stephenson & Chappell, 1988; formerly mapped as Glen Gordon Volcanics; more extensive outcrops in adjacent Kangaroo Hills Mineral Field
unit overlies the Hodgkinson Formation unconformably and the Silver Valley Conglomerate, possibly conformably; intruded by late Carboniferous–early Permian granites of the Ingham, Tate and Tully Batholiths; unconformably overlain by the Cainozoic Atherton Basalt	volcanic rocks erupted in a subaerial environment	Best, 1962; de Keyser, 1964; Branch, 1966; Blake, 1972; Sheraton & Labonne, 1978; Donchak & Bultitude, 1998; Bultitude & Garrad, 1997; unit contains I- and A-type rocks and may consist of rocks of two distinct ages (mid–late Carboniferous and early Permian)
either unconformably overlies or intrudes Hodgkinson Formation rocks	uncertain whether unit represents extrusive or high-level intrusive sequence, or both	Jones & others, 1990; Donchak & others, 1992; granular groundmass and general lack of obvious volcanic textures imply unit is at least partly intrusive
faulted against Hodgkinson Formation rocks; intruded and hornfelsed by the Nulbullulul Granite	volcanic rocks probably mainly subaerial	Ewart, 1985; Donchak & others, 1992; sequence very poorly exposed and of uncertain extent; tentatively correlated with the Obree Point Volcanics
very poorly exposed except in coastal headlands; assumed to be in faulted contact with adjacent Hodgkinson Formation rocks; intruded and hornfelsed by the Bunk Creek Granite	uncertain; volcanic rocks interpreted to be mainly subaerial deposits; sediments probably deposited in fluviatile, lacustrine, or alluvial fan environment(s)	Donchak & others, 1992; lava flows extensively altered, but essentially undeformed; several dacite and andesite lava flows represented
unconformable on Hodgkinson Formation; cut by intrusive rocks of the Claret Creek Ring Complex (mainly Munderra Granodiorite and Three Mile Microgranite), as well as by the Opah Granite and rhyolite dykes	mainly subaerial pyroclastic flow deposits	Branch, 1966; Bailey, 1969, 1977; Champion & Heinemann, 1994
unconformable on Hodgkinson Formation — contact generally marked by a zone of fault? breccia; inferred to be cut by gabbro, diorite, and granite of the Gurrumba Ring Complex	volcanic rocks erupted in a subaerial environment	Branch, 1966; Blake, 1972; referred to as the Gurrumba Volcanic Neck by Branch (1966)
unconformable on high-grade metamorphic rocks of probable Proterozoic age and the mid-Palaeozoic Chillagoe and Hodgkinson Formations; intruded by late Carboniferous granites	volcanic rocks erupted in a subaerial environment	Branch, 1966; Blake, 1972; Sheraton, 1974; Black, 1978, 1980
unconformable on Dargalong Metamorphics and Nundah Granodiorite; cut by Almac Granodiorite and dykes of microgranite, rhyolite, and rare glassy andesite	volcanic rocks erupted in a subaerial environment, as lavas and pyroclastic flows	Bultitude & Domagala, 1988; formation occupies an irregular, elongate, basin-like, subsidence structure which is cut by the Palmerville Fault; exposed mainly west of the Palmerville Fault in the Georgetown Region

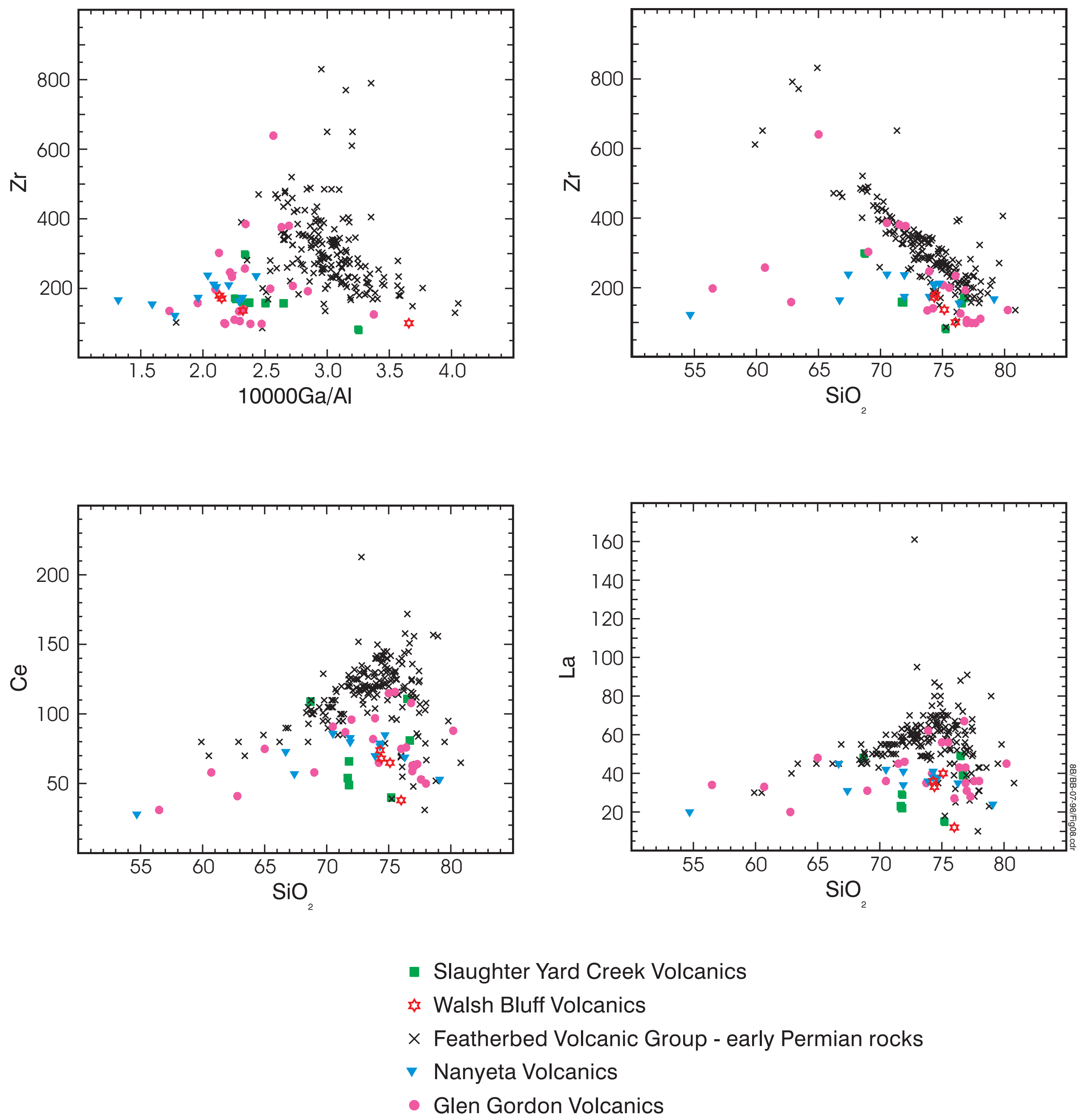


Figure 8. Zr (ppm) versus Ga/Al, and Zr, Ce and La (ppm) versus SiO_2 (wt%) plots for late Palaeozoic volcanic rocks in the south-eastern to south-western parts of the Cairns Region. Early Permian, A-type volcanic rocks of the Featherbed Volcanic Group have also been plotted for comparison.

are in the basal or lower parts of individual sequences.

Most of the silicic volcanic rocks are metaluminous to slightly peraluminous (ASI<1.1). Some rhyolites analysed from the Nanyeta and Slaughter Yard Creek Volcanics are moderately to highly peraluminous (1.1<ASI<1.4), possibly as a result of loss of alkalis and/or CaO during subsequent devitrification and alteration.

The I-type Nanyeta Volcanics show reasonably well-defined trends of increasing K_2O, Rb, Ba, and Th, and decreasing Ce, La, Y and Zr contents and Ga/Al ratios with increasing SiO_2 contents. They are clearly distinguished from the Permian A-type volcanic rocks of the Featherbed Volcanic Group on a Zr versus Ga/Al plot. The latter, with a few exceptions, are characterised by significantly higher Ga/Al ratios and Ce, La and Zr contents (Figure 8) at similar SiO_2 contents.

Silicic rocks with possible A-type affinities are present in the Slaughter Yard Creek Volcanics, consistent with their early Permian age (~275±3Ma; Black, 1978). All isotopically dated silicic volcanic rocks with A-type affinities elsewhere in the Cairns and Georgetown Regions have yielded early Permian ages.

Glen Gordon and Wallaman Falls Volcanics

The belt of predominantly silicic volcanic rocks extending discontinuously from north-west of Ravenshoe (in ATHERTON[9]) south-south-east to the Running River area (in southern INGHAM) was formerly mapped mainly as Glen Gordon Volcanics (Best, 1962; de Keyser, 1964; de Keyser & others, 1965; Branch, 1966). The term 'Glen Gordon Volcanics' in this report is applied only to the sequence exposed in the Ravenshoe area (which includes the type area and the Sunday Creek Volcanics of Best, 1962, and Branch, 1966). The volcanic rocks which crop out extensively north-west and north of Ingham (and, to a lesser extent, to the south) have been assigned to the Wallaman Falls Volcanics (Champion & Heinemann, 1994). They are >20km from the nearest mapped outcrops of Glen Gordon Volcanics (our terminology). Both units have yet to be examined in detail, and both can probably be further subdivided. Wellman (1997) identified two discrete cauldron subsidence structures in the Glen Gordon Volcanics, based on interpretation of aeromagnetic anomalies.

Two main facies were identified in the Glen Gordon Volcanics by Blake (1972). One consists mainly of rhyolite lava, volcanic breccia and tuff. The other facies consists mainly of rhyolitic ignimbrite.

The Wallaman Falls Volcanics crop out most extensively west of the trace of the Palmerville Fault (de Keyser & others, 1965), in INGHAM. The unit has a maximum exposed thickness of ~300–450m at Wallaman Falls (de Keyser & others, 1965; Branch, 1966). It consists mainly of rhyolitic to rhyodacitic ignimbrite (Branch, 1966). Stephenson & Chappell (1988) also reported bedded silicic tuffs on the Palm Islands.

Age

The lower part of the Glen Gordon Volcanics is intruded by granites of the O'Briens Creek Supersuite, in ATHERTON. The latter have yielded Rb–Sr isotopic ages mainly in the 300Ma–315Ma range (Black & others, 1978; Johnston & Black, 1986). However, the presence locally of silicic volcanic rocks with A-type affinities implies the upper part of the unit is Permian. The Glen Gordon Volcanics, therefore, probably range in age from Carboniferous to Permian.

The age of the Wallaman Falls Volcanics is also poorly constrained. The presence of silicic volcanic rocks with A-type affinities, as well as I-types, implies this formation also contains rocks of two distinct ages. This interpretation has been confirmed by recent SHRIMP dating. Selected samples have yielded ages of 326±6Ma (I-type rhyolitic ignimbrite north of the Black Burdekin River, at GR 3513 79610, Kirrama 1:100 000 Sheet area), and 279±5Ma (A-type rhyolite from the Seaview Range west of Ingham, at GR 3786 79320, Kangaroo Hills 1:100 000 Sheet area). The A-type volcanic rocks are, therefore, similar in age to recently dated samples (A-types) from the Nychum Volcanics, Featherbed Volcanic Group, and Hinchinbrook Granite.

Part of the unit is intruded by granites of the northern Ingham Batholith. The meagre data available indicate the granites were emplaced in the Carboniferous–Permian (Richards & others, 1966; unpublished data). Silicic volcanic rocks assigned to the unit on Hinchinbrook Island have been interpreted by Stephenson (1990) to pre-date his older granites and granodiorites. All are most probably Carboniferous.

Compositional and chemical characteristics

The analysed samples from the Glen Gordon Volcanics range in composition from andesite to rhyolite (Figure 9). The Glen Gordon Volcanics show a much greater compositional range than the Wallaman Falls Volcanics (mainly rhyolites, and some rhyodacites). Whether rocks of more basic composition are absent from the latter or whether the data merely reflect sampling bias (— the silicic rocks crop out more prominently than the basic rocks) is uncertain.

About half of the analysed samples from the Glen Gordon and Wallaman Falls Volcanics plot in the A-type field, with the A-type Hinchinbrook Granite (Stephenson & others, 1992), on the discrimination diagrams of Whalen & others (1987). The A-types are distinguished by anomalously high Ga/Al ratios, as well as FeO*, Ce, Ga, La, Pb, Zn, and Zr contents — characteristics shared with the Hinchinbrook Granite (*e.g.* Figure 9).

9 1:250 000 sheet areas hereon shown in capitals

Table 4. Details of selected granite groups of the Cairns Region.

SUPERSUITE/ BATHOLITH/ GROUP	ROCK TYPES	CONSTITUENT UNITS	DISTRIBUTION (AREA)
CENTRAL AND EASTERN HODGKINSON PROVINCE			
Cooktown Supersuite S-type	white–pale grey and pale bluish grey, fine to coarse-grained, highly porphyritic to even-grained, (altered cordierite–tourmaline) biotite–muscovite and muscovite–biotite granite; accessory garnet, topaz, sillimanite; plagioclase compositions generally $<An_{20}$; gneissic enclaves, miarolitic cavities and granophyric intergrowths common in some units; tectonic foliation well developed in places	numerous plutons delineated — see Appendix 1	north-eastern Hodgkinson Province, from Ninian Bay/Lizard Island to China Camp (~ 235km^2)
Pieter Botte Supersuite I-type	white to medium grey, fine to medium-grained, slightly to highly porphyritic hornblende–biotite granite, (hornblende–) biotite granite and biotite leucogranite; extensively deformed in places	Bunk Creek Granite, Nulbullulul Granite, Thornton Granite	1) area centred on Thornton Peak–Mount Pieter Botte (Nulbullulul), in south 2) headwaters of Granite and Slaty Creeks, north of Cedar Bay (~130km^2)
Yates Supersuite I-type	fine to medium-grained, even-grained to highly porphyritic, hornblende–biotite and (hornblende–) biotite granodiorite and granite; rare ortho- and clino-pyroxene; numerous relatively calcic plagioclase cores of ~An_{40}–An_{60} and sodic rims of ~An_{15}–An_{35}; sparse plagioclases with cores of An_{62}–An_{78} also present in Hope Vale and Leichhardt Pocket Granites; biotite flakes commonly show undulose extinction and, more rarely, small-scale kinks as a result of deformation	plutons delineated listed in Appendix 1	a western group of plutons associated with Whypalla and Mount Alto Supersuites; and an eastern group associated with Cooktown Supersuite (~134km^2)
Bartle Frere Supersuite I-type	pale grey to white, slightly to moderately porphyritic, hornblende–biotite granite and biotite granite; with minor tourmaline (locally), traces of ilmenite, allanite, biotite-rich clots (to ~2cm) and inclusions (to ~40cm) of biotite-rich gneiss; minor even-grained, fine–medium-grained (hornblende–) biotite leucogranite (as dykes and small pods); hornblende irregularly distributed	Bartle Frere Granite	prominent stock centred on Mount Bartle Frere, at the southern end of the Bellenden Ker Range (~134km^2)
Cape Melville Supersuite I-type	fine to coarse-grained, even-grained to highly porphyritic, (hornblende-) biotite granite; minor pegmatite pods and lenses, biotite-rich schlieren; small enclaves of (corundum–spinel–) biotite gneiss and quartz in places; generally more felsic than Yates Supersuite granites	Altanmoui Granite, Cape Bowen granite, Cape Melville Granite, Saint Pauls Hill Microgranite, Abbey Peak granite	Altanmoui and Cape Melville Ranges (~156km^2)
Wakooka Supersuite S-type	medium-grained, moderately porphyritic (muscovite–) biotite granite, with thin pegmatitic zones and rare miarolitic cavities; rare inclusions of biotite-rich gneiss and granite; minor even-grained to slightly porphyritic, altered cordierite?–tourmaline– muscovite–biotite granite	Wakooka Granite	small stock ~5km west of the Altanmoui Range (~1km^2)

1 for explanation of codes used see footnote 1, Appendix 1
2 average of two determinations
3 mg = [100MgO/40.32]/[FeO/71.86 + .8998Fe_2O_3/79.85 + MgO/40.32]

AGE	RELATIONSHIPS	GEOCHEMICAL CHARACTERISTICS	REFERENCES & COMMENTS
late Permian	intrude Hodgkinson Formation; cut by scattered dykes and pods of fine to medium-grained biotite granite, and by rare dolerite dykes	relatively high K_2O, Rb, V, Y and low CaO, P_2O_5, Sr, Ba, Nb, Ga; commonly fractionated; significant Sn mineralisation associated with granites of this supersuite	Lucas & de Keyser, 1965b; Morgan, 1965; Black, 1978; Sheraton & Labonne, 1978; Tate, 1983; Jones & others, 1990; Champion, 1991; Bultitude & Champion, 1992; Bultitude, 1993; Champion & Bultitude, 1994; generally more K-feldspar rich than granites of the Whypalla Supersuite
261±3Ma, Nulbullubul Granite (SHRIMP)	intrude Hodgkinson Formation, Obree Point Volcanics and unnamed volcanic rocks in the Cape Tribulation area (unit Cv)	relatively high SiO_2, FeO*, K_2O, Rb, Th, Y, Zr and low Al_2O_3, CaO, and Sr compared to Yates Supersuite granites	similar chemically and mineralogically to granites of the Cape Melville Supersuite; distinguished by relatively low Ba and high Rb and U contents
early (western group) to late (eastern group) Permian	intrude Hodgkinson Formation and, locally, late Carboniferous volcanic rocks; cut by granite dykes; unconformably overlain by Mesozoic Laura Basin sequence and Cainozoic Piebald Basalt	metaluminous–slightly peraluminous; unfractionated with low–moderate Rb contents and Rb/Sr ratios and absence of Ba depletion; characterised by relatively high Al_2O_3, CaO, Sr, V, and low SiO_2, K_2O, Rb, Th, Zr, Y, Cu compared with Cape Melville Supersuite granites	de Keyser & Lucas, 1968; Champion, 1991; Bultitude & Champion, 1992; Champion & Bultitude, 1994; plutons contain ilmenite rather than magnetite
early? Permian	intrudes Hodgkinson Formation; main granite intruded by dykes and pods of finer grained leucogranite (included as part of unit)	relatively high SiO_2, FeO*, Na_2O, K_2O, Ga, Zr, and low Al_2O_3, CaO, Ba, and Sr contents compared to Yates Supersuite granites; distinguished from Cape Melville and Pieter Botte Supersuites by relatively high Na_2O, Sr and low K_2O, Zr contents F U R H[1]	de Keyser, 1964; de Keyser & Lucas, 1968; Bultitude & Champion, 1992; Champion & Bultitude, 1994; unit essentially undeformed, in contrast to nearby Bellenden Ker Granite; some leucogranites have miarolitic cavities
280±2Ma[2], Cape Melville Granite (Rb–Sr)	intrude Hodgkinson Formation; unconformably overlain by Mesozoic Laura Basin succession; cut by scarce microgranite dykes	slightly peraluminous; similar major element concentrations to the Ootann Supersuite granites; characterised by lower Al_2O_3, MgO, mg[3], CaO, Sr, V, Cr and higher K_2O, Rb, Zr, Y, La, Ce, Ga compared with Yates Supersuite granites	Lucas, 1964; Lucas & de Keyser, 1965a; Sheraton & Labonne, 1978; Bultitude & Champion, 1992 Bultitude, 1993; Champion & Bultitude, 1994
early Permian	intrudes Hodgkinson Formation	higher Rb and Rb/Sr than Cape Melville Supersuite granites; relatively low P_2O_5, K_2O, V, Cr, and Ni and high Na_2O, Pb, Th, La, and Ce contents compared with Cooktown Supersuite granites F F R–SR H	Lucas, 1964; Bultitude & Champion, 1992; Bultitude, 1993; Champion & Bultitude, 1994

Table 4 (continued)

SUPERSUITE/ BATHOLITH/ GROUP	ROCK TYPES	CONSTITUENT UNITS	DISTRIBUTION (AREA)
Mount Alto Supersuite S-type	medium-grained, slightly to moderately porphyritic, (biotite–) garnet–tourmaline–muscovite granite	Mount Alto Granite	several stocks and pods south and south-west of Mount Carbine (~9km^2)
Wangetti Supersuite S-type	medium-grained, even-grained to highly porphyritic, tourmaline–muscovite granite and (tourmaline–) muscovite–biotite granite; miarolitic cavities common; locally deformed	Wangetti Granite	small roughly concentric plutons or zones in White Cliff Point area, Cook Highway, north of Cairns (~3km^2)
Whypalla Supersuite S-type	mainly medium to coarse-grained, highly porphyritic to equigranular, muscovite–biotite granite; widespread traces of garnet, and tourmaline; rare sillimanite, orthopyroxene, clinopyroxene; plagioclase (An_{61}–An_0) gen. >K-feldspar; enclaves of (garnet–) biotite gneiss, 'microdiorite', 'micrograníte', quartz, and locally-derived metasedimentary rocks widespread and locally common; well-developed tectonic foliation in places; irregular pegmatite pods and lenses, up to ~30cm wide and 60cm long, present in some plutons	numerous plutons delineated — see Appendix 1	scattered batholiths and stocks, eastern Hodgkinson Province (~1700km^2)
Tinaroo Supersuite S-type	white to pale grey, medium-grained, slightly to moderately porphyritic, biotite granite; with euhedral–subhedral feldspar phenocrysts to ~3cm, traces of garnet; moderately well-developed foliation in marginal zones	Tinaroo Granite	Lamb Range south-west of Cairns (~ 305km^2)
Bellenden Ker Supersuite S-type	mainly moderately to highly porphyritic biotite granite — commonly extensively deformed with a well-developed mylonitic foliation; subordinate even-grained to slightly porphyritic (tourmaline–) muscovite–biotite granite (with rare garnet, altered cordierite? in places)	Bellenden Ker Granite, Walshs Pyramid Granite, Mount Peter Granite, several informal units	forms the rugged Bellenden Ker, Malbon Thompson and Graham Ranges, and Walshs Pyramid, between Cairns and Innisfail, as well as Fitzroy Island (~460km^2)
Emerald Creek Supersuite S-type	white to grey and pale brown, medium-grained, even-grained to slightly porphyritic, muscovite-biotite granite; traces of garnet present locally; phenocrysts of (in decreasing order of abundance) plagioclase, K-feldspar, quartz; variably deformed (mainly undulose extinction in quartz and mica grains, and slightly bent mica flakes) and locally foliated	Emerald Creek Microgranite	irregular, north-trending pluton, ~ 15km south-east of Mareeba (~23km^2)
Mount Formartine Supersuite S-type	mainly medium-grained, even-grained, muscovite–biotite granite, with scattered enclaves; extensively deformed, recrystallised; commonly with a well-developed mylonitic foliation	Mount Formartine Granite	scattered elongate stocks and dyke-like intrusions, Cairns area (~78km^2)

4 Agp = Agpaitic Index = Al(molecular)/(Na + K)(molecular)

AGE	RELATIONSHIPS	GEOCHEMICAL CHARACTERISTICS	REFERENCES & COMMENTS
early Permian; 269±8Ma, 271±5Ma (SHRIMP)	intrudes Hodgkinson Formation; locally cut by numerous north-north-west-trending intermediate to basic dykes, as well as by rare dykes of aplite, aplitic microgranite	relatively low CaO, Sr, Ba, Nb, Sc, Mn, Zn, Ga, and high Rb, V, Y; highly fractionated, with >800ppm Rb and ~60–200ppm Sn F F R H	Champion, 1991; Bultitude & Champion, 1992; Champion & Bultitude, 1994; Davis & others, 1998; tourmaline crystallised relatively early, taking the place of biotite
between 273Ma and 285Ma, assuming an initial $^{87}Sr/^{86}Sr$ ratio in the range from 0.710–0.715	intrudes Hodgkinson Formation	relatively high P_2O_5, Ga, Nb, Rb, V, and low K_2O, CaO, Sr, Ba, Y F F R H	Willmott & others, 1988; Bultitude & Champion, 1992; Champion & Bultitude, 1994; similar petrographically to Mount Alto Granite
mainly early Permian; 282±9Ma (Rb–Sr)	intrude Hodgkinson Formation; pods and dykes of more felsic, fractionated microgranite. commonly intrude the main granite intrusions (generally around the margins)	slightly–moderately peraluminous; relatively high CaO, Ba, Sr, Y, and low Nb, Rb, V, Sc, Mn, Zn, Ga	Black, 1978; Higgins & others, 1987, Bateman, 1989, Champion, 1991; de Keyser & Lucas, 1968; Bultitude & Champion, 1992; Champion & Bultitude, 1994; associated with significant Sn and W mineralisation in places
~280Ma (Rb–Sr)	intrudes high-grade metamorphic rocks mapped as part of the Hodgkinson Formation, as well as the Emerald Creek Microgranite; cut by numerous dykes of fine-grained, biotite leucogranite	relatively high CaO, Sr, Ba, Y, and low K_2O, Ga, Rb, V; primitive ε_{Nd} F F R H	Mancktelow, 1974, 1982; Black, 1978, 1980; Bultitude & Champion, 1992; Champion & Bultitude, 1994; very similar petrographically and chemically to Whypalla Supersuite granites, but is distinct isotopically
280±4Ma, Bellenden Ker Granite (SHRIMP)	intrude Hodgkinson Formation; cut by dykes and small pods of more felsic, fine to medium-grained granite	similar to Whypalla and, to a lesser extent, Cooktown Supersuites — distinguished by relatively high K_2O, V, Pb and low CaO, Sr; some units (*e.g.* Walshs Pyramid Granite) are fractionated	Willmott & others, 1988; Bultitude & Champion, 1992; Champion & Bultitude, 1994; Bellenden Ker Granite is a composite unit; tourmaline relatively common in some units
most probably late Carboniferous or early Permian	intrudes Hodgkinson Formation; cut by Tinaroo Granite and dykes of muscovite–biotite granite	relatively high CaO, MgO, mg, and low K_2O, Y, Agp^4 F U R M–H	Bultitude & Champion, 1992; Champion & Bultitude, 1994
357±6Ma (SHRIMP)	intrudes Hodgkinson Formation; cut by irregular quartz veins, up to ~15cm thick	relatively high TiO_2, Rb and low CaO, K_2O, Pb, Th, Zr, Y, La, Ce F U R H	Willmott & others, 1988; Champion, 1991; Bultitude & Champion, 1992; Champion & Bultitude, 1994; Zucchetto & others, 1998; contains some of the most extensively deformed and recrystallised granites in the eastern Hodgkinson Province

Table 4 (continued)

SUPERSUITE/ BATHOLITH/ GROUP	ROCK TYPES	CONSTITUENT UNITS	DISTRIBUTION (AREA)
DUNK ISLAND–PALM ISLANDS BELT			
Hinchinbrook Supersuite A-type	mainly (arfvedsonite–) biotite granite with numerous interstitial and miarolitic cavities; minor porphyritic microgranite, pegmatite, aplite, pyroxene-bearing granite	Hinchinbrook Granite	mainly mountainous country forming southern half of Hinchinbrook Island (~95km^2)
Palm Islands Batholith I-type	porphyritic titanite–hornblende–biotite granite, porphyritic microgranite, pegmatite, granodiorite, biotite granite; mafic enclaves up to several metres long locally abundant	undivided and unnamed granite; previously mapped as unnamed unit Cgb	Palm Islands (~50km^2)
Bedarra granite belt mainly I-type; minor A-type?; rare S-type?	porphyritic biotite granite; minor aplitic biotite granite, gabbro; dykes of relatively biotite-rich granite; traces of tourmaline and garnet (S. Wegner, James Cook University of North Queensland, personal communication, 1997)	several informal units delineated mainly using mineralogy and geochemistry	islands forming south-east trending belt, from Dunk Island in north to the Brook Islands in south (~5km^2)
RAVENSHOE–INGHAM BELT			
Tully Batholith I-type (Ingham Supersuite)	range from quartz gabbro to biotite granite — mainly hornblende–biotite granite to biotite–hornblende granodiorite; clino- and ortho- pyroxene present in more mafic units	Tully Granite Complex	north-westerly to northerly trending belt between Tully and Tarzali (~800km^2)
Ingham Batholith I-type (Ingham Supersuite); minor A-type (Hinchinbrook Supersuite)	hornblende–biotite granite to granodiorite?, biotite granite, (arfvedsonite–) biotite granite, (molybdenite–) biotite leucogranite; minor biotite–hornblende granodiorite, diorite, aplitic biotite microgranite	Hinchinbrook Granite, Ingham Granite Complex, several unnamed informal units — most plutons not delineated; previously mapped mainly as units Cga, Cgb, Cgp (INGHAM) and unit Pzg (INNISFAIL)	north-west-trending belt in the Ingham–Kirrama–Koombooloomba area, in far south of region; also includes granites of Hinchinbrook, Garden and Goold Islands (Hinchinbrook Granite described separately); extends into adjacent regions to the west (~1150km^2)
CHILLAGOE–MOUNT GARNET–HERBERTON BELT			
Lags Supersuite A-type	highly porphyritic to even-grained microgranite to microgranodiorite; minor microdiorite, dacite (intrusive)	Bustlem Microgranite, Lags Microgranite, Saint Helena Monzogranite, Maneater Granodiorite, unit Pmg, Yokas Microgranite	dykes, lenses and stocks associated mainly with early Permian and probable early Permian volcanic rocks of the Featherbed Volcanic Group (~146km^2)

AGE	RELATIONSHIPS	GEOCHEMICAL CHARACTERISTICS	REFERENCES & COMMENTS
275±5Ma (Rb–Sr)	post-dates unnamed granodiorite and granite, porphyritic microgranite (ring dyke), Wallaman Falls Volcanics, and a basic dyke swarm; cut by porphyritic microgranite and rare basic dykes	leucocratic (SiO_2 generally >75%) and highly fractionated; unit shows *in situ* fractional crystallisation trend of overall upward enrichment in Rb, Pb, Zn, Zr, Th, and Nb, and depletion in Sr F F–U O–SO H	de Keyser & others, 1965; de Keyser, 1966; Ewart, 1978; Stephenson, 1990, personal communication, 1995; Stephenson & others, 1992; not examined during current survey
late Carboniferous or early Permian 281–274Ma (K–Ar)	intrude Wallaman Falls Volcanics; cut by mafic and felsic dykes	similar to Ootann Supersuite granites F U–F O M–H	de Keyser & others, 1965; Stephenson & Chappell, 1988; P.J. Stephenson, James Cook University of North Queensland, personal communication, 1995; not examined during current survey
336±5Ma, Tapp-Ana gr; 335±6Ma, North Island gr. (SHRIMP)	intrude Barnard Metamorphics	CaO, P_2O_5, Sr, V, Ga, Nb, Zn, and Zr decrease with increasing SiO_2 in most rocks, and K_2O, total alkalies, Pb, Rb, and Y increase; relatively mafic granites on Wheeler and North Islands have anomalously high Zr, Ce, Y, Nb, Ga, Zn, and Ga/Al	de Keyser, 1964; de Keyser & others, 1965; Bultitude & Garrad, 1997; Bultitude & others, 1998a; unpublished data; rel. mafic granites on Wheeler and North Islands may be A types
286±4Ma (SHRIMP); 273–302Ma (K–Ar)	intrude Hodgkinson Formation, Glen Gordon Volcanics; unconformably overlain by Atherton Basalt	well-defined trend of decreasing TiO_2, FeO*, MgO, CaO, P_2O_5, Sr, Ga, Zn and increasing Pb, Th, K_2O, Rb, U, Nb with increasing SiO_2 — Zr, Y, Ce, and La vary only slightly M–F U–F R–O M–H	de Keyser, 1964; de Keyser & others, 1965; mafic units common compared to the Ingham Batholith
301±6Ma, 282±4Ma (SHRIMP)	intrude Glen Gordon and Wallaman Falls Volcanics, and unit Pz; cut by dolerite dykes (locally forming small swarms); unconformably overlain by Cainozoic Atherton Basalt	I-type granites show well-defined trend of decreasing TiO_2, FeO*, MgO, CaO, P_2O_5, Sr, Zn and increasing Pb, Th, K_2O, Rb, U, Nb with increasing SiO_2 — Zr, Y, Ce, and La vary only slightly except for a few samples; a few felsic units (A-types) show significant enrichment in Ce, La, Zr, and, to a lesser extent, Ga M–F U–F SR–SO M–H	de Keyser, 1964; de Keyser & others, 1965; Richards & others, 1966;
279±4Ma, Lags Microgranite; 280±4Ma, Bustlem Microgranite (Rb–Sr)	intrude Hodgkinson Province rocks and Featherbed Volcanic Group	relatively high Ba, Zr; moderately high Ce, Y, Zn, Ga, and high Ga/Al ratios; unfractionated to slightly fractionated M–F U O–R H	Mackenzie & others, 1993; Bultitude & others, 1995; commonly characterised by complex mineralogy (particularly the more basic members) with biotite, garnet, hornblende, apatite, hypersthene, fayalite, and rare clinopyroxene?

Table 4 (continued)

SUPERSUITE/ BATHOLITH/ GROUP	ROCK TYPES	CONSTITUENT UNITS	DISTRIBUTION (AREA)
Almaden Supersuite I-type	grey, even-grained to highly porphyritic, hornblende–biotite and biotite–hornblende granodiorite; minor (hornblende–) biotite granite, tonalite, quartz monzodiorite, quartz monzonite?, quartz diorite, leucogranite, aplite; rare gabbro or quartz gabbro; mafic enclaves common — range up to ~2m across in the Almac and Ruddygore Granodiorites (most <30cm in diameter)	numerous plutons delineated — see Appendix 1	major component of the northern Tate Batholith, Chillagoe area (~515km^2)
Claret Creek Supersuite I-type	even-grained to porphyritic, biotite microgranite, biotite-hornblende granite and granodiorite to tonalite; with ovoid dioritic inclusions up to ~40cm across; intrusive rhyolite to dacite; rhyolitic to dacitic? breccia	Ballast Creek Dacite, Hammonds Creek Granodiorite (part)?, Munderra Granodiorite, The Gorge Rhyolite, Three Mile Microgranite?	main outcrops form semi-circular area ~25km west-north-west of Mount Garnet (~25km^2)
Gurrumba Ring Complex I-type	fine to medium-grained quartz diorite, diorite, olivine gabbro; fine to coarse-grained granite, granophyric granite	three informal subunits delineated as result of recent GSQ mapping; Blake (1972) delineated four unnamed subunits	small, irregular, elliptical area ~19km north-west of Mount Garnet (~8km^2)
Ootann Supersuite I-type	mainly medium to coarse-grained, even-grained to moderately porphyritic biotite granite; subordinate hornblende–biotite granite and granodiorite; minor leucogranite, microgranite, aplite; biotite>hornblende (scarce or absent); accessory minerals include zircon, apatite, magnetite, ilmenite, allanite, fluorite, xenotime, monazite, thorite	~50 formal and informal units — see Appendix 1	major component of the Tate Batholith, in southwestern part of Hodgkinson Province (~5000km^2)
O'Briens Creek Supersuite I-type	leucocratic, porphyritic to even-grained biotite granite and microgranite; miarolitic cavities common; pegmatitic lenses and pods widespread; extensive areas of alteration and greisen development; plagioclase mainly in oligoclase–albite range; accessory and secondary minerals include zircon, monazite, allanite, thorite, opaques, apatite, fluorite, tourmaline, topaz, sericite, muscovite, chlorite, beryl (rare), phenacite (rare); granophyric rocks common in Go Sam Suite	numerous named and unnamed plutons — see Appendix 1	extensive areas in the Herberton–Emuford–Mount Garnet–Tate River area (~2 500km^2)

5 $Eu/Eu^* = Eu_N/[(Sm_N + Gd_N)/2]$; N = chondrite normalised

AGE	RELATIONSHIPS	GEOCHEMICAL CHARACTERISTICS	REFERENCES & COMMENTS
~303Ma–~280Ma (Rb–Sr)	intrude Hodgkinson Province rocks, and older units of the Featherbed Volcanic Group; also intrude and are cut by granites of the Ootann Supersuite; cut by Lags Supersuite granites and by rare plugs of Cainozoic basalt/dolerite	~56–72% SiO_2; relatively high K_2O, K/(Na + K), Rb, Rb/Sr, Th, U, and low Ba, Sr	Black, 1978, 1980; Black & others, 1978; Richards, 1980, 1981; Champion, 1991; Champion & Chappell, 1992; Bultitude & others, 1993b, 1995; Mackenzie & others, 1993; Champion & Heinemann, 1994; as mapped also contains some undelineated rel. felsic monzogranite of the Ootann Supersuite
300±5Ma, 290Ma (Rb–Sr)	intrude Hodgkinson Formation, Ootann Supersuite granites and Claret Creek Volcanics; cut by rhyolite dykes	~65–77% SiO_2; relatively high Al_2O_3, CaO, Na_2O, Sr, and low K_2O, Rb, Th, U compared with granites of the Almaden Supersuite	Branch, 1966; Bailey, 1977; Black, 1980; Champion & Chappell, 1992
~303Ma (Rb–Sr)	intrude Hodgkinson Formation and Emuford Granite; inferred to post-date Gurrumba Volcanics	olivine gabbro has anomalously high Al_2O_3, CaO; very little data for the more felsic rocks	Branch, 1966; Blake, 1972; Black, 1978, 1980; olivine gabbro is a cumulate with abundant highly calcic plagioclase
~316Ma–~290Ma (Rb–Sr)	intrude Hodgkinson Province rocks, older units of the Featherbed Volcanic Group, and Almaden Supersuite granites; also truncate the Palmerville Fault in places; locally cut by microgranite, rhyolite, andesite, and rare dolerite dykes, as well as by porphyritic microgranite of the Lags Supersuite	generally >70% SiO_2; relatively low Sr, Sr/Y ratios, and large negative Eu/Eu*[5], evolved initial $^{87}Sr/^{86}Sr$ ratios and ε_{Nd} values; generally more felsic than granites of the Almaden Supersuite	Black, 1978; Richards, 1981; Bailey, 1984; Blevin, 1990; Champion, 1991; Champion & Chappell, 1992; Bultitude & others, 1993b; presence locally (*e.g.* in the Election Granite) of miarolitic cavities consistent with relatively high emplacement levels; generally characterised by presence of relatively large, subhedral to anhedral grains of orthoclase microperthite; plagioclase compositions mainly in the oligoclase–albite ($\sim An_{30}$–$<An_5$) range
~307–315Ma, Nettle Suite; 310–315Ma, Go Sam Suite (Rb–Sr)	cut by Ootann Supersuite granites, pods and dykes of rhyolite, and locally by numerous quartz veins and greisen (alteration) zones; inferred to post-date Almaden and Ootann Supersuite granites in Herberton area (Clarke, 1990)	>70% SiO_2; contain significantly higher abundances of HFSE, HREE, and F than Ootann Supersuite granites; associated, in particular the late-stage, highly fractionated microgranites, with extensive tin mineralisation	Johnston, 1984; Witt, 1985, 1987, 1988; Pollard, 1984, 1988; Johnston & Black, 1986; Clarke, 1990; Champion, 1991; Champion & Chappell, 1992; Bultitude & others, 1993b; Champion & Heinemann, 1994; Donchak & Bultitude, 1994, 1998; characterised by highly fractionated compositions

Table 4 (continued)

SUPERSUITE/ BATHOLITH/ GROUP	ROCK TYPES	CONSTITUENT UNITS	DISTRIBUTION (AREA)
BARNARD BELT — MACROSSAN PROVINCE			
Mission Beach Granite Complex I-type and possible I-type	mainly medium-grained, even-grained biotite granite (I-type?), with a weak to well-developed foliation and rare garnet xenocrysts?; minor mafic granodiorite–diorite? (I-type); units commonly extensively recrystallised	several informal units recently referred to as Garners diorite, Timana diorite, South Mission granite	scattered outcrops from South Mission Beach to Russell River area, and on Timana Island; scattered rocky outcrops in headlands from South Mission Beach to Garners Beach (~$48km^2$)
Tam O'Shanter Supersuite S-type	medium-grained, even-grained to slightly porphyritic (altered cordierite?–) muscovite–biotite granite with numerous enclaves (up to ~5m; most <10cm) of biotite gneiss and quartz; extensively deformed and recrystallised with a well-developed gneissic foliation; plagioclase compositions in the oligoclase range (~An_{14}–An_{23})	Tam O'Shanter Granite	prominent outcrops along coast at Tam O'Shanter Point (<$1km^2$)

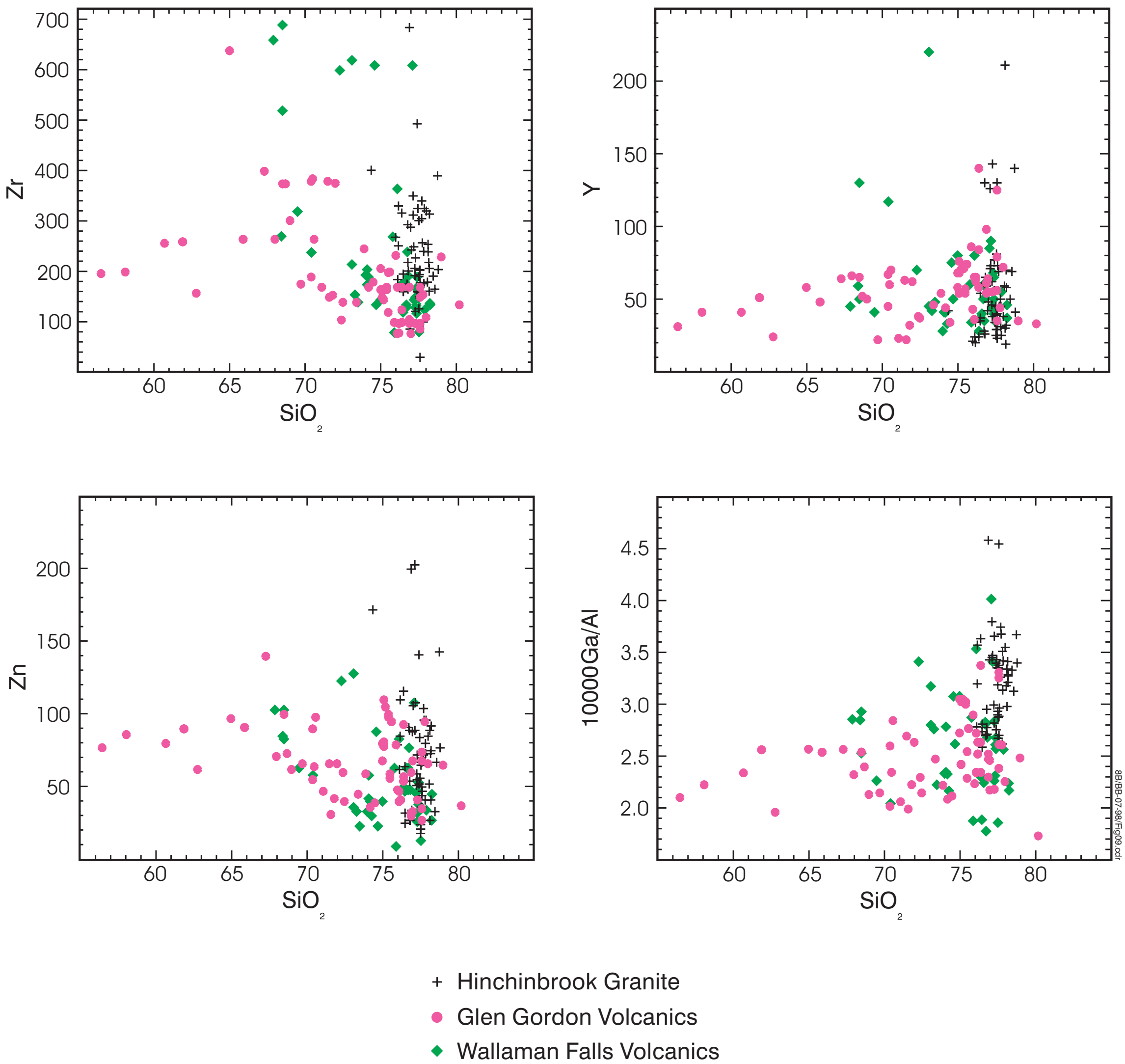


Figure 9. Zr, Y, Zn (ppm), and Ga/Al versus SiO_2 (wt%) plots for the late Palaeozoic volcanic rocks in the south-eastern part of the Cairns Region. Analyses of the early Permian, A-type Hinchinbrook Granite are also shown for comparison.

AGE	RELATIONSHIPS	GEOCHEMICAL CHARACTERISTICS	REFERENCES & COMMENTS
early?–late Ordovician; granite which intrudes Tam O'Shanter Granite has yielded a SHRIMP age of 463±7Ma	intrudes metasedimentary rocks of the Barnard Metamorphics, and Tam O'Shanter Granite	felsic I-type? granite characterised by relatively high CaO, Na_2O, Sr, P_2O_5 and low K_2O, Th compared with the Tam O'Shanter Granite; Sr depleted, Y undepleted M–F U R–O M–H	Bultitude & Garrad, 1997; Bultitude & others, 1998a; poorly exposed and extensively weathered away from coast
486±10Ma (SHRIMP)	intrudes metasedimentary rocks of the Barnard Metamorphics; unit cut by pod of biotite granite which has yielded a SHRIMP age of 463±7Ma	relatively high K_2O and K_2O/Na_2O; Sr depleted, Y undepleted F U R H	Bultitude & Garrad, 1997; similar chemically to Whypalla Supersuite granites and Ordovician granites of the Ravenswood Batholith, Charters Towers area

The two formations show little evidence of feldspar fractionation. K/Rb ratios, for example, remain more or less constant in units containing between ~50% and ~75% SiO_2. Some units in the Glen Gordon Volcanics with higher SiO_2 contents show a very poorly defined trend of decreasing K/Rb ratios with increasing Rb contents, consistent with feldspar fractionation. In contrast, the Hinchinbrook Granite has a very well-defined trend of increasing Rb contents with decreasing K/Rb ratios (Figure 10), implying fractional crystallisation of feldspars played a major role in the evolution of the granite.

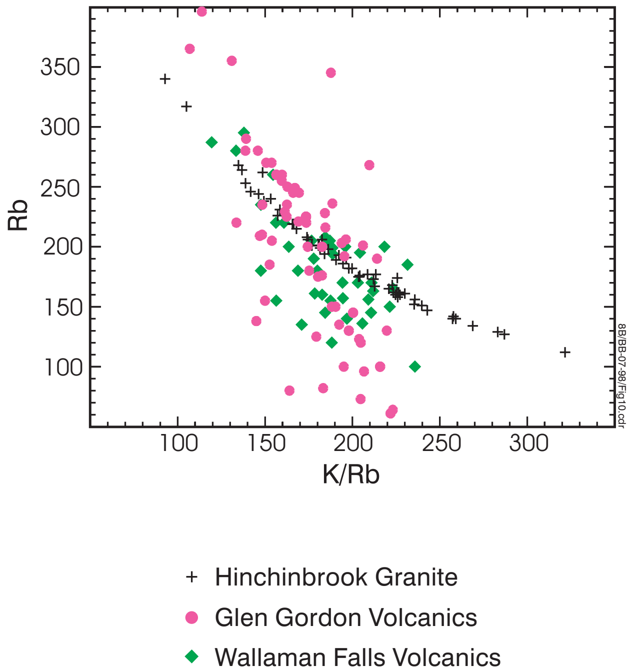


Figure 10. Rb (ppm) versus K/Rb plot for the Glen Gordon and Wallaman Falls Volcanics. Also shown for comparison are analyses of the A-type Hinchinbrook Granite

Featherbed Volcanic Group

The Featherbed Volcanic Group forms one of the most extensive silicic volcanic sequences in north Queensland. The volcanic complex is elongated parallel to the Palmerville Fault and other major, north-westerly striking faults in the Hodgkinson Province. The complex is confined mainly to a composite volcano-tectonic subsidence structure (the Featherbed Cauldron complex of Oversby & others, 1980; Mackenzie, 1993; Mackenzie & others, 1993), ~100km long and 30km wide. This structure consists of the Boonmoo Sag, and the Boxwood, Doolan Creek, Djungan, Eight Mile, Mount Mulligan, Tennyson, Wakara, Wolfram, and Yongala (Featherbed Caldera of Mackenzie & others, 1993) Cauldrons (Mackenzie, 1997). The Tennyson, Yongala, Djungan and Wakara Cauldrons are 'classic' ring fault and ring dyke-bounded cauldron collapse structures, as may be the Mount Mulligan, Wolfram, Doolan Creek and Boxwood structures. The Boonmoo Sag, in contrast, is a basin-like sag structure, without peripheral ring fault(s) or ring dykes (Mackenzie, 1993, 1997).

In addition, the Nightflower Dacite may also be preserved in a subsidence structure (Nightflower Cauldron). This sequence is almost completely fault bounded and partly intruded by porphyritic microgranite (as ring dykes). There are also scattered domes/flows/pods of dacite-rhyolite? around the faulted perimeter. These were assigned to the early Permian Wakara Subgroup by Mackenzie & others (1993) and Bultitude & others (1995).

However, recently acquired chemical data for one of these units (unit Plq of Bultitude & others, 1995) indicate it is not an A-type, and that it is chemically similar to late Carboniferous I-types of the Featherbed Volcanic Group. It is, therefore, highly likely that the dacite–rhyolite? domes/flows/pods (units Plq, Plj and Plr of Bultitude & others, 1995) were erupted around the perimeter of a subsidence structure which formed before the Wakara Cauldron, and that they form part of the Nightflower Dacite sequence.

Stratigraphy and rock types

The Featherbed Volcanic Group consists of:

(1) the Boonmoo and Tennyson Volcanic Subgroups, which, together with the Boxwood Volcanics, Jamtin Rhyolite, Beapeo Rhyolite, Wallaroo rhyolite[10], Redcap Dacite, Doolan Creek Rhyolite, and Nightflower Dacite, are late Carboniferous,

(2) the Timber Top Volcanic Subgroup, of probable late Carboniferous–early Permian age, and

(3) the Yongala, Djungan, and Wakara Volcanic Subgroups, all of early Permian age. Details of rock types, thicknesses, relationships and geochemical characteristics are listed in Table 3. Total preserved volume of eruptive rocks is ~3000km^3 (Mackenzie, 1997).

About 85% (by volume) of the Featherbed Volcanic Group is welded rhyolitic ignimbrite, and about 10% is dacitic to andesitic ignimbrite (Boonmoo Volcanic Subgroup, Redcap Dacite, Nightflower Dacite; Mackenzie, 1997). The remaining 5% consists of:

(1) dacitic to andesitic lavas in the Boonmoo Volcanic Subgroup,

(2) scattered rhyolitic lava flows and domes which crop out around the margins of the Yongala Cauldron, the Djungan Cauldron, and, in particular, the Wakara Cauldron,

(3) rare porphyritic andesitic lava(s) of the Timber Top Volcanic Subgroup,

(4) rare unwelded pyroclastic rocks (including air-fall tuffs), and

(5) very rare reworked (sedimentary) volcaniclastic rocks.

There are several significant differences between rocks of the Djungan, Featherbed, Timber Top (dacitic-rhyolitic rocks only), and Wakara Volcanic Subgroups and the adjacent late Carboniferous volcanic rocks. The late Carboniferous rocks are I-types and span the compositional range from andesite to rhyolite. However, the rocks of early Permian and probable early Permian age are of A-type character and most are rhyolites or rhyodacites.

The early Permian ignimbrites of the Featherbed Cauldron complex are also noteworthy for the presence of extensive rheomorphically deformed zones. These zones are common in the lowermost parts of the Yongala and Djungan Volcanic Subgroups and resulted from plastic flow in hot, thick ignimbrite sheets. They are up to hundreds of metres thick in the western part of the Yongala Cauldron (Mackenzie, 1997). Vitrophyres are also extensively developed. These glassy zones are commonly many tens of metres thick, and may be up to ~200m thick in places (*e.g.* in the eastern part of the Wakara Cauldron).

A massive, lithics-rich volcanic breccia or ignimbrite, containing clasts up to ~40m long and 15m wide, is exposed over an area of several tens of square kilometres in the western part of the Wakara Cauldron (Mackenzie & others, 1993); it is probably a vent or near-vent deposit.

Eruptive history

Volcanism began ~308–313 million years ago in the far south-east, (with eruption of the lowermost units of the Boonmoo Volcanic Subgroup, probably in a sag structure) and in the far north of the complex (with eruption of the Nightflower Dacite, possibly in a cauldron subsidence area) (Mackenzie, 1997). A major volcanic-intrusive episode occurred at ~300Ma, with development of the Boxwood, Doolan Creek, Eight Mile, Tennyson, and Wolfram Cauldrons. The Jamtin Rhyolite and Redcap Dacite were also emplaced during this episode,

10 informal name

both possibly representing outflow equivalents of units in the Eight Mile Cauldron (Mackenzie, 1997). The Mount Mulligan Cauldron (Timber Top Volcanic Subgroup) appears to have formed slightly later than the Boonmoo and Wolfram Cauldrons (Mackenzie, 1997), but was overprinted by the next major volcanotectonic episode. This episode was responsible for the formation of the Yongala Cauldron, at ~290Ma, and was followed by formation of the adjacent Djungan and Wakara Cauldrons at ~280Ma (Mackenzie & others, 1993; Bultitude & others, 1996b).

The Wakara Cauldron sequence is the youngest in the Featherbed Cauldron complex and forms the north-western extremity of the complex. It covers ~350km^2, and has a maximum exposed thickness of ~1500–2000m (Mackenzie, 1993). Rocks in the lowermost exposed part of the sequence overlie those of the Yongala and Djungan Cauldrons in the south-east and east, respectively (Mackenzie, 1993). The remainder of the perimeter is fault- and ring dyke-bounded. The central and northern parts of the caldera form a secondary collapse structure, with maximum subsidence in the north (Mackenzie, 1993). This structure is partly bounded by arcuate bodies of at least partly intrusive, coarse to very coarse, lithics-rich ignimbrite or breccia in the south-east and south-west.

The Ticklehim Rhyolite, the second youngest unit in the Wakara Cauldron has yielded a Rb–Sr isotopic age of 278±3Ma (Mackenzie, 1993). Mackenzie & others (1993) also reported a Rb–Sr isotopic age of 281±2Ma for the Lumma Rhyolite, the youngest unit in the Djungan Volcanic Subgroup (Djungan Cauldron).

Mineralogical and chemical characteristics

The voluminous early Permian felsic ignimbrites of the Featherbed Volcanic Group represent the most extensive development of A-type volcanic rocks in the region. They are generally distinct, lithologically, mineralogically and chemically, from the late Carboniferous representatives (I-types) of the group. Crystals of garnet (or reacted garnet) orthopyroxene, clinopyroxene, fayalite and allanite are locally prominent, particularly in the vitrophyres; most of these minerals have not been found in the late Carboniferous volcanic rocks.

Chemically, the early Permian rocks (A-types) are characterised by relatively high Pb, Zr, Nb, Zn, Ga and F contents and show a well-defined trend of markedly decreasing Zr contents with increasing SiO_2 (Figure 11). These A-type rocks are also distinguished by relatively high Ba contents and Ga/Al ratios (Figure 11). Both the late Carboniferous I-type and early Permian A-type volcanic rocks contain fractionated representatives indicated, for example, by elevated Rb (>300ppm) contents in the more siliceous rocks (Figure 11). Ba increases in both the I- and A-types with increasing SiO_2 contents to ~71% SiO_2 and decreases with further increases in SiO_2 content (*e.g.* figure 7B in Bultitude & others, 1996b). Such trends are consistent with the onset of K-feldspar fractionation at ~71% SiO_2.

Timber Top Volcanic Subgroup and units Cad, Plb

The dacitic–rhyolitic volcanic rocks (A-types) of the Timber Top Volcanic Subgroup are compositionally distinct from the other A-type volcanic rocks of the Featherbed Volcanic Group (Figure 11). Al_2O_3, MgO, and Zr contents are lower, and TiO_2 contents are higher in the A-type rocks of the Timber Top Volcanic Subgroup at comparable SiO_2 (or FeO*) contents (Figure 11). Rb contents increase gradually with increasing SiO_2 contents, but the rocks are not highly fractionated (Rb<300ppm).

Andesite mapped at the base of the succession exposed south of Controversy Hill does not plot on extensions of the trends shown by the more silicic members of the Timber Top Volcanic Subgroup for most elements (Figure 11). Linear or curvilinear compositional trends or arrays on Harker-type variation diagrams are generally thought to indicate derivation from a common parental magma or source-rock assemblage. Instead, the andesite has marked geochemical affinities with the late Carboniferous, I-type members of the Featherbed Volcanic Group (Figure 11). This similarity in chemical compositions may indicate the andesite is significantly older (late Carboniferous) than the more siliceous, A-type, rocks of the Timber Top Volcanic Subgroup.

In contrast, an analysis of porphyritic andesite (unit Cad of Mackenzie & others, 1993), which forms small outcrops ~11km south of Mount Mulligan, plots on the same trends as the A-type dacitic–rhyolitic volcanic rocks of the Timber Top Volcanic Subgroup and the

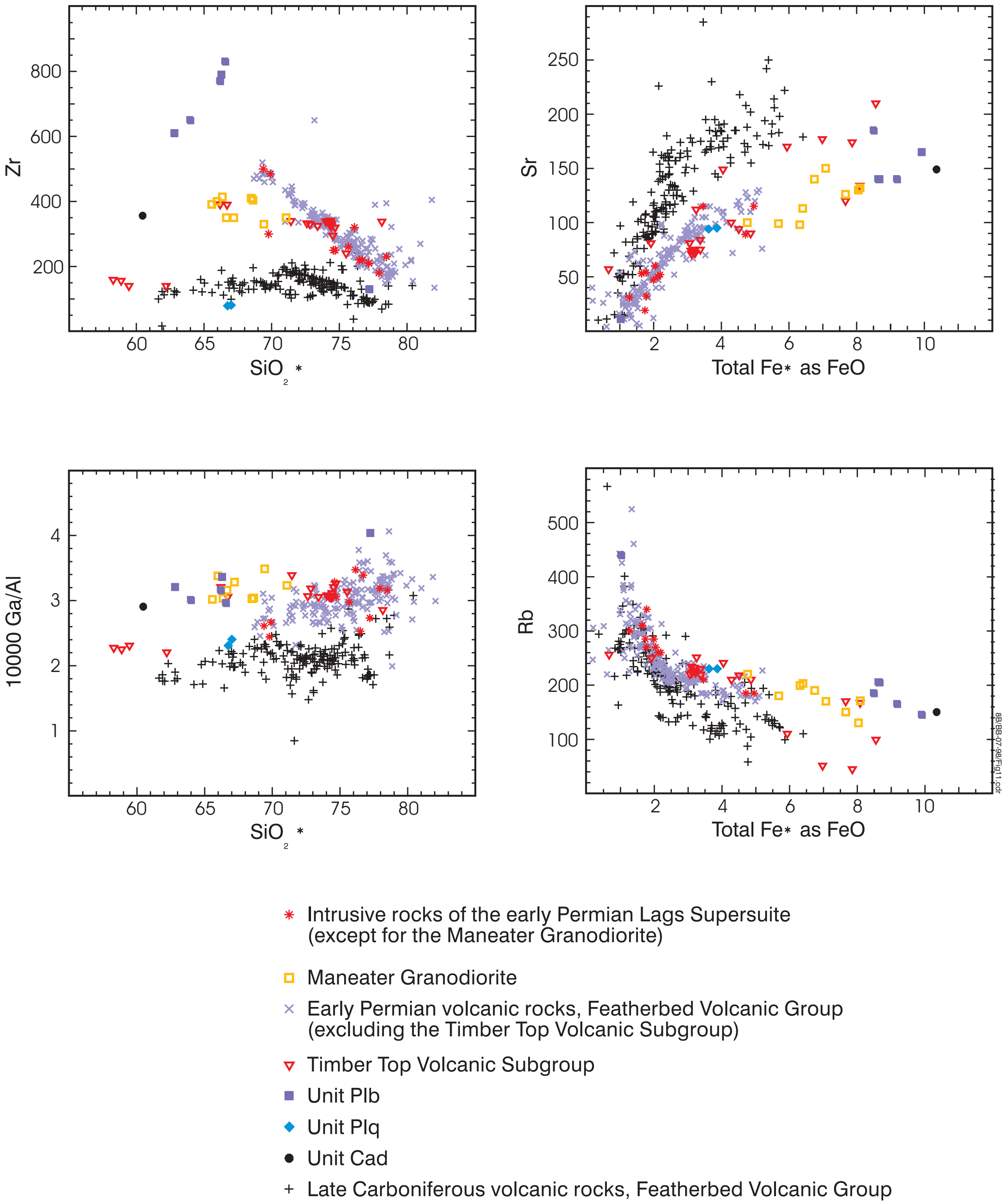


Figure 11. Zr, Rb, Sr (ppm), and Ga/Al versus SiO_2 or FeO (wt%) plots for the Featherbed Volcanic Group and comagmatic intrusive rocks. SiO_2 and FeO recalculated volatile free.*

Maneater Granodiorite for most elements. It is therefore reasonable to postulate unit Cad is genetically related to those rocks and to be of similar age (probably early Permian rather than late Carboniferous).

Similarly, recently acquired chemical data for rhyolite lava of unit Plq of Bultitude & others (1995) indicate it has affinities with the late Carboniferous volcanic rocks (I-types) of the group rather than the early Permian A-types of the Wakara Volcanic Subgroup, with which it had been included. The unit, therefore, may be late Carboniferous and form part of the Nightflower Dacite succession, with which it is associated spatially (Bultitude & others, 1995).

Dacitic lava forming part of unit Plb (Bultitude & others, 1995), one of the oldest units in the Wakara Volcanic Subgroup has many chemical similarities (except for anomalously high Zr contents) with the Timber Top Volcanic Subgroup (*e.g.* Figure 11), implying derivation from magma of similar composition. The unit is far removed from the Timber Top Volcanic Subgroup, but the chemical data may indicate they are of similar age — and significantly older than the overlying ignimbrites of the Wakara Volcanic Subgroup.

Similarities between I-type volcanic rocks of the Featherbed Volcanic Group and granites of the Almaden and Ootann Supersuites

The late Carboniferous I-type rocks of the Featherbed Volcanic Group are very similar chemically to the Almaden and Ootann Supersuite granites (Figure 12) which intrude the volcanic rocks and crop out extensively in areas adjacent to the group — the I-type volcanic rocks with $>\sim 70\%$ SiO_2 closely resembling the relatively felsic Ootann Supersuite granites, and the more mafic I-type volcanic rocks the granitic rocks of the Almaden Supersuite. The main difference between the volcanic and granitic rocks is the slightly higher Y contents of the Almaden Supersuite granites (Figure 12). There is almost a complete overlap in chemical compositions in rocks containing $>60\%$ SiO_2, implying the late Carboniferous volcanic rocks are comagmatic with granitic rocks of the Almaden and Ootann Supersuites. Mafic volcanic rocks with SiO_2 contents of $<\sim 60\%$ SiO_2 are extremely rare in the late Carboniferous sequences. In contrast, mafic rocks with SiO_2 contents as low as $\sim 55\%$ SiO_2 are fairly common in the Almaden Supersuite (Figure 12). At least some of the mafic granitic units may, therefore, represent cumulates.

Source rock characteristics

Isotopic and other data have been interpreted to indicate the late Carboniferous I-type magmas were derived from a relatively old (~1500Ma) hydrous igneous source (Mackenzie, 1990; Black & McCulloch, 1990). Black & McCulloch (1990) presented Nd–Sm and $^{87}Sr/^{86}Sr$ isotopic data which indicate a significantly younger source was at least partly involved in the genesis of the A-type magmas. The A-type rocks are isotopically less evolved than the late Carboniferous I-types of the Featherbed Volcanic Group.

The isotopic and chemical data indicate the A-type magmas could not have been produced by melting of refractory residue remaining after the generation of the late Carboniferous I-type magmas.

Remarks

The advent of the Yongala Cauldron marked a profound change in the type and volume of volcanic detritus erupted from the Featherbed Cauldron complex. Rather than the relatively low-volume eruptions that characterised the late Carboniferous volcanic activity, the early Permian activity was distinguished by eruptions of large-volume, high-temperature (indicated by the abundance of rheomorphically deformed ignimbrite and vitrophyre) pyroclastic flows with a restricted compositional range.

Nychum Volcanics

The Nychum Volcanics contain a diverse range of rock types (Table 3; Bultitude & others, 1995, 1996b) which contrast markedly with the silicic volcanic rocks of the adjacent Wakara Volcanic Subgroup (Featherbed Volcanic Group), of about the same age. The majority of the volcanic rocks analysed are either rhyolites or andesites (Figure 13). Rhyolitic lava flows are concentrated in the upper part of the formation in the south-east. Numerous andesitic and rare basaltic and dacitic lava flows crop out in the basal (oldest) part, as well as scattered thin layers of rhyolitic pyroclastic deposits (mainly airfall tuff). In contrast, rhyolitic ignimbrite is relatively common in the north-western (youngest) part of the unit, and basic to intermediate lava flows have not been found. The volcanic rocks in the south-east are cut by numerous north-westerly trending dykes of aphyric to porphyritic rhyolite and much scarcer vitric andesite and dacite (Morgan, 1968a; Bultitude & others, 1995).

Age

Fossil plant flora in an irregularly bedded volcanic sandstone (tuff) which crops out in Elizabeth Creek ~2.5km west-north-west of Nychum homestead indicate the unit is early Permian (Rigby, 1993). Supporting evidence is provided by a recent SHRIMP age of 277±4Ma yielded by a sample of rhyolite lava from the bed of Elizabeth Creek (Bultitude & others, 1995, 1996b). This lava flow forms the upper part of the sequence in the Nychum area. The isotopic age is essentially identical to that

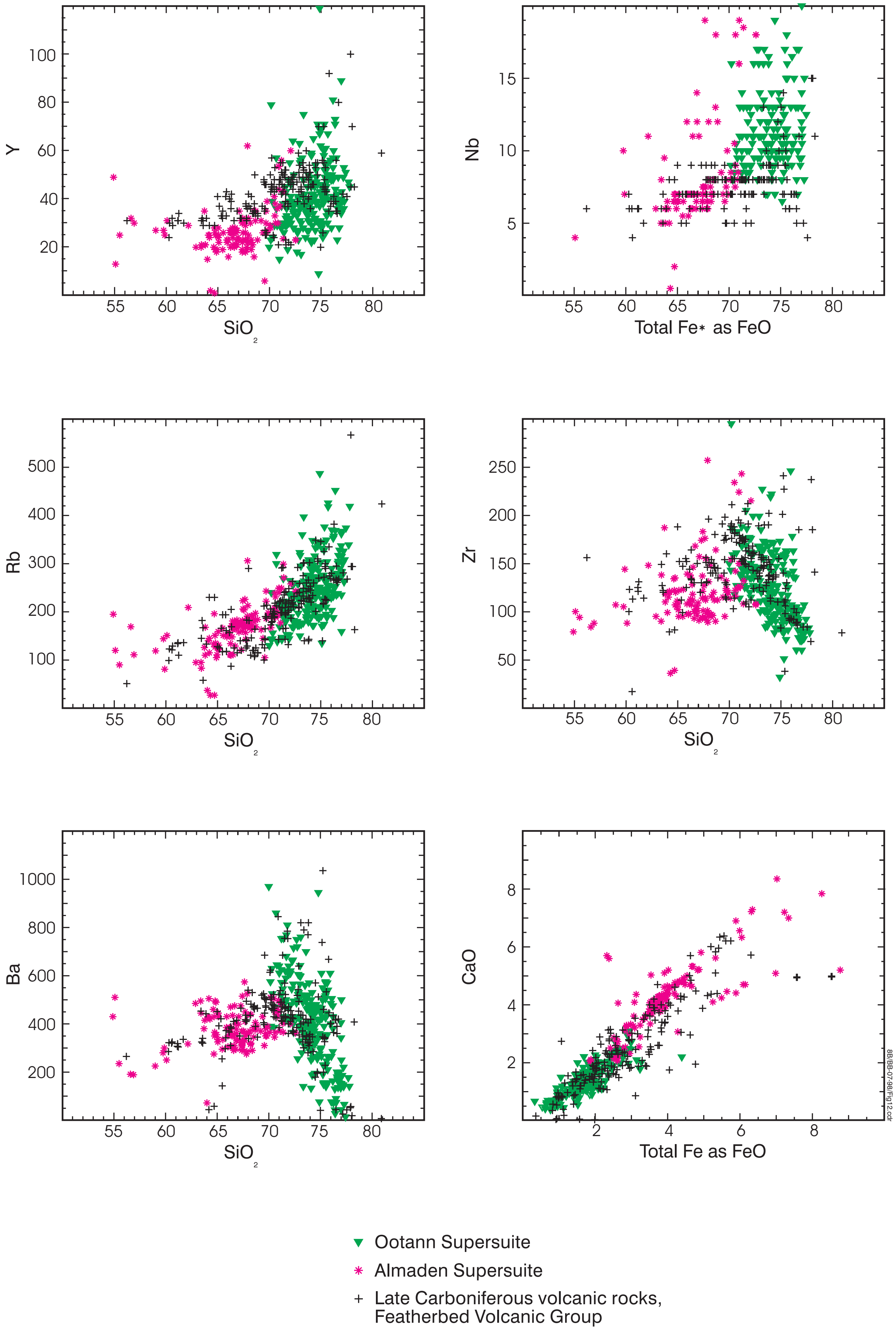


Figure 12. Selected variation diagrams highlighting the chemical similarities between late Carboniferous volcanic rocks of the Featherbed Volcanic Group and granites of the Almaden and Ootann Supersuites.

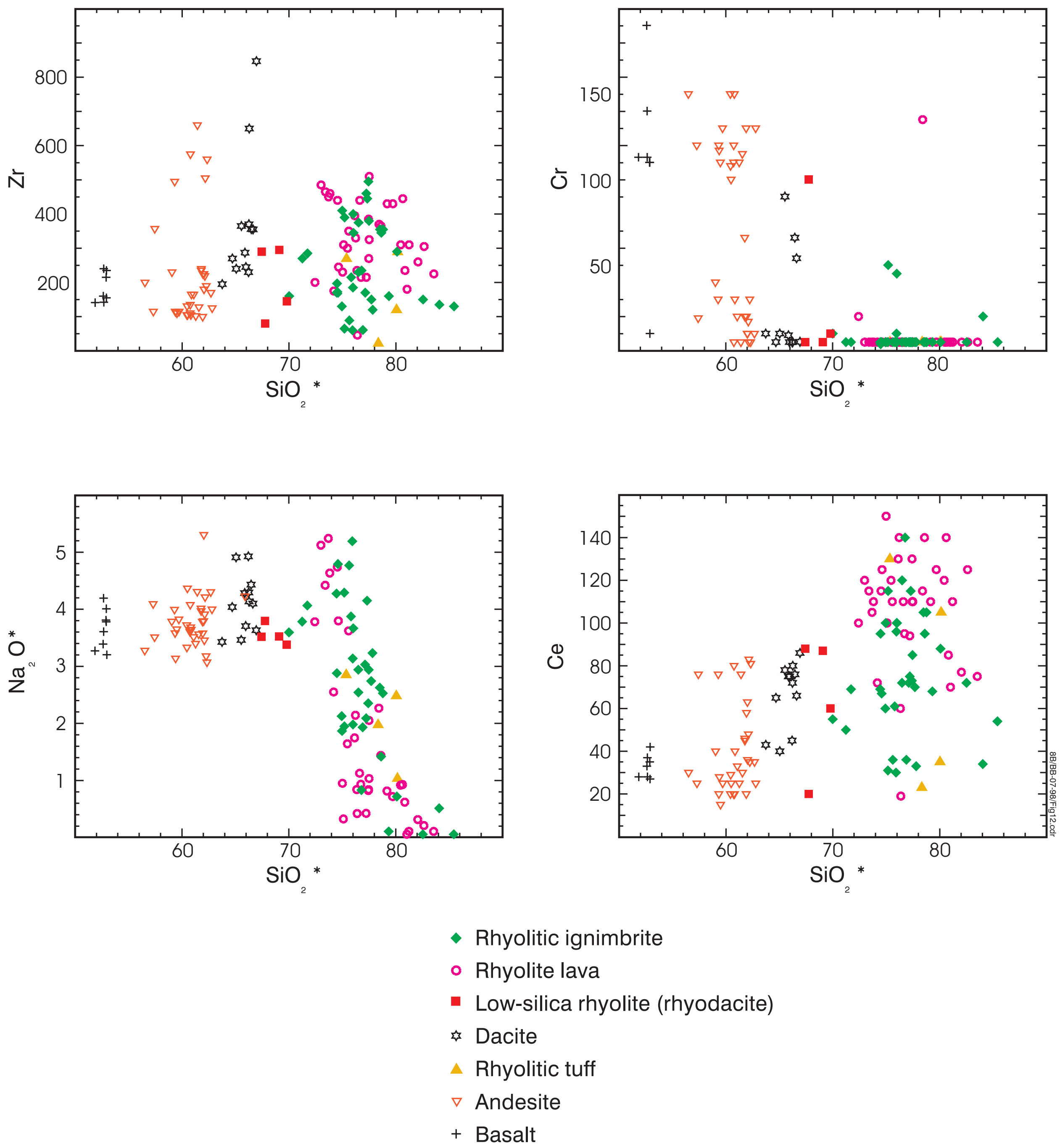


Figure 13. Zr, Cr, Na_2O, and Ce versus SiO_2 plots for the Nychum Volcanics. Note the anomalously high Zr contents of some andesites, dacites and rhyolites. Trace element abundances are in parts per million, major oxides in weight per cent (calculated anhydrous).

(278±3Ma, using Rb–Sr techniques) obtained for the Ticklehim Rhyolite, one of the youngest units in the nearby Wakara Volcanic Subgroup (Mackenzie & others, 1993).

The ring fault–dyke system bounding the Wakara Caldera, and which may be inferred to be ~280Ma (the age of infilling porphyritic microgranite; Mackenzie, 1993; Mackenzie & others, 1993), also reportedly truncates adjacent basic lavas of the Nychum Volcanics and the Ticklehim Creek Dyke Swarm (Morgan, 1974; B.S. Oversby, AGSO, personal communication, 1989; Mackenzie, 1993). The maximum age of the Nychum Volcanics in the south-east is constrained by the superposition of units ~2.5km east-south-east of Nychum homestead. In this area basic lava of the Nychum Volcanics overlies the late Carboniferous Nightflower Dacite (Featherbed Volcanic Group) and dacitic–rhyodacitic lava currently (and probably incorrectly) assigned to the Wakara Volcanic Subgroup. Recently obtained analyses of samples from the lava flow indicate it is not an A-type, and that it is chemically similar to late Carboniferous I-types of the Featherbed Volcanic Group. The lava flow, therefore, may form part of the

Nightflower Dacite succession. The Nightflower Dacite has yielded a Rb–Sr isotopic age of 308±4Ma (Mackenzie, 1993).

The Nychum Volcanics are overlain in the west by the late Jurassic?–early Cretaceous Gilbert River Formation (of the Carpentaria Basin succession).

Characteristics

The intermediate to basic lava flows in the south-east are commonly interlayered with rhyolitic tuff. The absence of rhyolite lavas from this, the oldest part of the unit implies the silicic volcanic activity was either:

(1) entirely explosive with the production of mainly pyroclastic airfall deposits (and possibly some thin pyroclastic flow and surge deposits), or

(2) centred in the area of the adjacent Featherbed Cauldron complex where it may have been associated with the production of voluminous silicic ignimbrites of the early Permian Wakara and/or Djungan Volcanic Subgroups.

The Nychum Volcanics differ in several significant aspects from the adjacent Featherbed Volcanic Group of about the same or slightly older age. There are no obvious subsidence structures and the succession is very thin compared with the Featherbed sequence. Intermediate to basic lava flows are concentrated in the oldest part of the unit and are much more abundant than in the Featherbed Volcanic Group. Rhyolite lavas are much more voluminous compared with those in the nearby Featherbed Volcanic Group and ignimbrites are significantly less abundant (and much thinner).

Geochemistry and presence of A-types

Geochemical data indicate the volcanic rocks form several distinct compositional groups which do not appear to represent a simple fractional crystallisation series (Bailey & others, 1982). Many of the silicic volcanic units (mainly lava flows, but also some rhyolitic ignimbrites), as well as some of the intermediate rocks, have A-type affinities (Figure 13; Bultitude & others, 1995, 1996b).

The single most diagnostic feature which distinguishes the A-type volcanic rocks of the Nychum Volcanics from the I-types is their relatively high Zr contents (Bultitude & others, 1995). These are interpreted to indicate the A-type volcanic rocks formed from higher temperature melts (with resultant higher zircon solubilities) than those which produced the I-type volcanic rocks. There is compelling field evidence to support such an interpretation. Individual lava flows of A-type rhyolite generally form tabular sheets rather than domes, and extensive obsidian zones are common. One lava flow of aphyric obsidian and devitrified obsidian, in particular, has a preserved length of ~8km; it is currently being investigated as a source of perlite. Another thick, tabular flow extends over ~80km^2. Some of the glassy silicic volcanic rocks contain crystals of fayalite, clinopyroxene, and orthopyroxene. These characteristics indicate high eruption temperatures, relatively low magma viscosities, and possibly high effusion rates and low volatile (particularly water) contents.

Rhyolite lava with A-type affinities in the north-west is interlayered with I-type silicic lavas. Both the A-type lava and underlying I-type lava have similar ε_{Nd} values, implying derivation from source rocks of similar age. The relatively high temperatures required to produce the A-types may have been initiated by mantle upwelling or basic magma influx in a relatively localised area (with respect to the Nychum Volcanics) during extension and/or underplating.

Although most of the rocks classified as A-types are rhyolites (SiO_2>70%), some of the more basic rocks in the formation also have A-type characteristics. The andesites (SiO_2~60–62%), in particular, form two distinct groups (calc-alkaline and tholeiitic; Bailey & others, 1982) on a Zr versus SiO_2 plot (as well as other plots). The calc-alkaline andesites are characterised by Zr contents of <300ppm and the tholeiitic andesites by Zr contents of between ~500ppm and 700ppm (Figure 13).

Nychum Volcanics compared to the Featherbed Volcanic Group, and Almaden and Ootann Supersuites

The Nychum Volcanics have significantly lower MgO, CaO and V contents than the granites of the Almaden and Ootann Supersuites and are chemically distinct. They are also lower in MgO than the Featherbed Volcanic Group rocks at equivalent SiO_2 contents, and significantly lower in V than the late Carboniferous rocks of the group. Volcanic rocks containing <~70% SiO_2 have significantly higher Na_2O than rocks of the Featherbed Volcanic Group and Almaden and Ootann Supersuite granites. Na_2O contents in the Nychum Volcanics show a marked inflection at ~70% SiO_2, and they decrease significantly at higher SiO_2 concentrations (Figure 13) — in contrast to the other three groups in which Na_2O does not change significantly with increasing SiO_2 contents.

KENNEDY PROVINCE — VOLCANIC ROCKS, COOKTOWN– CAPE TRIBULATION AREA

Little Forks Volcanics

An enigmatic unit of fine-grained silicic igneous rocks crops out over ~1km^2 near the junction of Parrot Creek and the Annan River (in COOKTOWN). Jones & others (1990) described the unit as a sequence of felsic lava flows and pyroclastic deposits. According to these authors the unit (referred to as the 'Little Forks acid volcanics' on their figure 1, page 1549) unconformably overlies the Hodgkinson Formation and is cut by rhyolite/microgranite dykes. The unit was assigned to the Little Forks Volcanics by Donchak & others (1992). A conflicting interpretation has been presented by Law (1989), who interpreted the unit as a high-level intrusive. The most noteworthy features of the few rocks examined by the writer are the xenomorphic granular groundmass textures, the general lack of obvious volcanic textures such as flow banding or eutaxitic foliation, and the pervasive alteration (reflected in the abundance of sericite and, to a lesser extent, tourmaline). The observed field characteristics and micro-textures imply these rocks probably form part of a very high-level intrusive complex. The unit is moderately deformed.

Obree Point Volcanics

The Obree Point Volcanics form scattered outcrops along the coast north of Cedar Bay and in the adjacent hinterland. The unit is poorly exposed away from the coast and its full extent is unknown. Flow banded and commonly autobrecciated, porphyritic dacite (several lava flows) is the dominant rock type in most outcrops examined. Other rock types recorded include andesite (lava), andesitic to dacitic tuff and lapilli tuff, volcanic breccia, and boulder conglomerate.

A sample from a dacite lava flow in the Obree Point area has recently yielded a SHRIMP age of 299±6Ma. The Obree Point Volcanics, therefore, are older than the middle to late Permian Normanby Formation, which crops out farther to the north-west. The unit also pre-dates the nearby late Permian granites of the Cooktown and Pieter Botte Supersuites — the presence of abundant fine secondary biotite (particularly in the dacite lava flows) implies the sequence has been thermally metamorphosed. Furthermore, the Bunk Creek Granite in the upper reaches of Slaty Creek has a chilled margin adjacent to the contact with the volcanic rocks, and contains inclusions of hornfelsed sedimentary and volcanic rocks.

Unnamed volcanic rocks in the Cape Tribulation area

Volcanic rocks of the Cape Tribulation area are very poorly exposed. Outcrops west of Cape Tribulation were briefly described by Ewart (1985) who regarded them as part of the Hodgkinson Formation. The extent of the unit is unknown. Andesitic tuff reported by Fawckner (1981, page 93) from the Cape Tribulation area, and interpreted by him to be part of the Hodgkinson Formation, probably also forms part of this unit. Similarly, hornfelsed volcanic siltstone containing altered glass shards (D.E. Mackenzie, AGSO, personal communication, 1995) at Alexandra Bay may also form part of the unit, rather than the Hodgkinson Formation.

The rocks examined by the writer on the ridge extending west from Cape Tribulation to the Mount Sorrow Tableland consist mainly of massive volcanic breccia. Clasts are dominated by aphyric to moderately porphyritic dacite, with subordinate andesite fragments, and scattered rounded fragments of arenite and volcanic siltstone and mudstone. The presence of scattered angular quartz grains in the matrix implies the sequence may have undergone some local reworking. Other rock types present include dacitic to andesitic tuff (laminated to medium bedded) and argillaceous siltstone.

The volcanic rocks in the Cape Tribulation area are tentatively correlated with the late Carboniferous–early Permian Obree Point Volcanics which crop out farther north, along the coast. The sequence is interpreted to pre-date the nearby late Permian Nulbullulul Granite. Rocks adjacent to the granite are extensively recrystallised and contain abundant fine metamorphic biotite and secondary amphibole, as well as rare tourmaline. Although the unit is altered and recrystallised it does not appear extensively deformed.

KENNEDY PROVINCE — GRANITES

Introduction

Numerous granite plutons, of late Carboniferous–Permian age, (Table 4 and Appendix 1) are exposed in the region. Many of the granites were emplaced along or adjacent to major north-westerly to northerly trending faults or shear zones. Most of the Permian S-type granites (*e.g.* the Desailly, Kelly St George and Cannibal Creek Granites), in particular, have pronounced north-westerly or northerly elongations. At least some of these S-type granites were apparently emplaced along or adjacent to major discontinuities in the Hodgkinson Province and underlying basement rocks during regional deformational events involving significant east-west shortening (Davis, 1993, 1994).

The late Palaeozoic granites are predominantly medium to high-level intrusions. A few (*e.g.* the Wabaredory Granite, Bilch Creek Granodiorite) intrude or are closely associated with volcanic rocks of about the same age, and may represent subvolcanic intrusions. Most plutons are surrounded by relatively narrow (generally <1.5km wide) contact metamorphic aureoles. The typical country rocks in the outermost parts of aureoles developed in the Hodgkinson Formation are indurated arenite, and mudstone and slate with mica-rich spots. Rocks in the inner parts commonly contain porphyroblasts of cordierite (generally altered) and andalusite, and rare garnet and staurolite (also Morgan, 1964a; Forsythe & Higgins, 1990).

The Cannibal Creek Granite is surrounded by an exceptionally well-developed aureole, 1–2km wide. The innermost 200–500m of the aureole consist mainly of andalusite schist. Altered cordierite and rare staurolite have been reported locally (Bateman, 1983, 1985a,b; Davis, 1993). Studies of the mineral assemblages in the metamorphic aureole of the Cannibal Creek Granite indicate formation at pressures of 200–300MPa (*i.e.* emplacement to a depth of ~7–10km; Bateman, 1985a). The Tinaroo Batholith is also partly enclosed by an anomalously wide zone of relatively high-grade (upper greenschist-upper amphibolite), regional metamorphic rocks (see previous section on the Barnard Province).

Emplacement of the granites of the Almaden Supersuite into calcareous rocks of the Chillagoe Formation resulted in extensive development of skarn rocks and marble; wollastonite is very common and tilleyite is present in places. Granodiorite adjacent to the calc-silicates was also extensively modified to (titanite–) diopside-bearing leucogranite or diopside–plagioclase rock.

CHILLAGOE–HERBERTON AREA

Introduction

The granites of this group, together with associated volcanic rocks, form a very extensive area of late Palaeozoic igneous rocks in eastern Australia. Several major supersuites have been defined by Champion (1991) and Champion & Chappell (1992). Some relatively small units, such as the intrusive rocks of the Gurrumba Ring Complex, have not been assigned to supersuites because of a lack of analytical data. The granitic rocks range from diorite to syenogranite; quartz-rich compositions predominate (Figure 14). The felsic supersuites are associated with significant mineralisation in the region.

O'Briens Creek Supersuite

The O'Briens Creek Supersuite comprises fractionated biotite granite and subordinate biotite leucogranite (Table 4 and Appendix 1), which crop out over ~2 500km^2 in the Cairns and Georgetown Regions. Granites of the O'Briens Creek Supersuite commonly form relatively large (>200km^2) plutons (*e.g.* the Emuford Granite) which are extensively intruded by finer grained granite and leucogranite.

Johnston & Black (1986) reported the ages of the granites of the Nettle and Go Sam Suites to be ~308Ma–314Ma. Black (1978) and Black & others (1978) reported Rb–Sr isotopic ages of ~309Ma–314Ma for granites and associated mineralisation in the Emuford and Herberton areas (but see Clarke, 1990, 1995). Black & others (1978) also recorded the presence of ~300Ma granite near Herberton. The data indicate the O'Briens Creek Supersuite granites adjacent to and east of the Palmerville Fault are mainly older than the granites of the Ootann and Almaden Supersuites in the same

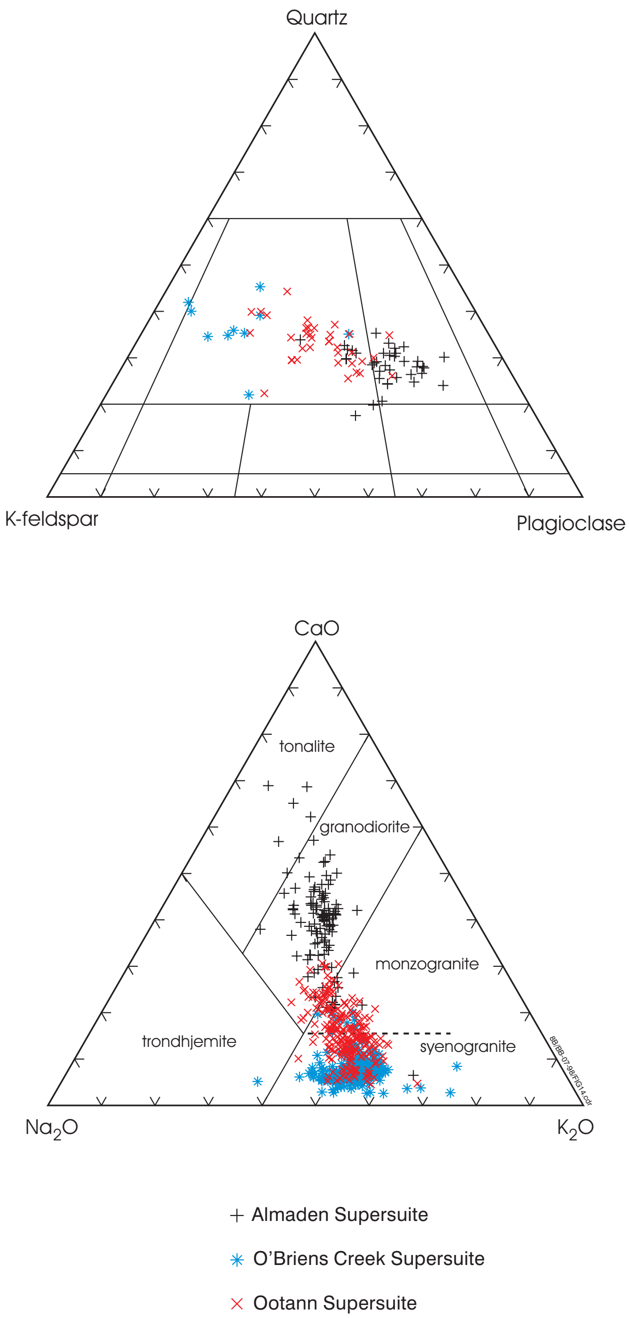


Figure 14. Modal and chemical classifications of late Palaeozoic I-type granites in the western part of the Cairns Region (including some data from Richards, 1981).

general area — the granites around Herberton apparently being exceptions (Clarke, 1990, 1995).

The O'Briens Creek Supersuite granites, as well as the more felsic members of the Ootann Supersuite, show widespread pervasive alteration of plagioclase, K-feldspar, and biotite, and extensive growth of minerals such as chlorite, secondary biotite, muscovite, albite, topaz and fluorite. These changes have been documented by Pollard (1984, 1988), Witt (1987), and Taylor & Pollard (1988) who deduced that they represent *in situ* interaction between grains and residual late-magmatic fluids. A significant result of the above studies is that the alteration essentially represented a closed system and was mainly isochemical at the scale at which the rocks were sampled for chemical analysis — *i.e.* element abundances and geochemical trends shown by the majority of the O'Briens Creek Supersuite granites reflect primary magmatic crystallisation processes. The granites of the Go Sam and Cherry Tree Suites are exceptions. According to Johnston & Black (1986) and Clarke (1995) these granites show evidence of hydrothermal alteration which resulted in significant element transfer.

Granites of the O'Briens Creek Supersuite are distinguished by their elevated Th, Zr, Y, Nb, F and HREE contents and Ca/Sr ratios compared with the other granites in the Chillagoe–Herberton area (Johnston & Black, 1986; Pollard, 1988; Champion, 1991; Figure 15). The granites are extensively mineralised. The elevated Sn and Nb, as well as F, Rb, U, Th, Ga, and Li abundances which characterise the late granites of the Go Sam Suite resulted mainly from extensive fractional crystallisation — the high Sn and Nb contents reflecting precipitation of cassiterite and columbite (Johnston & Black, 1986; Pollard, 1988; Champion, 1991).

Ootann Supersuite

The **Ootann Supersuite** is the most extensive of the supersuites in the Cairns Region; it also extends west of the Palmerville Fault. The granites of the Ootann Supersuite (Table 4 and Appendix 1) are generally more felsic (SiO_2>~70%) than those of the Almaden Supersuite; Figures 15 and 16). Rock types range from hornblende–biotite granodiorite to biotite leucogranite and aplite; (hornblende–) biotite granite predominates (Appendix 1; Figure 14).

Emplacement ages for members of the supersuite range from ~315Ma to ~290Ma (Appendix 1). Members of the supersuite (*e.g.* the Ootann Granite) which form extensive outcrops in the central part of the belt are about 300Ma and essentially of similar age to the nearby Almaden Supersuite granites — in most places where granites of the two supersuites are in contact, those of the Ootann Supersuite post date those of the Almaden Supersuite. Granites of the two supersuites are commonly closely associated spatially, implying they could be genetically related.

The granites of the Ootann Supersuite show a relatively restricted range in SiO_2 contents — from ~70 to 78% SiO_2 (Figure 15; Champion, 1991). The felsic members are slightly peraluminous. The supersuite (— also the O'Briens Creek Supersuite) is characterised by relatively high Rb, Rb/Sr and Ca/Sr, low Sr contents and Sr/Y and K/Rb ratios, large negative Eu/Eu*[11] anomalies, and evolved initial $^{87}Sr/^{86}Sr$ ratios and ε_{Nd} values (Champion, 1991; Champion & Chappell, 1992). More evolved members of the supersuite are depleted in TiO_2, FeO*, MgO, CaO, Ba, Sr, Sc, V, Cr, Ni, and Eu, and enriched in Rb, Pb, Th, and U. The Ootann Supersuite is distinguished from the O'Briens Creek Supersuite by significantly lower concentrations of HFSE[12], HREE[13] and F. Geochemical trends in these two supersuites were controlled by fractional crystallisation involving mainly plagioclase, together with some quartz and K-feldspar (in the most felsic units; Champion, 1991; Champion & Chappell, 1992).

Red Dome intrusive suite

The Cu–Au mineralisation at Red Dome mine, north-west of Chillagoe, is closely associated with high-level intrusive rhyolite–micro-granite (Torrey & others, 1896). The chemical affinities of these rocks are, therefore, of great interest to exploration companies. A complicating factor in classifying the Red Dome intrusive rocks is the extensive alteration displayed by most of them. Variable potassic alteration and, generally to a lesser extent, other styles of alteration (*e.g.* carbonate replacement, endoskarn development) are very widespread. Only the least altered samples have been plotted on the variation diagrams (Figure 16), using relatively immobile TiO_2 as the x-axis discriminant.

The intrusive rocks are highly fractionated, with elevated HFSE concentrations (*e.g.* relatively high Nb and Zr contents; Figure 16), and represent minimum melt compositions. They are too felsic and fractionated to be members of the Almaden Supersuite. Their relatively high Zr and Nb concentrations, in particular, imply possible affinities with the O'Briens Creek Supersuite (Figure 16). However, the intrusives are far removed from other members of the supersuite, which crop out much farther south. The Red Dome intrusive rocks almost invariably plot in, or adjacent to, zones where the fields defined by the members of the O'Briens Creek and Ootann Supersuites overlap — *i.e.* the intrusive rocks closely resemble more highly fractionated members of the Ootann Supersuite (Figure 16). The Ootann Supersuite is well represented in the Chillagoe area. Consequently, the Red Dome intrusive suite has been assigned to the Ootann Supersuite.

Almaden Supersuite

The granites of the **Almaden Supersuite** have a relatively restricted distribution compared with those of the other major Carboniferous supersuites. Individual plutons range in size from ~280km^2 (*e.g.* the Ruddygore Granodiorite east of Chillagoe) to <10km^2 (*e.g.* the Airport Quartz Diorite east of Mount Garnet).

The Almaden Supersuite consists predominantly of biotite-hornblende granodiorite (Figure 14) but also includes hornblende-biotite granodiorite, (hornblende-) biotite granite, tonalite, diorite, monzodiorite, and rare quartz monzonite (Figure 14; Table 4 and Appendix 1). Some of the more mafic units contain clino- and ortho-pyroxene, generally in trace amounts — and mainly as relict cores in hornblende grains. The Retire Monzodiorite is exceptional in that it contains hypersthene, augite, hornblende and biotite in roughly equal proportions (~10%).

Isotopic age data indicate most of the Almaden Supersuite granites are late Carboniferous (~300Ma–305Ma; Appendix 1). An exception is the Silver Pot Granodiorite (terminology of Champion & Heinemann, 1994; previously mapped as part of the Kalunga Granodiorite) exposed south-south-west of Herberton; this unit has yielded Rb–Sr biotite ages of 276Ma and 280Ma (Appendix 1; Black & others, 1978).

The granites of the Almaden Supersuite show a range in SiO_2 contents from ~55% to ~72% (Figure 15). The supersuite contains most of the mafic late Palaeozoic I-types exposed in the region. The Almaden Supersuite granites are distinguished from granites of the Ootann Supersuite by relatively high CaO and Sc contents, and low SiO_2, Na_2O, K_2O, Ce, Rb, Y, ASIs and Rb/Sr ratios. They typically contain

11 Eu/Eu* = $Eu_N/[(Sm_N + Gd_N)]$; N = chondrite normalised
12 HFSE = high field strength elements
13 HREE = heavy rare earth elements (Gd–Lu)

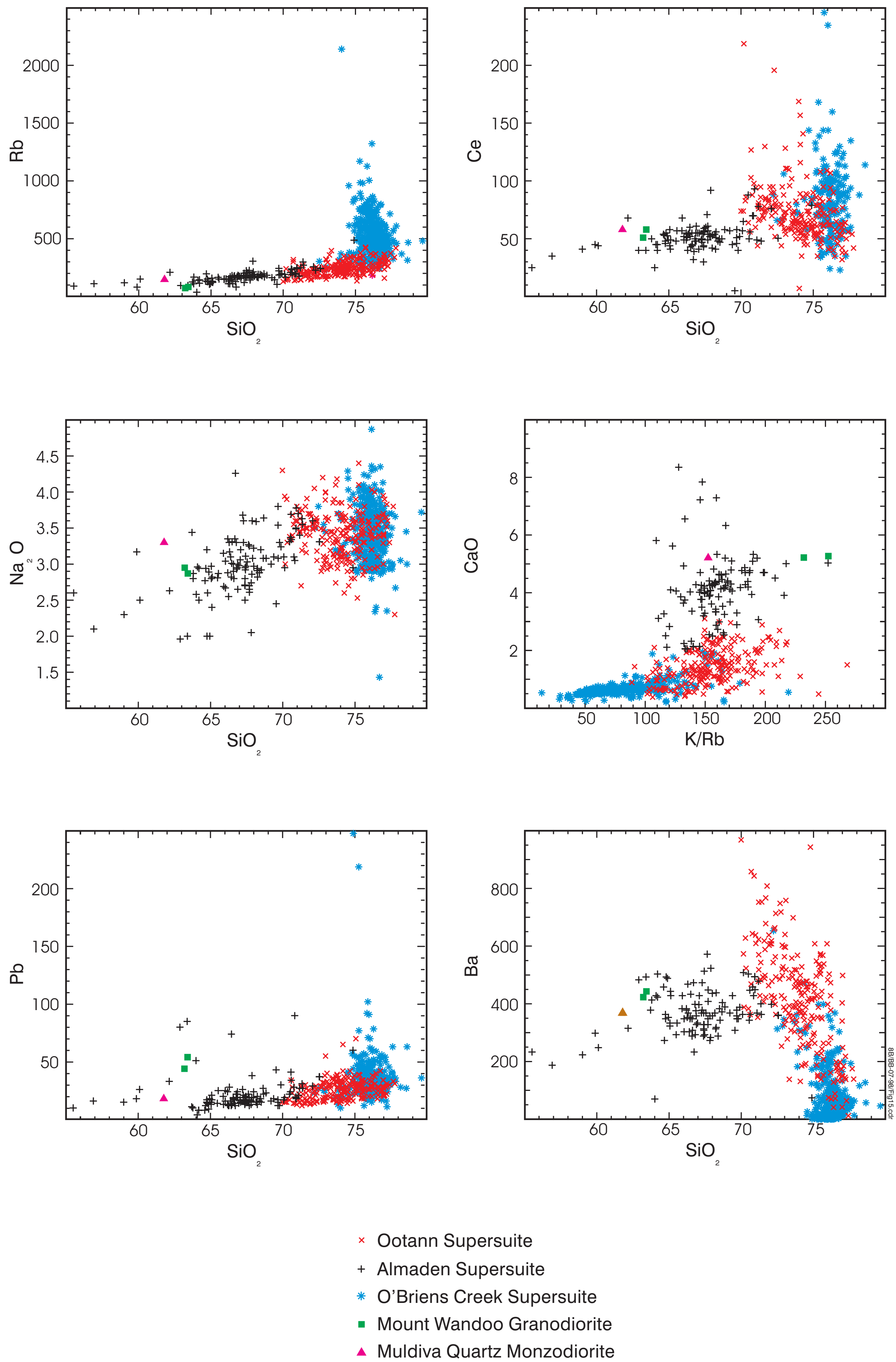


Figure 15. Variation diagrams showing chemical differences between granites of the Almaden, O'Briens Creek, and Ootann Supersuites. Also plotted for comparison is an analysis of the Mount Wandoo Granodiorite which crops out west of the Palmerville Fault and is spatially associated with significant gold mineralisation.

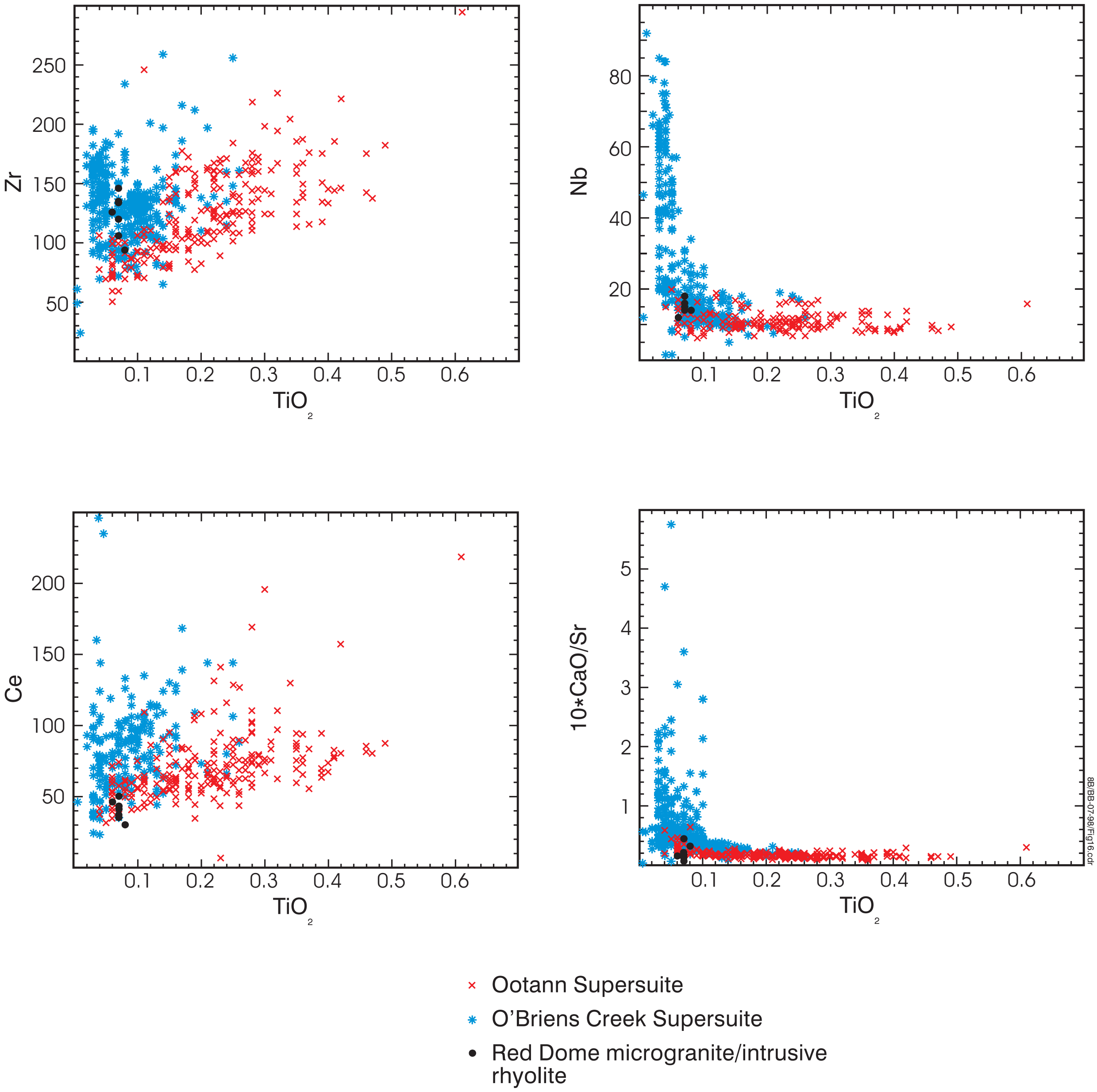


Figure 16. Zr, Nb, Ce (ppm), and CaO/Sr versus TiO_2 (wt%) plots for the O'Briens Creek and Ootann Supersuites and intrusive rocks in the area of Red Dome gold mine. Some of the analyses of the Red Dome intrusive rocks are from Woodbury (1994).

hornblende and relatively calcic plagioclase (compared to the Ootann Supersuite granites).

Some units of the supersuite (*e.g.* the Ruddygore Granodiorite) contain more felsic variants (SiO_2>72%) which were not delineated during the recent mapping. At least some of these, such as the felsic granite at the Ruddygore mine and the one forming Mount Coonbeta at Chillagoe, are similar chemically to Ootann Supersuite granites, and with more detailed mapping would probably have been delineated as part of that supersuite

Similarly, the Silver Pot and Kalunga Granodiorites, contain felsic rocks (*e.g.* 67490062R, 68590058, 7490064R1; Sheraton, 1974a,b) with chemical characteristics more in keeping with Ootann Supersuite granites.

The *Retire Suite* of the Almaden Supersuite is distinguished by anomalously high Pb contents (Figure 15). The suite is dominated by mafic rocks (diorites, monzodiorites — mainly of the Retire Monzodiorite and Prices Dam Igneous Complex). It may also include the pod of felsic granite (with >70% SiO_2 and >80ppm Pb; Figure 15) tentatively and, probably erroneously, assigned to the adjacent Wotan Granodiorite by Bultitude & others (1995). The *Mount Wandoo Granodiorite*, which crops out west of the Palmerville Fault in the Georgetown Region, is also a member of the Retire Suite. Granodiorite of the Prices Dam

Igneous Complex exposed at GR 2146 81318 has relatively high CaO and, to a lesser extent, Al_2O_3, Ga, Sc and Zn contents, and low K_2O, P_2O_5, ASI, Ba, La and Rb. These characteristics may reflect the presence of cumulate minerals — mainly calcic plagioclase.

Claret Creek Supersuite

The Claret Creek Supersuite is represented by units of the Claret Creek Ring Complex in the Cairns Region (Champion, 1991). The Claret Creek Ring Complex, comprising biotite and hornblende-bearing granodiorite and tonalite, biotite microgranite, and comagmatic rhyolitic volcanic rocks and dacitic ring dykes, has been described in detail by Bailey (1977). The Claret Creek Supersuite was emplaced in the late Carboniferous (Black, 1980).

SiO_2 contents in the granitic rocks of the Claret Creek Supersuite range from ~66% to 76%; both metaluminous and peraluminous varieties are represented (Bailey, 1977; Champion, 1991). The rocks of the complex are characterised by relatively high Al_2O_3, Na_2O, Sr, Sr/Rb, K/Rb and significantly lower K_2O, Rb, Th, U and Y contents compared with the granites of the Almaden, Ootann and O'Briens Creek Supersuites (Figures 6 and 17; Champion, 1991). The chemistry reflects the abundance of plagioclase and quartz in the rocks, and the scarcity of K-feldspar.

Gurrumba Ring Complex

The Gurrumba Ring Complex (Table 4; Blake, 1972), one of the largest unassigned units, has an elliptical outcrop ~5km long and up to ~3km wide in the south-western part of the region. It is made up of granophyre, olivine gabbro and a range of intermediate rocks, mostly of dioritic composition (Blake, 1972). The rocks are commonly intimately intermixed, forming net-veined complexes. The intrusive rocks are mainly concentrated in a ring dyke which encloses two small outcrops of porphyritic rhyolite lava (Blake, 1972).

Samples of olivine gabbro collected by the writer are characterised by exceptionally high CaO (~14%) and Al_2O_3 (~26–27%) contents, consistent with the presence of abundant highly calcic plagioclase (bytownite–anorthite). The gabbro is the clearest example of a cumulate in the region. The spatially associated silicic lava (Gurrumba Volcanics) and/or granophyre may represent complementary magma compositions.

The lack of chemical data has prevented the classification of the intrusive rocks into supersuites.

Hammonds Creek Granodiorite

The Hammonds Creek Granodiorite (Blake, 1972), which crops out south-west of Mount Garnet, was formerly assigned to the Almaden Supersuite (*e.g.* Champion, 1991). However, the available chemical data define two distinct fields on some variation diagrams. One group plots with the Almaden Supersuite for most elements and the other with the Claret Creek Supersuite (Figure 17). Notable exceptions are Na_2O and Sr. The Hammonds Creek Granodiorite generally contains significantly less Na_2O than the Claret Creek Supersuite rocks and plots with the Almaden Supersuite. Conversely, Sr contents are significantly higher in those samples of Hammonds Creek Granodiorite which closely resemble the Almaden Supersuite for most other elements (*e.g.* Figure 17). The chemical data imply the Hammonds Creek Granodiorite maybe a composite unit.

Lags Supersuite

Scattered dykes, lenses, and small plutons (Table 4 and Appendix 1) of early Permian (~280Ma) and probable early Permian (Maneater Granodiorite) microgranite cut the Featherbed Volcanic Group and adjacent units. These microgranites have extensively infilled ring fractures bounding the major cauldron subsidence areas in which the volcanic rocks accumulated. They range in composition from biotite microgranite to hornblende–biotite microdiorite (Bultitude & others, 1993a; Mackenzie & others, 1993), and are generally slightly to highly porphyritic. Phenocrysts consist mainly of quartz (locally embayed), K-feldspar, and plagioclase.

Hornblende and biotite in various proportions are the typical mafic minerals, although hornblende is absent from the more silicic units, such as the Lags Microgranite. A noteworthy feature is the complex mineralogy displayed by the more mafic granites and the granodiorites — *e.g.* the Saint Helena Monzogranite. This unit contains minor hypersthene and garnet and rare augite, as well as hornblende and biotite, and there are

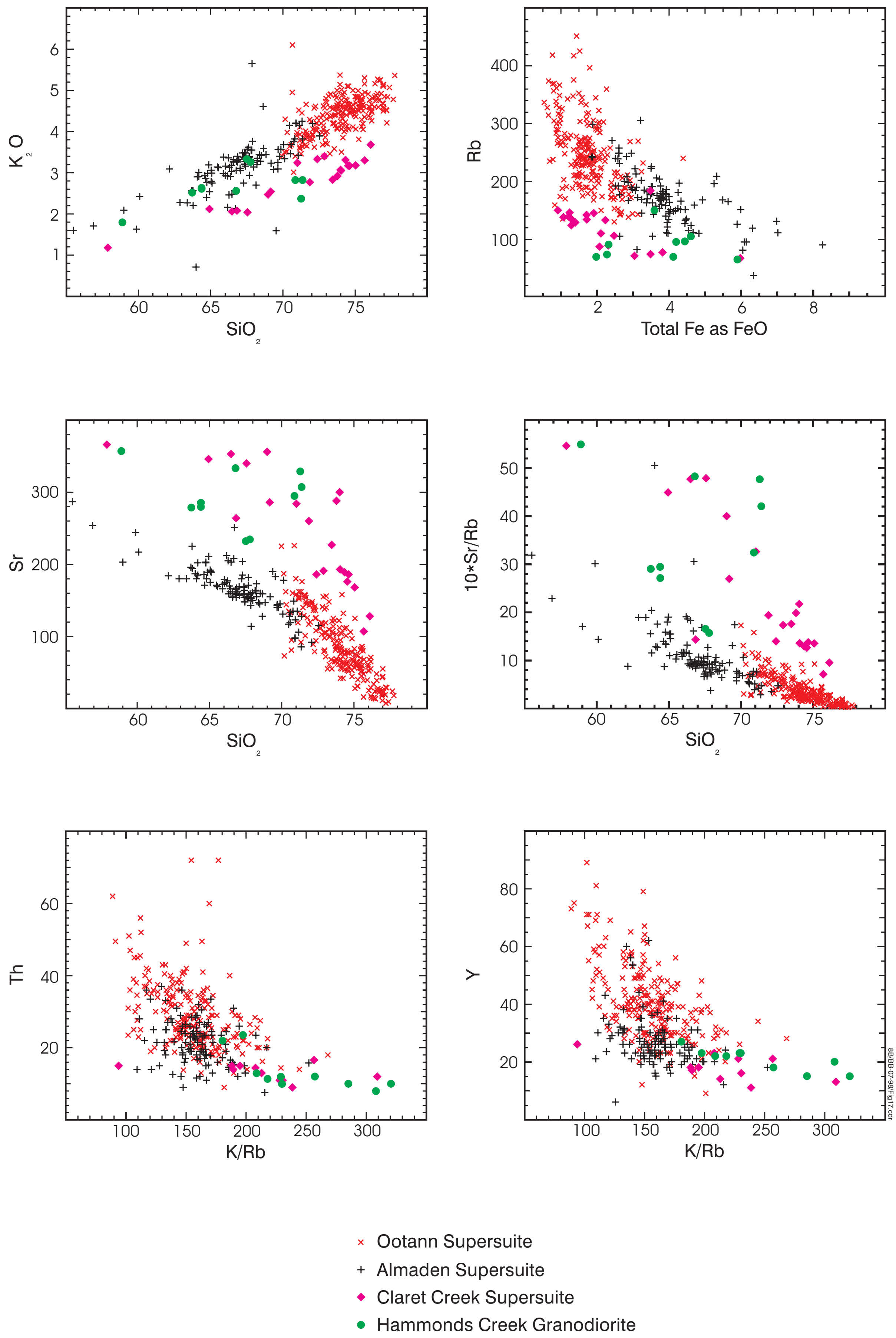


Figure 17. K_2O and Rb versus FeO, Sr and Sr/Rb versus SiO_2, and Th and Y versus K/Rb plots for the Almaden, Claret Creek and Ootann Supersuites and Hammonds Creek Granodiorite. Oxides are in wt%, trace elements in ppm. Plots include data from Bailey (1969, 1977), Sheraton (1974), Richards (1981), and Champion (1991). The Claret Creek Supersuite includes extrusive rocks of the Claret Creek Ring Complex.*

generally complex reaction relationships between the various mafic minerals.

The Timber Top Volcanic Subgroup is intruded by several high-level comagmatic plutons ranging in composition from granodiorite to granite (Figure 11). These plutons have been mapped as the **Maneater Granodiorite** (Mackenzie & others, 1993; Bultitude & others, 1996b). The mafic minerals consist mainly of hornblende and biotite; more mafic units also contain traces of clinopyroxene and orthopyroxene, as well as rare garnet (also Mackenzie & others, 1993). Apatite is relatively common. Some plutons are characterised by granophyric textures.

Chemical characteristics

The microgranites are distinguished chemically by relatively high Ba and Zr contents, moderately high Ce, Y, Zn and Ga concentrations, and high Ga/Al ratios (Figure 11). They are only slightly fractionated or unfractionated (Figure 11) and are A-types (Mackenzie, 1990; Bultitude & others, 1993a). Furthermore, the intrusive rocks have compositions strikingly similar to those of the early Permian volcanic rocks (A-types) of the Featherbed Volcanic Group (Bultitude & others, 1993a; Figure 11), with which they are closely associated. These similarities in composition and age indicate the volcanic rocks and high-level intrusives are genetically related (comagmatic).

Most of the analysed samples of Maneater Granodiorite are chemically distinct from the other analysed early Permian, A-type, high-level intrusive units (Lags Microgranite, unnamed unit Pmg, Yokas Microgranite) which intrude rocks of the Featherbed Volcanic Group farther to the west and south-west (Figure 11).

KENNEDY PROVINCE — CAIRNS–CAPE MELVILLE AREA

Emerald Creek Supersuite

The Emerald Creek Supersuite comprises one mapped unit — the Emerald Creek Microgranite (Figure 18). The Emerald Creek Microgranite crops out in the south-western part of the Tinaroo Batholith and contains biotite and muscovite in roughly equal amounts. The contact between the microgranite and metasedimentary rocks

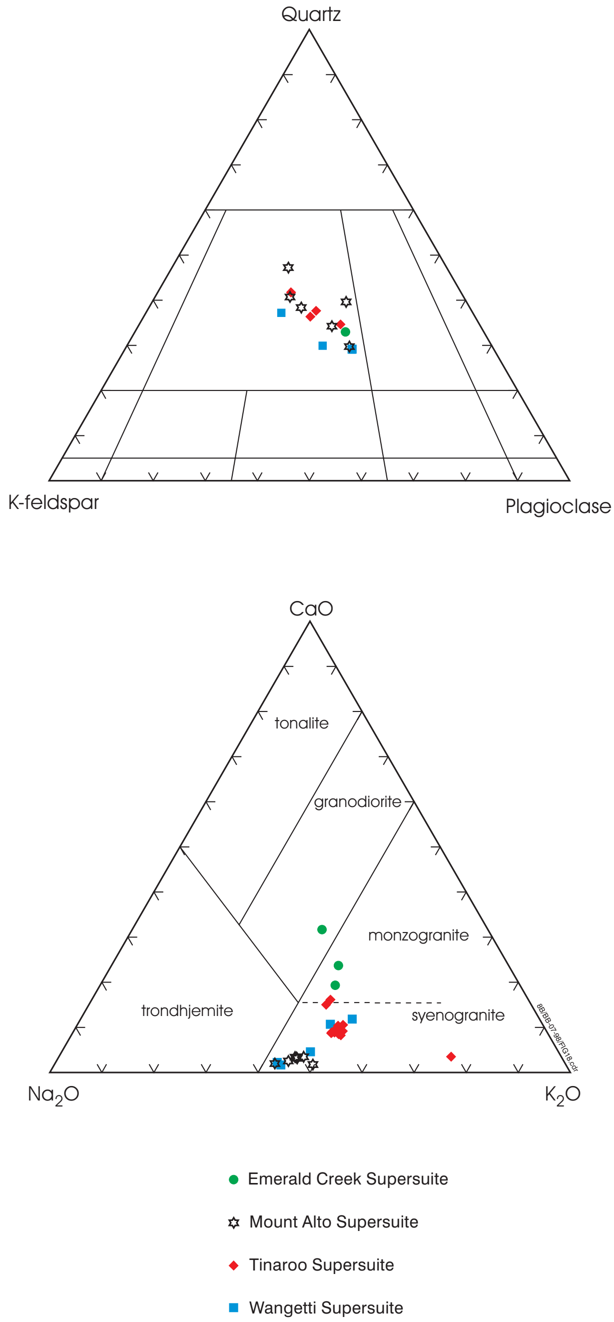


Figure 18. Modal data for granites from the minor S-type supersuites of the central and eastern Cairns Region.

mapped as part of the Hodgkinson Formation is reported to be shallowly dipping (Mancktelow, 1974, 1982; Rubenach & Bell, 1988). According to Mancktelow the shallow dip resulted in the development of a diffuse contact zone, up to ~300m wide, containing high-grade regional metamorphic rocks. The age of the Emerald Creek Microgranite is uncertain. The unit may be significantly older than the nearby granites of the Tinaroo and Whypalla Supersuites.

Despite mineralogical similarities, the Emerald Creek Microgranite is geochemically distinct compared with units of similar SiO_2 contents in the Tinaroo and Whypalla Supersuites (Table 5;

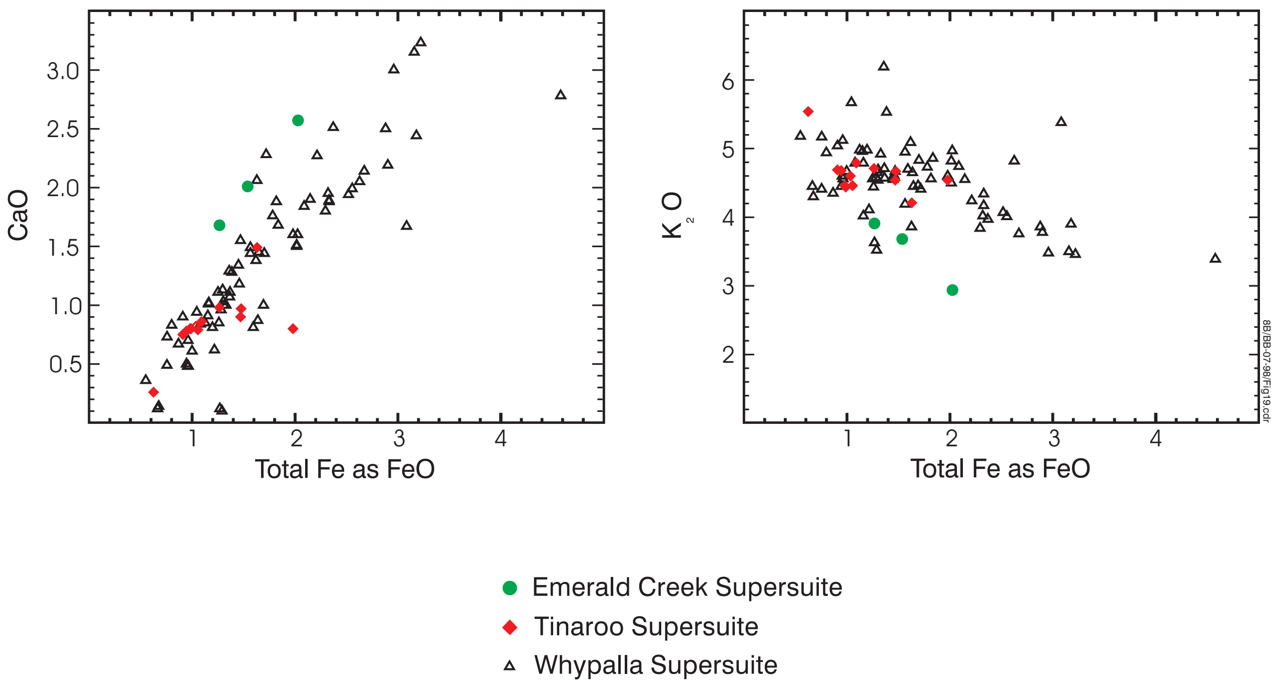


Figure 19. CaO and K_2O versus FeO (wt%) plots for the Emerald Creek, Tinaroo and Whypalla Supersuites. Granites of these supersuites are closely associated spatially in the south-eastern part of the Cairns Region.*

Champion, 1991). The Emerald Creek Microgranite is characterised by relatively high CaO and MgO contents and mg-values, and low K_2O, Y, and Agp[14] (Figure 19).

Tinaroo Supersuite

The Tinaroo Supersuite also consists of one unit — the composite Tinaroo Granite (Rubenach & Bell, 1988; Willmott & others, 1988; Table 4; Figure 18). The Tinaroo Granite has yielded K–Ar biotite and muscovite ages (corrected for spike and calibration errors) ranging from 268Ma–283Ma and Rb–Sr ages in the range from 253Ma–285Ma (most calculated using assumed initial $^{87}Sr/^{86}Sr$ ratios in the range from 0.710–0.715) (Richards & others, 1966; Black, 1978, 1980; Champion, 1991). The majority are in the 270Ma–280Ma range (Bultitude & Champion, 1992). They indicate the unit is most probably early Permian and about the same age as units in the Whypalla Supersuite. The relatively young K–Ar dates probably represent reset or partially reset ages which resulted during subsequent deformation(s) during the Hunter–Bowen Orogeny.

The Tinaroo Granite has similar mineralogical, petrographic and geochemical characteristics to units in the Whypalla Supersuite (*e.g.* Figure 19, Table 5) and possibly should be included in that supersuite. However, despite these similarities, the unit is distinct isotopically. The Tinaroo Granite is characterised by a primitive ε_{Nd} value (-2.01, at 280Ma) compared with members of the Whypalla Supersuite (-3.85–6.43, at 280Ma; Champion, 1991; Champion & Bultitude, 1994).

Whypalla Supersuite

Granites of the Whypalla Supersuite (Table 4 and Appendix 1) form an extensive north-westerly trending belt in the central and eastern parts of the Hodgkinson Province. The Whypalla Supersuite corresponds mainly to the Mareeba and Cannibal Creek Granites of Amos & de Keyser (1964) and de Keyser & Lucas (1968). The units consist predominantly of (garnet–tourmaline–muscovite–) biotite granite, cut by scattered dykes and pods of microgranite. Many of the units, particularly the Mount Carbine and Whypalla Granites, have several textural and compositional variants. Most of these probably represent discrete plutons. Rare screens of hornfelsed country rocks are present locally between adjacent plutons. The presence of early crystallised garnet, rare sillimanite, interstitial apatite, and tourmaline, together with their peraluminous character indicates the Whypalla Supersuite granites are most probably S-types. The relatively mafic McLeod Granite is anomalous. Although it has been classified as an S-type, some orthopyroxene grains in the granite have relict cores of clinopyroxene. The presence of clinopyroxene may indicate some

14 Agp = Agpaitic Index = Al/(Na + K) (molecular)

Table 5. Geochemical characteristics of S-type granites of the eastern Hodgkinson Province (modified from Champion, 1991).

Mount Formartine Supersuite	relatively high Rb; low CaO, K_2O, Pb, Th, Zr, Y, La, Ce	
Emerald Creek Supersuite	relatively high CaO, MgO, mg[1]; low K_2O, Y, Agp[2]	
GROUP 1 relatively high CaO, Sr, Ba; low Rb, V		
Tinaroo Supersuite	relatively high Y; low K_2O, Ga; primitive ε_{Nd}	
Mount Alto Supersuite	relatively high Nb, Sc, Mn, Zn, Ga; low Y	
Whypalla Supersuite	relatively high Y; low Nb, Sc, Mn, Zn, Ga	
	Cannibal Creek Suite	relatively high P_2O_5, MgO, mg, $(Ce/Y)_N$[3]; low Y
	Curraghmore Suite	relatively high Y, La, Ce, $(Ce/Y)_N$
	Mount Pike Suite	relatively high Y; low Pb, Th, La, Ce, $(Ce/Y)_N$
	Whypalla Suite	relatively high Y; low $(Ce/Y)_N$
	Mount Carbine Suite	relatively low Zr, Pb
	Mareeba Suite	relatively high Ni; low Pb, Zr, Ga
GROUP 2 relatively high TiO_2, Rb, V; low CaO, Sr, Ba		
Wangetti Supersuite	relatively high Al_2O_3, P_2O_5, Zn, Nb, Ga; low K_2O, Y	
Cooktown Supersuite	relatively high K_2O, Y; low P_2O_5, Nb, Ga	
	Cooktown group relatively high Al_2O_3, CaO, Ba, Sr, V; low U	
	Cooktown Suite	high MgO, mg, P_2O_5, Cr; low Y
	Mount Hartley Suite	high La, Ce, Th, Zr
	Waterfall Suite	high ASI, low Agp
	Collingwood group relatively high K_2O, Y; low P_2O_5, Nb, Ga	
	Collingwood Suite	high Na_2O, K_2O; low ASI, Cr, Zn
	Big Tableland Suite	high Nb; low Zn
	Roaring Meg Suite	high Zn; low Nb
	Mount Poverty Suite	high Nb, Zn, Ga

1 mg = mg-value = 100MgO/[MgO + FeO + .8998Fe_2O_3] (molecular)
2 Agp = Agpaitic Index = Al_2O_3/(Na_2O + K_2O) (molecular)
3 $(Ce/Y)_N$ = Ce/Y, with both Ce and Y normalised to chondrite abundances

mixing or mingling between S- and I-type magmas to generate the McLeod Granite.

Miarolitic cavities have been detected in a few units (*e.g.* the Kelly St George and Koobaba Granites). Their relative scarcity compared with the granites of the Cooktown Supersuite may imply slightly deeper levels of emplacement.

Age

The granites of the Whypalla Supersuite have yielded a relatively wide range of isotopic ages (Richards & others, 1966; Black, 1978; Forsythe & Higgins, 1990; Bultitude & Champion, 1992; unpublished data). Most are in the range from ~275Ma to 285Ma — these are probably close to the crystallisation ages. Partial to complete resetting during the Hunter–Bowen Orogeny (in the late Permian–Triassic) is reflected in some of the K–Ar and Rb–Sr dates. The Mount Pike Granite, for example, has yielded an anomalously young Rb–Sr age of 255±2Ma and an even younger K–Ar age (240±2Ma; Bultitude & Champion, 1992). A SHRIMP age of 284±4Ma was subsequently obtained from another portion of the same bulk sample from which the specimen used for the K–Ar dating was obtained. This is interpreted to be the crystallisation age of the unit.

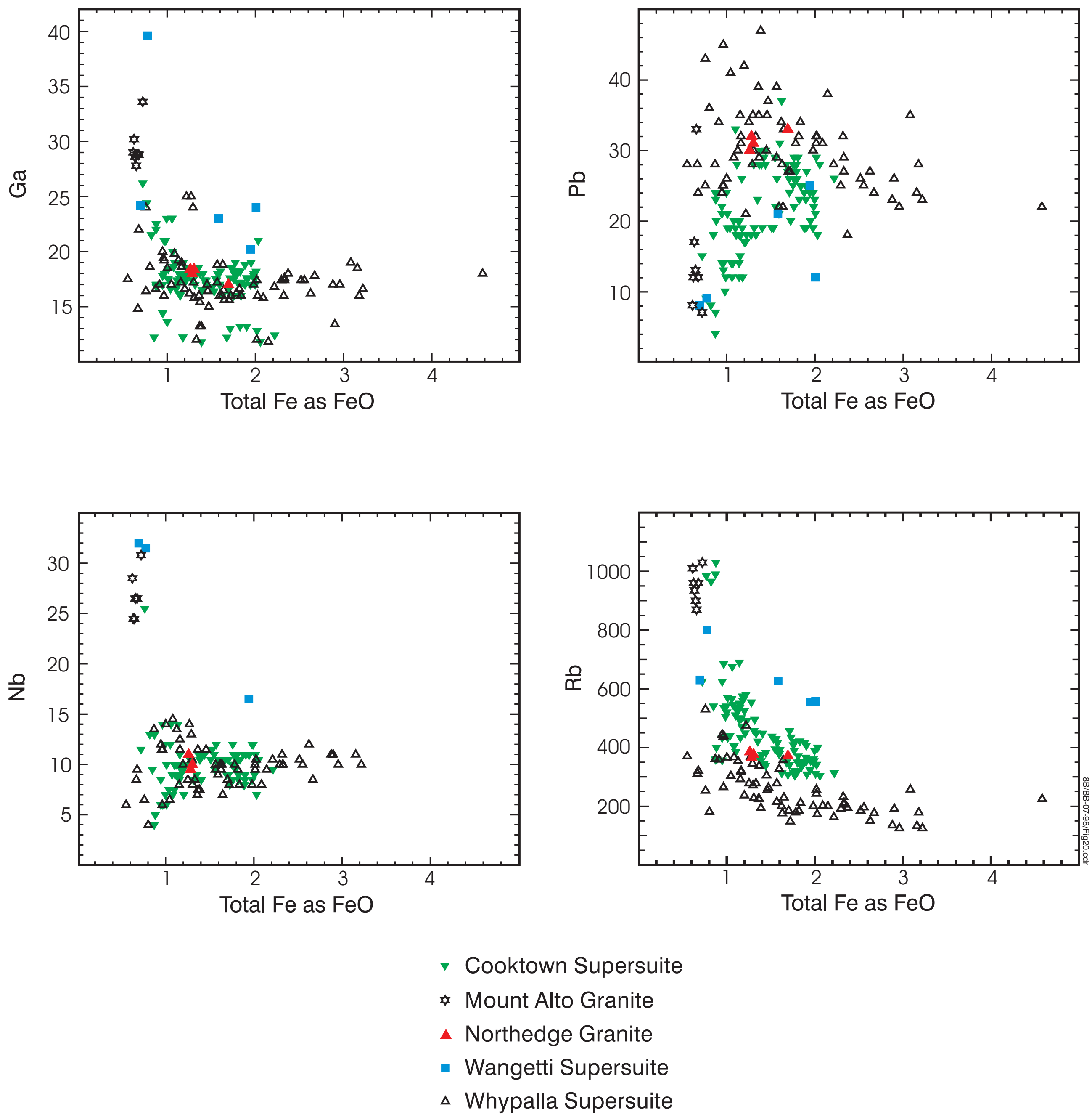


Figure 20. Geochemical plots for selected S-type granites of the eastern Hodgkinson Province. The plots show the similarities between the Northedge Granite and granites of the Whypalla Supersuite and the highly fractionated character of the Mount Alto Granite (Mount Alto Supersuite).

Bateman (1983, 1989) recorded a Rb–Sr age of 270Ma for the Cannibal Creek Granite and interpreted it as a reset Devonian crystallisation age. There is little or no field evidence to support this hypothesis. Another sample collected during the recent survey has yielded a Rb–Sr whole rock–biotite age of 275Ma. SHRIMP analyses of zircons from the same bulk sample yielded an age of 299±5Ma. This date is thought to represent a mixed age resulting from the presence of only very narrow rims of younger (early Permian) magmatic zircon on cores of older (inherited) zircon.

Chemical characteristics

The slightly to moderately peraluminous granites of the Whypalla Supersuite are characterised by (at similar FeO* contents) higher CaO, Ba, Sr and Pb concentrations and K/Rb ratios, and lower P_2O_5, TiO_2, Rb, V, Cr, Cu, and Sn contents (Figure 20; Champion, 1991; Champion & Bultitude, 1994) compared with the granites of the Cooktown Supersuite (Table 5). A few felsic, highly fractionated granites and microgranites show element enrichments and depletions similar to those displayed by the Cooktown Supersuite. The geochemical trends displayed by the Whypalla (and Cooktown) Supersuite granites (*e.g.* increasing Rb and Rb/Sr ratios, and decreasing Ba and K/Rb ratios with decreasing FeO*) imply fractional crystallisation (involving mainly feldspars) played a major role in their evolution.

The geochemical characteristics of the supersuite are consistent with derivation from an immature, relatively Ca-rich supracrustal source (Champion, 1991; Champion & Bultitude, 1994).

Mount Alto and Wangetti Supersuites

The S-type Mount Alto and Northedge Granites which crop out over relatively small areas south of Mount Carbine were originally assigned to the Mount Alto Supersuite (Champion, 1991; Champion & Bultitude, 1994). However, additional mineralogical and geochemical studies indicate the Northedge Granite closely resembles granites of the Whypalla Supersuite (*e.g.* Figure 20). Consequently, the Northedge Granite is assigned to the Whypalla Supersuite in this report. Both granites were previously mapped or described as part of the Mareeba Granite (Morgan, 1964a; de Keyser & Lucas, 1968; Sheraton & Labonne, 1974, 1978).

The Wangetti Granite, the sole member of the Wangetti Supersuite, was delineated as a unit distinct from the Mareeba Granite by Willmott & others (1988). Willmott & others interpreted the unit as a zoned pluton with a relatively mafic core of porphyritic muscovite–biotite granite (subunit $Prgw_2$) and a more extensive rim of even-grained, leucocratic tourmaline–muscovite granite (subunit $Prgw_1$). The latter is very similar mineralogically (and chemically) to the Mount Alto Granite (*e.g.* Figures 20 and 21). They share the distinction of being the only granites in the eastern Hodgkinson Province in which biotite is very scarce or absent and tourmaline displays textural features indicative of having crystallised early. The Mount Alto Granite also contains traces of manganiferous garnet, whereas garnet has not been detected in the Wangetti Granite.

The S-type granites of the Mount Alto and Wangetti Supersuites are characterised by marked element enrichments and depletions compared with the granites of the Whypalla and Cooktown Supersuites — the two major S-type groups in the region. The Mount Alto Granite is one of the most highly fractionated granites in the eastern Hodgkinson Province, analysed samples containing >800ppm Rb (Figure 20).

The geochemical trends shown by the granites of the Mount Alto and Wangetti Supersuites are mainly due to fractional crystallisation processes. They are similar to those documented for many other highly fractionated S-type magmas (*e.g.* Pichavant & others, 1987, 1988a, b; Mackenzie & others, 1988; Kontak, 1990; Manning & Hill, 1990). The granites are moderately to highly peraluminous; the ASI ranges from 1.1 to >1.2 in the most highly evolved rocks.

Major element trends displayed by the Mount Alto and Wangetti Supersuites are similar to those shown by the Cooktown Supersuite granites (*e.g.* Figure 21). TiO_2, CaO and MgO decrease to very low amounts with decreasing FeO*. P_2O_5 increases markedly in the Wangetti Supersuite (Figure 21) so that the CaO/P_2O_5 ratio approaches unity in the most highly fractionated rocks. In contrast, P_2O_5 contents do not change markedly with fractionation (*e.g.* increasing Rb) in the Mount Alto Supersuite. However, they do not decrease to the very low amounts found in highly fractionated I-type granites — *e.g.* Carboniferous I-type granites in the Chillagoe–Herberton area to the south and south-west (Champion & Chappell, 1992).

Trace element trends defined by the granites of the two supersuites are similar to, but more pronounced than, those delineated by most granites of the Cooktown and Whypalla Supersuites. Rb, Rb/Ba, Rb/Sr, Cs, U, Nb, Ta, Sc, Mn, Zn, Ga, and Sn increase markedly and Ba, Sr, Pb, Th, Zr, Hf, Y, HREE, LREE, $(Ce/Y)_N$, Eu, V, Cr, Ni, and K/Rb significantly decrease with increasing differentiation in these granites (*e.g.* Figures 20 and 21; Champion, 1991; Champion & Bultitude, 1994).

Bellenden Ker Granite/Bellenden Ker Supersuite

Units (including the I-type Bartle Frere Granite) forming the Bellenden Ker Batholith (Willmott & others, 1988; Bultitude & Champion, 1992) had been mapped as part of the Mareeba Granite by de Keyser & Lucas (1968). Willmott & others (1988) subsequently mapped the northern half of the batholith and delineated the Bellenden Ker Granite as well as several unnamed, informal units.

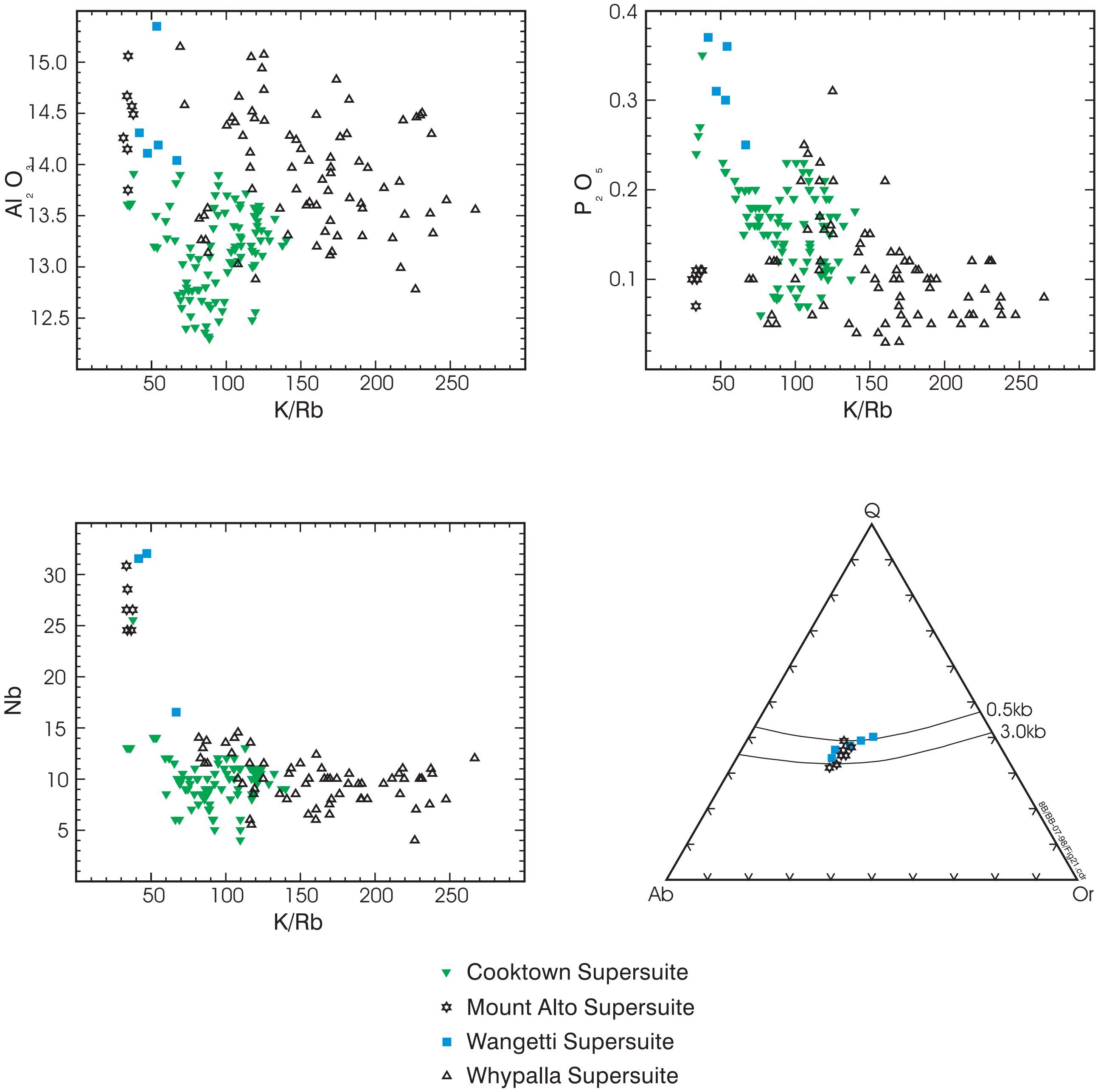


Figure 21. Al_2O_3, P_2O_5 (wt%), and Nb (ppm) versus K/Rb, and normative Q–Ab–Or plots for the Wangetti and Mount Alto Supersuites. Note the evolved character of the granites of these two supersuites compared to the Cooktown and Whypalla Supersuites; and also the contrasting behaviour of P_2O_5 in the two supersuites.

As currently mapped, most of the Bellenden Ker and Malbon Thompson Ranges consist of the *Bellenden Ker Granite* (Table 4 and Appendix 1; Willmott & others, 1988). The unit comprises extensive outcrops of mainly variably and commonly extensively deformed (mylonitised), coarsely and highly megacrystic, relatively biotite-rich granite. Scattered pods of finer grained, more even-grained, felsic (garnet-altered cordierite?–tourmaline–muscovite–) biotite granite are common around the margins of the megacrystic granite, particularly in the northern part of the Bellenden Ker Range and at Bessie and Palmer Points. Walshs Pyramid, for example, consists of medium-grained, even-grained to only slightly porphyritic (tourmaline–muscovite–) biotite granite (*Walshs Pyramid Granite*; Bultitude & others, 1998a) which is significantly more felsic than the type Bellenden Ker Granite. Probably all of these felsic intrusions post-date the latter but their extents and relationships with adjacent plutons have not been established in most cases. These units, with the exception of the Walshs Pyramid Granite, are included in the Bellenden Ker Granite on recent maps.

The Bellenden Ker Granite with all its variants resembles granites of the Whypalla Supersuite — and like the latter it contains few, if any, diagnostic minerals to indicate whether the constituent plutons are S- or I-types. The presence locally of rare aggregates (clots) of fine white mica possibly after cordierite, sparse garnet, and interstitial apatite, the local abundance of tourmaline (*e.g.* in the summit area of Bellenden Ker Centre Peak, and in the granite forming Walshs Pyramid), and their peraluminous character are interpreted to indicate the granites of the Bellenden Ker Batholith are probably S-types.

Deformational effects in the Bellenden Ker Granite range from slight to very extensive. A mylonitic foliation with prominent 'S' and 'C' planes is well developed in the summit area and eastern side of the Bellenden Ker Range and on the eastern side of the Graham Range. The Bellenden Ker Range is bounded to the east by the Russell–Mulgrave Shear Zone. Kinematic indicators in deformed granite west of the shear zone indicate a dominant east-block-up sense of shear.

Age

A sample of coarsely megacrystic granite similar to the type Bellenden Ker Granite at Kearneys Falls has yielded a SHRIMP age of 280±4Ma. K–Ar ages (corrected) of 238Ma and 251Ma had been previously obtained from the unit (Richards & others, 1966). These dates are similar to those yielded by samples of extensively deformed granites from elsewhere in the eastern Hodgkinson Province (Bultitude & Champion, 1992). They are interpreted as reset ages and not the age of crystallisation of the granite (cf. Willmott & others, 1988). The 238Ma date may reflect some argon loss, as suggested by Richards.

Chemical characteristics

The granites of the Bellenden Ker Batholith — except for the hornblende-bearing I-type granites forming Mount Bartle Frere — are hereon assigned to the *Bellenden Ker Supersuite* and tentatively classified as S-types. The granites of the Bellenden Ker Supersuite are distinguished from the Whypalla Supersuite granites by relatively high TiO_2, K_2O and V, and low Al_2O_3, CaO, Na_2O, Ba, and Sr contents — as well as by contrasting trends displayed by ASIs and elements such as La, Ce and Y on Harker-type variation diagrams.

Rb contents (and Rb/Sr and Rb/Ba ratios) remain more or less constant in rocks containing <~72% SiO_2 (Figure 22). These parameters increase significantly in rocks with higher SiO_2 contents, and Ba and Sr show marked depletion (*e.g.* Figure 22). These trends are consistent with feldspar fractionation having played a dominant role in the evolution of the more felsic granites of the supersuite.

The most fractionated granite is Walshs Pyramid Granite (Bultitude & others, 1998a), west of Gordonvale. This granite contains ~600ppm Rb, ~30ppm Ba, and ~5–10ppm Sr (Figure 22). The very low Sr and Ba contents may indicate the pluton has undergone subsolidus hydrothermal alteration. Alternatively, the data of Blundy & Wood (1991) showing that the partition coefficients for Sr and Ba in plagioclase increase significantly in albite-rich compositions, may account for the very low Sr and Ba contents of the highly fractionated Walshs Pyramid Granite.

P_2O_5 decreases with increasing SiO_2 in most samples (Figure 22), in contrast to the trend of increasing P_2O_5 with increasing SiO_2 in S-type granites of the Lachlan Fold Belt (*e.g.* Chappell & White, 1992; Chappell & Champion, 1994). However, the Whypalla Supersuite granites show a similar trend (Figure 22). Similarly, La and Ce do not change significantly with increasing SiO_2 (typical I-type characteristics according to Chappell & White, 1992 and Chappell & Champion, 1994) in most samples — some microgranites do show marked depletion. The most mafic Whypalla Supersuite granites have similar La and Ce contents, but the supersuite is characterised by significant La and Ce depletion with increasing SiO_2. Y increases with increasing SiO_2 in the Bellenden Ker Supersuite — another I-type trait — except in some relatively P_2O_5-rich microgranites which are significantly depleted (Figure 22).

Bartle Frere Supersuite

The I-type *Bartle Frere Supersuite* comprises one unit — the *Bartle Frere Granite* (Table 4; Figure 23). The Bartle Frere Granite forms a prominent, rugged stock at the southern end of the Bellenden Ker Range and was included in the Bellenden Ker Batholith by Willmott & others (1988). It was formerly mapped as part of the Mareeba Granite (de Keyser, 1964; de Keyser & Lucas, 1968), but is mineralogically and chemically distinct. The Bartle Frere Granite contains minor hornblende (<biotite) and traces of primary titanite, allanite and ilmenite.

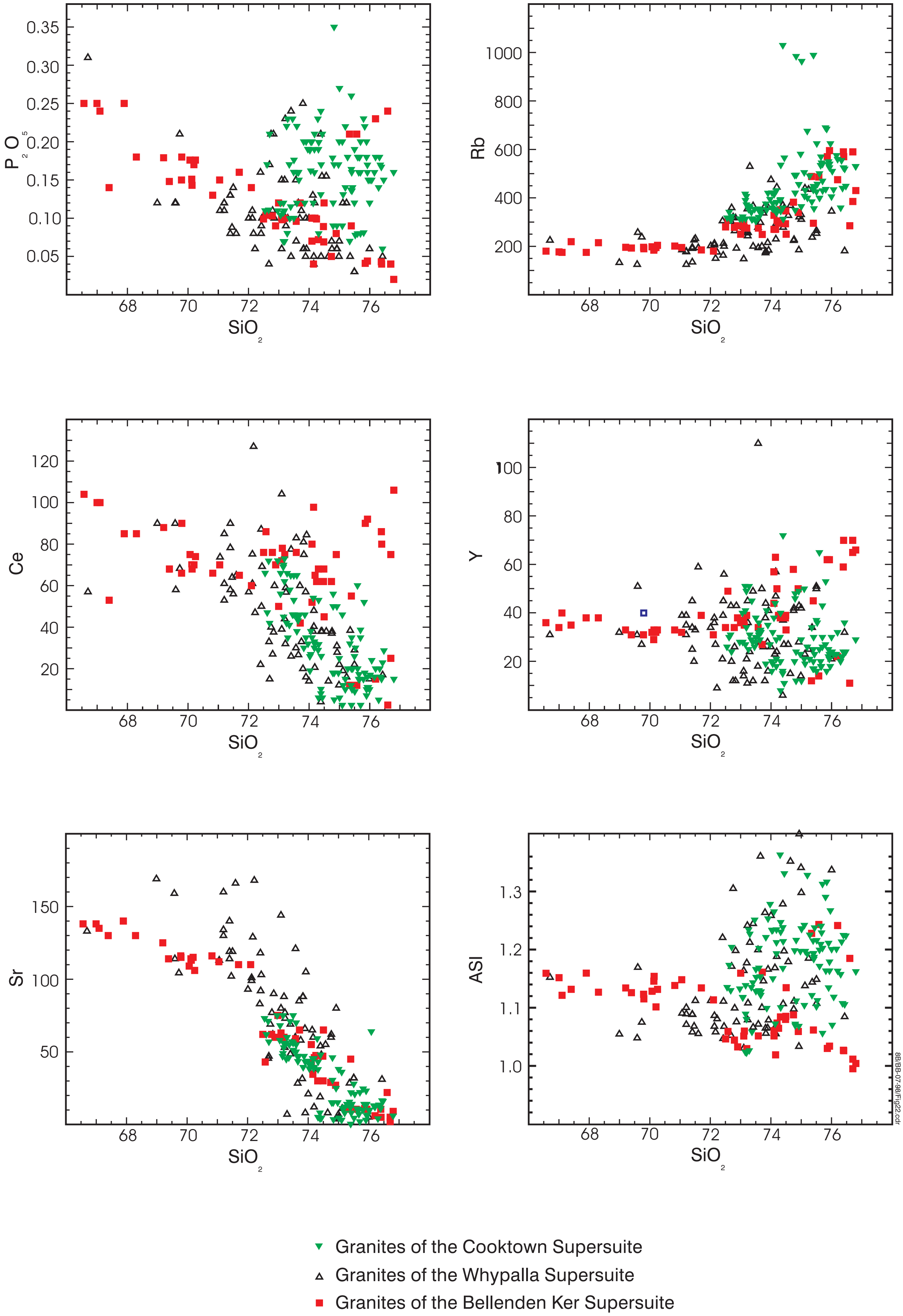


Figure 22. Chemical variation diagrams for the major S-type granite supersuites, central and eastern Cairns Region.

The Bartle Frere Granite is similar chemically to the granites of the Cape Melville and Pieter Botte Supersuites (Figure 24). It is more felsic than the Yates Supersuite granites. The unit is characterised by relatively high SiO_2, Na_2O, total alkalis, Ga, Sn and Zr contents and low Al_2O_3, CaO, Ba and Sr concentrations compared with the granites of the Yates Supersuite (*e.g.* Figure 24). The supersuite is distinguished from the granites of the Cape Melville and Pieter Botte Supersuites mainly by relatively high Al_2O_3, Na_2O, Ga and Sr and low K_2O, Rb, Th and Zr contents. The Bartle Frere Granite, like the granites of the Pieter Botte and Yates Supersuites is cut by dykes and pods of more highly fractionated, finer grained leucogranite (Figure 24). At least some of the microgranites contain traces of hornblende, as well as minor biotite.

Remarks

The granites of the Bellenden Ker Batholith appear to have been emplaced to about the same level in the crust as the granites of the major supersuites recognised elsewhere in the eastern Hodgkinson Province. Microgranite dykes which cut the Bartle Frere Granite contain small miarolitic cavities. Furthermore, Willmott & others (1988) reported the presence locally of narrow hornfels zones typical of relatively high-level contact aureole granites (White & others, 1974) in the metasedimentary rocks surrounding the Bellenden Ker Granite.

The Bellenden Ker Granite and nearby granites of the S-type Whypalla Supersuite have broadly similar petrographic, geochemical and field characteristics. Al concentrations in biotites of the Bellenden Ker Granite are also similar to those in biotites (with similar mg-values) in S-type granites of the Whypalla and Cooktown Supersuites (Figure 25).

Cape Melville Supersuite

The units of the Cape Melville Supersuite (Table 4 and Appendix 1) were mapped as Altanmoui Granite by de Keyser & Lucas (1968). Lucas (1964) and Morgan (1964b) had previously expressed doubts on the validity of mapping all the granites adjacent to the coast in the far north of the region as part of the same unit. The Cape Melville Supersuite is characterised by a relatively restricted range of modal (and geochemical) compositions, especially compared to the Yates Supersuite (Figure 23).

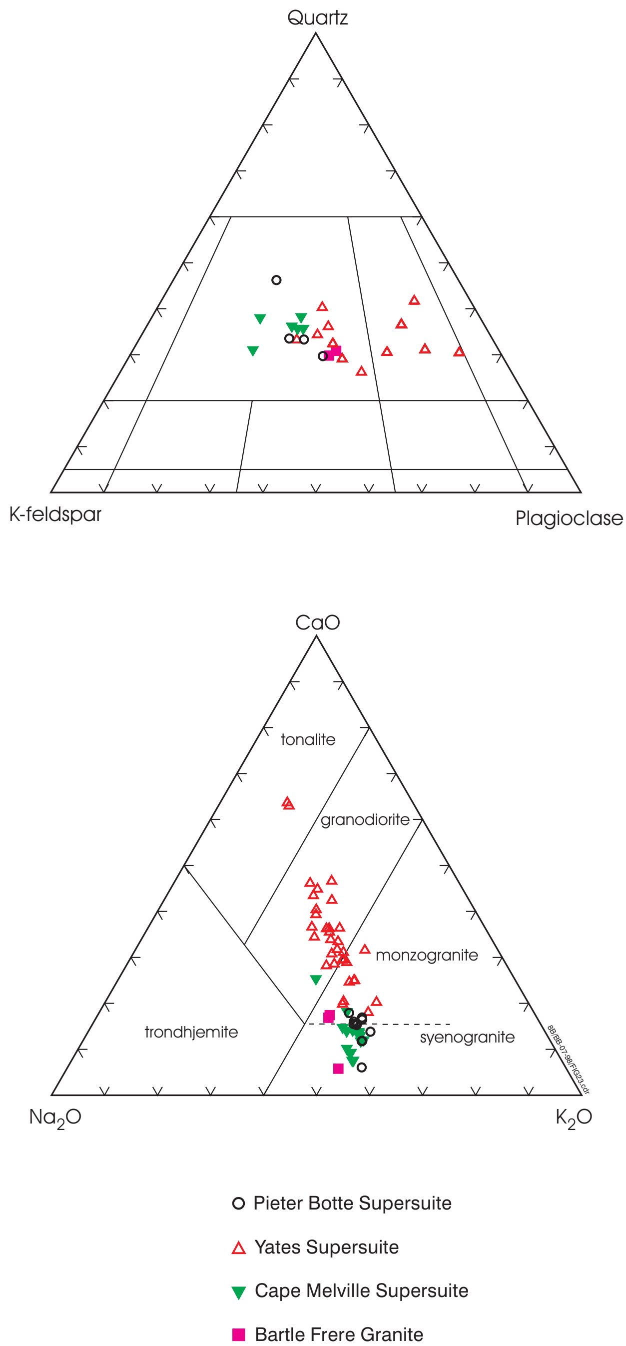


Figure 23. Modal and chemical data for I-type granites of the eastern part of the Cairns Region.

The Cape Melville Supersuite granites are I-types, indicated by the presence of traces of hornblende and allanite and geochemical characteristics. Enclaves are common and locally conspicuous, in the Cape Melville and Altanmoui Granites (especially the former). Among the more unusual enclaves in some of the Cape Melville Supersuite granites are scattered inclusions of quartz (to 15cm), and thinly banded biotite gneiss and other biotite-rich, high-grade metamorphic rocks, some of which contain corundum porphyroblasts up to ~3mm long and green spinel (Bultitude & Champion, 1992; Bultitude, 1993). The presence of these enclaves may

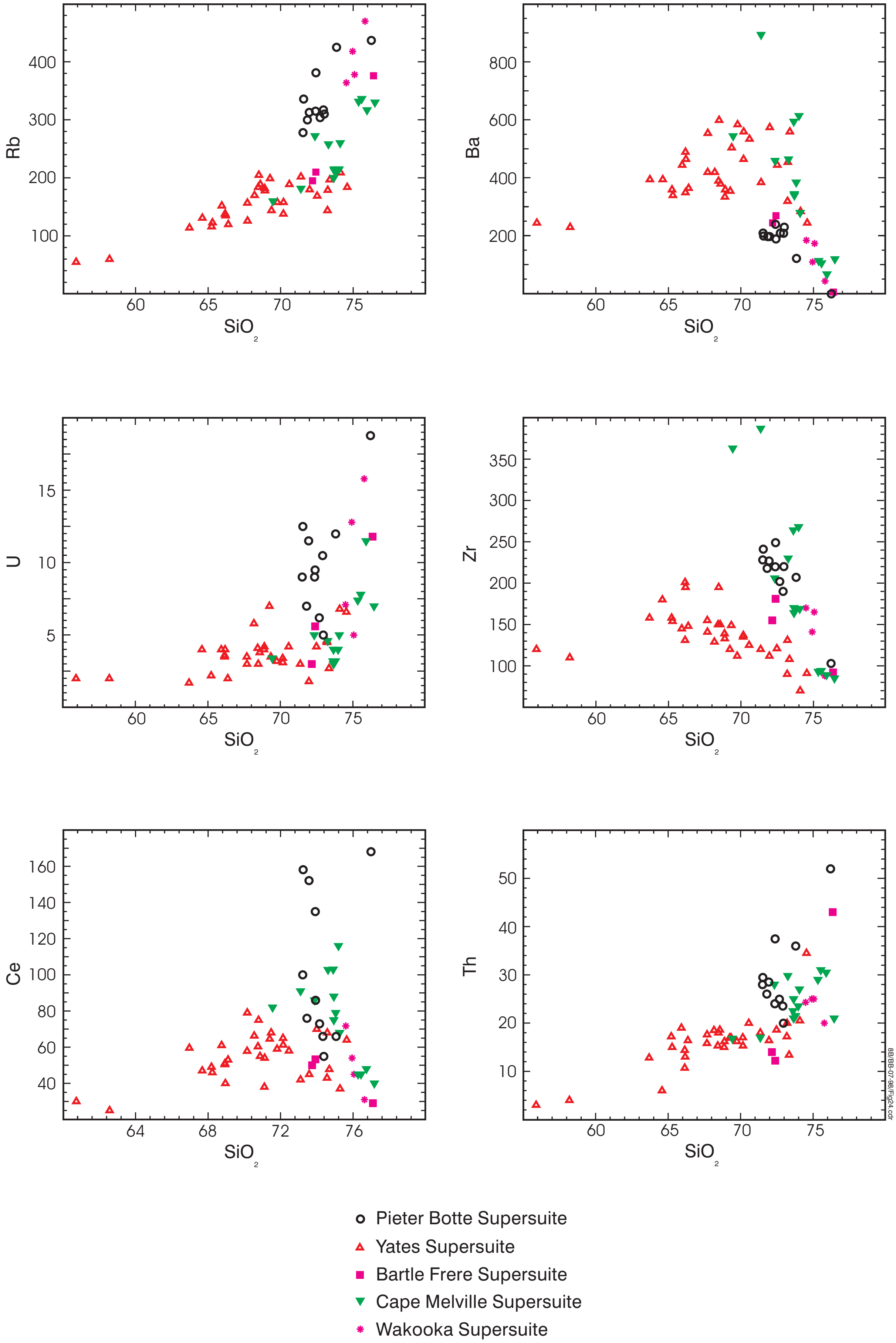


Figure 24. Selected variation diagrams for the Permian I-type granites of the eastern Cairns Region and the granites (S-types?) of the Wakooka Supersuite. Trace element concentrations are in ppm amd major oxides in wt%. Also shown are the granites of the Bartle Frere Supersuite (I-types) from the south-eastern part of the region.

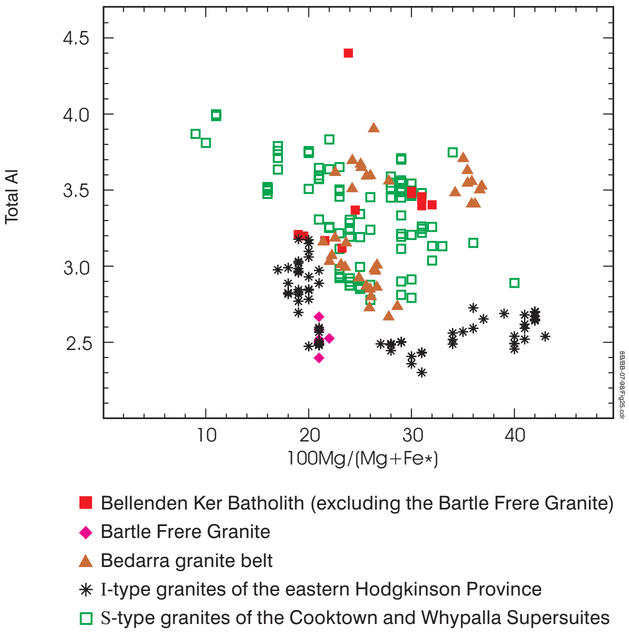


Figure 25. Total Al versus mg-value for biotites in selected S- and I-type granites from the eastern Hodgkinson Province.

indicate some assimilation or minor mixing of supracrustal rocks in the granitic magmas which produced the Cape Melville Supersuite.

Age

Recent Rb–Sr biotite–whole rock dating (Bultitude & Champion, 1992) yielded ages of 277Ma, 279±2Ma and 281±2Ma for the Altanmoui and Cape Melville Granites. These results are similar to the ages of the Whypalla Supersuite granites and the western belt of Yates Supersuite granites.

Chemical characteristics

The Cape Melville Supersuite granites are generally slightly peraluminous with normative corundum contents as high as ~1.3%. They are distinguished from the Yates Supersuite by higher K_2O, Th, Zr, Nb, Y, and Cu, and lower Al_2O_3, MgO, CaO, Sr, V and Cr contents (*e.g.* Figure 24), as well as lower mg-values, and higher Rb/Sr and Rb/Ba ratios. The Cape Melville Supersuite granites have similar major element contents to the granites of the Ootann Supersuite (Champion & Chappell, 1992), but are distinguished by their trace element abundances.

The Cape Melville Granite, in particular, is characterised by relatively high (>250ppm) Zr concentrations (Figure 24) — much higher than those in the Carboniferous I-type granites to the south-west (Champion & Chappell, 1992). The relatively high Zr in the Cape Melville Granite is matched by enriched LREE[15] abundances (*e.g.* 40–50ppm La and 100–120ppm Ce). The granites of the Cape Melville Supersuite are similar, in these respects, to the A-type Lags Supersuite and the early Permian A-type volcanic rocks of the Featherbed Volcanic Group.

Rb, Pb, Th and U appear to behave incompatibly and increase with increasing SiO_2 (and decreasing FeO*). U and Th are enriched in the Cape Melville Supersuite, with up to 15ppm U and 30ppm Th. High K_2O, Th and U are common features of fractionated I-type felsic granites elsewhere (Champion & Chappell, 1992).

Wakooka Supersuite

The Wakooka Granite forms a small stock (~1km^2) west of the Altanmoui Range, in the far north of the region (Bultitude, 1993). The unit was formerly mapped as part of the Altanmoui Granite by Lucas & de Keyser (1965a) and de Keyser & Lucas (1968). It consists of medium-grained, moderately porphyritic biotite granite. The Wakooka Granite is intruded by a pod or lens of fine to medium-grained felsic granite (*e.g.* in the bed of a tributary of Wakooka Creek at GR 2358 83934, Jeannie River 1:100 000 Sheet area). The felsic granite contains sparse subhedral to anhedral grains (up to ~1mm) of altered cordierite?.

The Wakooka Granite was classified as a felsic I-type by Champion (1991) and Champion & Bultitude (1994) and included in the Cape Melville Supersuite. The Wakooka Granite and I-type Cape Melville Granite (Cape Melville Supersuite) possess similar element concentrations for many major and trace elements (*e.g.* Figure 24). However, the Wakooka Granite is more highly fractionated than the Cape Melville Granite.

The Wakooka Granite is also geochemically distinct from the Permian S-type Cooktown and Whypalla Supersuites. It is characterised, for example, by lower V and P_2O_5 contents than the Cooktown Supersuite granites, and higher Ce and Pb concentrations than most of the Whypalla Supersuite (Figure 26).

The close spatial relationship between the unit and the lens/pod of finer grained granite

15 LREE = light rare earth elements (La–Sm)

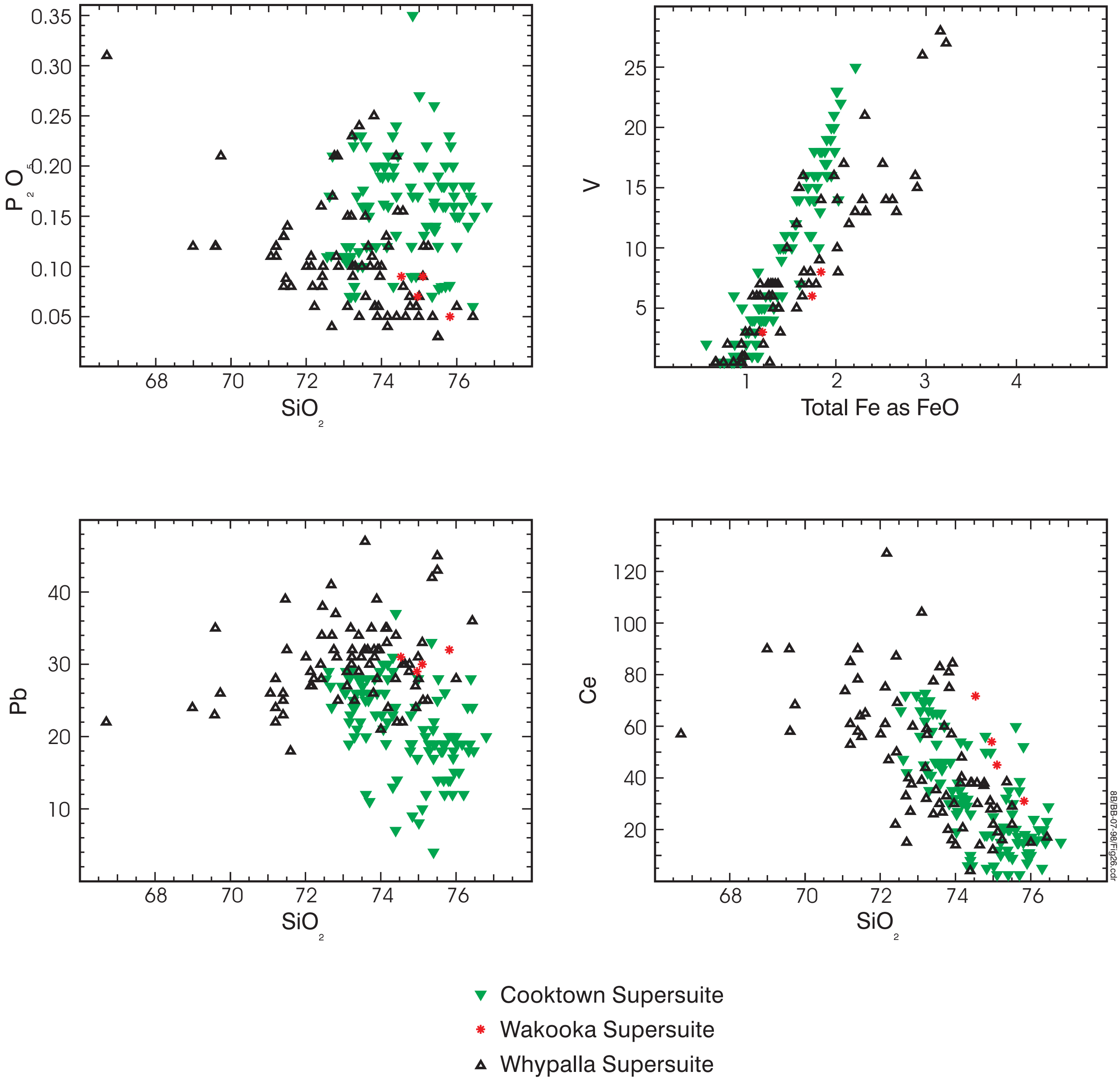


Figure 26. P_2O_5 (wt%), Pb, and Ce (ppm) versus SiO_2 (wt%), and V (ppm) versus FeO (wt%) plots for the Permian S-type granites of the Cooktown, Wakooka and Whypalla Supersuites, eastern Cairns Region.*

containing sparse grains of altered cordierite? may indicate the two are genetically related. Furthermore, the Al contents of the biotite grains may also indicate the Wakooka Granite is an S-type. Biotites analysed from a sample of Wakooka Granite are characterised by significantly higher Al contents than those analysed from the I-type granites of the Yates and Cape Melville Supersuites (at equivalent mg-values; Figure 25).

The Wakooka Granite and associated pod/lens of more felsic granite are therefore tentatively classified as S-types and assigned to the Wakooka Supersuite.

Yates Supersuite

The I-type Yates Supersuite contains the most mafic units in the eastern Hodgkinson Province, and has by far the greatest compositional range — from tonalite or quartz diorite to granite (~64–73% SiO_2; Table 4 and Appendix 1; Figure 23). Many of the units had previously been mapped as part of the Finlayson or Mareeba Granites (de Keyser & Lucas, 1968).

The plutons of the Yates Supersuite appear to be epizonal to possibly mesozonal intrusions. Miarolitic cavities have not been detected. Nevertheless, Morgan (1965) reported narrow, low-grade, contact metamorphic aureoles around the Trevethan and Puckley Granites, and similar narrow, low-grade aureoles are poorly exposed around the other members of the supersuite. The sedimentary rocks have been converted to mainly biotite–quartz hornfels, spotted schist and (cordierite–) andalusite schist adjacent to granite contacts (de Keyser, 1961; Morgan, 1965). In addition, hornblendes analysed from units of the Yates Supersuite have relatively low Al_2O_3 contents (Bultitude & Champion, 1992), consistent with emplacement at relatively high levels in the crust (Hammarstrom & Zen, 1986; Hollister & others, 1987; Johnson & Rutherford, 1988; Blundy & Holland, 1990).

Age

Published and unpublished isotopic data indicate the Yates Supersuite granites form two distinct age groups — a western group (associated mainly with the granites of the Whypalla and Mount Alto Supersuites) comprising granites of ~280Ma–285Ma, and an eastern group (generally associated with Cooktown Supersuite granites) of ~260Ma (Bultitude & Champion, 1992). The Bakers Blue Granite and Trevethan Granodiorite have yielded Rb–Sr whole rock–biotite ages of 280±2Ma and 259±1Ma, respectively.

Mineralogical and chemical characteristics

The common presence of hornblende and allanite, as well as clinopyroxene locally, indicate the granitic rocks of the Yates Supersuite are of infracrustal origin. The widespread distribution of metasedimentary inclusions as well as rare quartz enclaves in some units, and the presence of garnet xenocrysts in the Talgijah Granodiorite imply some assimilation or minor mixing may have occurred between the parental magmas of the Yates Supersuite granites and the supracrustal rocks through which they passed.

The granites of the Yates Supersuite are metaluminous to slightly peraluminous. They are not highly fractionated, as indicated by low to moderate Rb contents and Rb/Sr ratios and absence of significant Ba depletion (*e.g.* Figure 24; Champion, 1991; Champion & Bultitude, 1994).

Remarks

The units forming the various suites are widely scattered and more detailed work may indicate that the supersuite can be subdivided into two or more supersuites. Nevertheless, the units show broadly similar characteristics and trends, especially when compared with the units of the Cape Melville and Pieter Botte Supersuites.

Cooktown Supersuite

Granites of the S-type Cooktown Supersuite (Table 4 and Appendix 1) form a north-north-west striking belt to the north-east of the belt of Whypalla Supersuite granites. Units at the southern end of the belt (in MOSSMAN) were previously mapped as part of the Mareeba Granite (Amos & de Keyser, 1964; de Keyser & Lucas, 1968); plutons farther north (in COOKTOWN) as Finlayson Granite and, in the far north (Barrow Point area, in CAPE MELVILLE) as part of the Altanmoui Granite (Lucas & de Keyser, 1965a).

The granites are epizonal, as indicated by the widespread distribution of miarolitic cavities and granophyric intergrowths of quartz and K-feldspar (Appendix 1) which are generally regarded to indicate high-level crystallisation (<200MPa, Burnham & Ohmoto, 1980). The relatively narrow, low-grade contact metamorphic aureoles developed in the enclosing country rocks also imply high levels of emplacement.

The presence of altered cordierite, the widespread distribution and local abundance of tourmaline, the relative abundance of K-feldspar (Figure 27), and the scarcity of garnet are the main mineralogical features which distinguish the Cooktown Supersuite granites from those of the Whypalla Supersuite. Furthermore, plagioclases in the more mafic units of the Whypalla Supersuite are characterised by significantly more calcic cores (up to $\sim An_{60}$) than those in the Cooktown Supersuite (Figure 28).

Age

A sample of a Cooktown Supersuite granite from Cooktown has yielded a SHRIMP date of 275±5Ma implying the age difference between at least some representatives of the Cooktown and Whypalla Supersuites may be <20 million years. In contrast, Richards & others (1966) and Black (1978) had previously proposed that most of these granites are ~15–20 million years younger than those of the Whypalla Supersuite (essentially their Mareeba Granite). The granites of the S-type Cooktown Supersuite are characterised by the presence of abundant

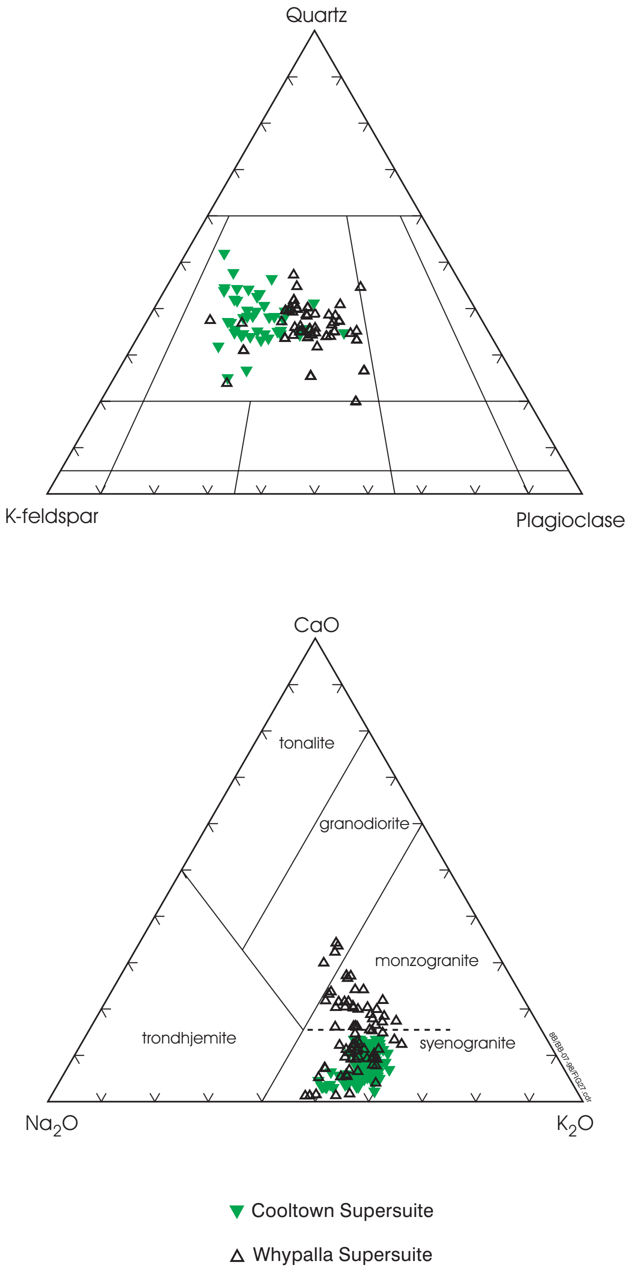


Figure 27. Modal and chemical data for granites from the Cooktown and Whypalla Supersuites, showing the relatively K-feldspar and quartz-rich character of most of the members of the Cooktown Supersuite.

inherited zircon grains with only narrow rims of zircon which crystallised during the latest magmatic event. Consequently, the SHRIMP date may represent a mixed age, and be slightly older than the actual crystallisation age (late Permian).

Most of the K–Ar mica ages reported by Richards & others (1966) are thought to reflect partial to complete resetting of the radiogenic isotopes during the major late Permian–Triassic Hunter–Bowen Orogeny which affected much of the Cairns Region (Bultitude & Champion, 1992).

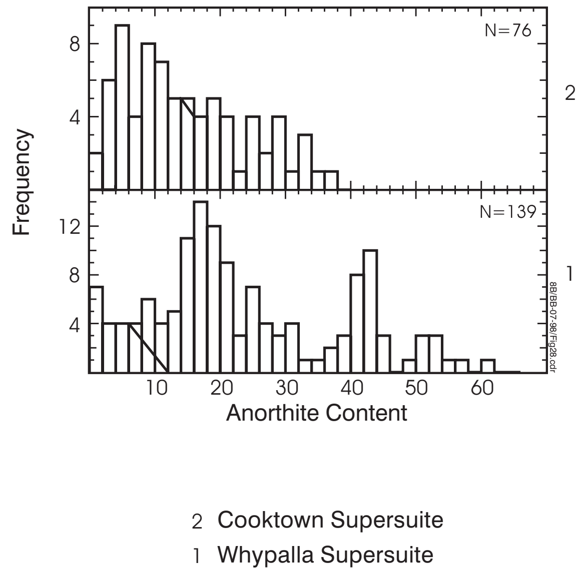


Figure 28. Plagioclase compositions (determined by electron microprobe) in granites of the Cooktown and Whypalla Supersuites. Note the more calcic compositions and the greater abundance of relatively calcic compositions in the Whypalla Supersuite granites. Most of the highly sodic plagioclase forms rims on more calcic cores or discrete grains in felsic microgranites. N = number of determinations.

Chemical characteristics

Most of the Cooktown Supersuite granites are very felsic (Figure 29). ASI values and P_2O_5 contents, contrary to trends in many other granites, increase with fractionation (*i.e.* decreasing K/Rb; Figure 29). The tendency for P_2O_5 to increase with fractionation has been attributed to the greater solubility of apatite in highly peraluminous melts (*e.g.* Cuney & Friedrich, 1987; Montel & others, 1988; although *cf*. Sawka & others, 1990).

K_2O contents are relatively high in the Cooktown Supersuite granites and decrease with fractionation (Figure 29). The high K_2O and low to moderate Na_2O and CaO contents of the Cooktown Supersuite (*e.g.* Figure 29) are characteristics of S-type granites in general (*e.g.* Chappell & White, 1984).

Th and U show divergent behaviour. U increases with decreasing K/Rb (Figure 29). In contrast, Th decreases markedly. Such trends for Th and U are common in felsic S-type granites elsewhere and are generally attributed to the fractionation of monazite (*e.g.* Miller & Mittlefehldt, 1982; Rapp & Watson, 1986) which has low solubility in peraluminous melts (*e.g.* Montel, 1986; Cuney & Friedrich, 1987; Rapp & others, 1987). The marked decrease in LREE abundances in the Cooktown Supersuite (and also the Whypalla Supersuite) granites (*e.g.* Figures 26 and 29) are consistent with such an

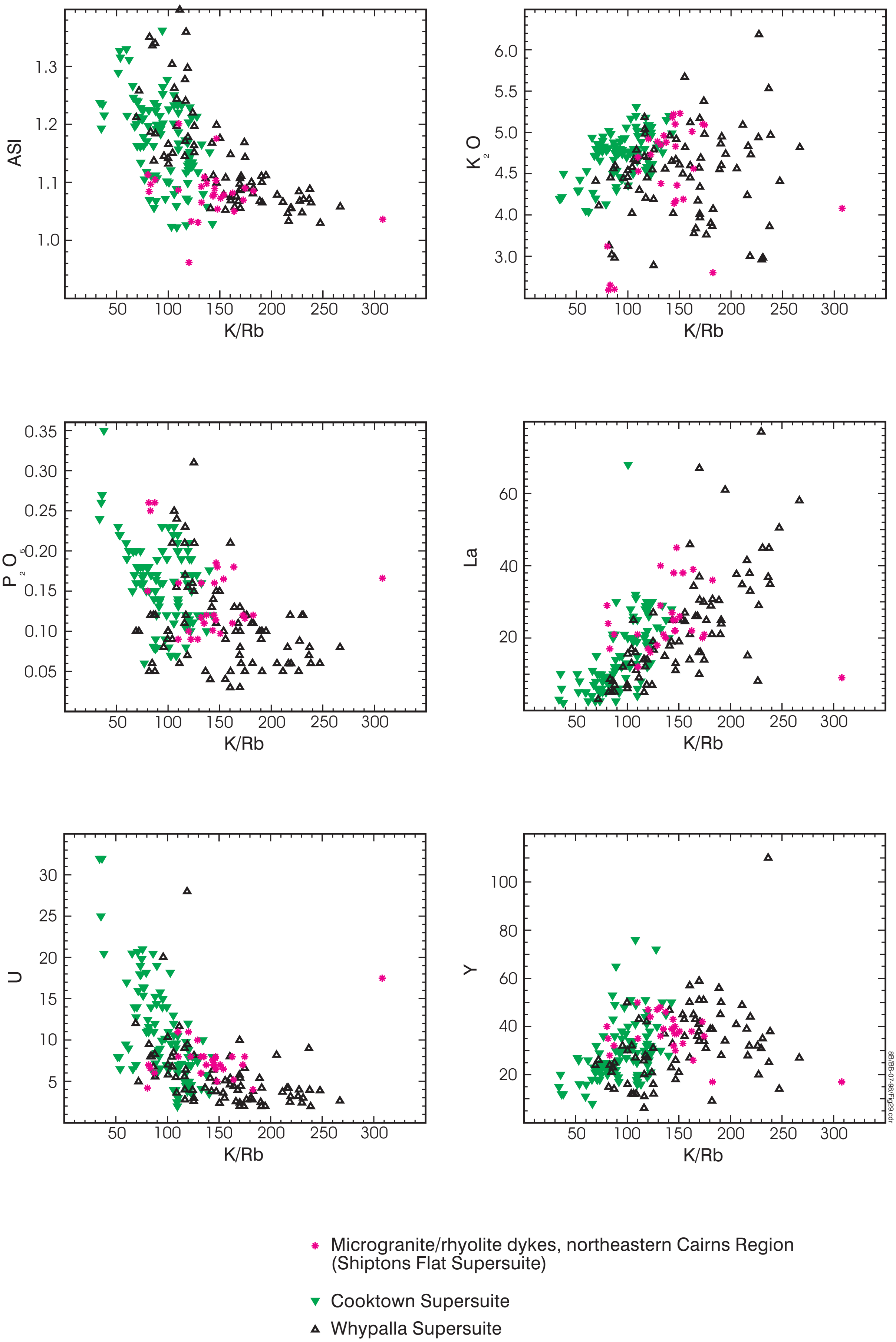


Figure 29. Selected Harker-type chemical variation diagrams for the granites of the Cooktown Supersuite. Also shown are the Whypalla Supersuite and microgranite/rhyolite dykes from the Barrow Point, Cooktown, and Shiptons Flat areas, north-eastern Cairns Region.

hypothesis. The abundances of the HREE[16] and Y also decrease markedly in the Cooktown Supersuite granites with fractionation, from ~20 to 5 times chondrite (Figure 29). Eu concentrations also decrease.

The variations in trace element abundances displayed by the granites of the Cooktown Supersuite, as indicated by Rb–Ba–Sr relationships, K/Rb, Rb/Sr and Rb/Ba ratios indicate fractional crystallisation of feldspars played a major role in their evolution.

Pieter Botte Supersuite

Granites of the Pieter Botte Supersuite were previously included in the I-type Yates Supersuite by Bultitude & Champion (1992) and Champion & Bultitude (1994) on the basis of the presence of hornblende, field characteristics, and distribution. However, the granites of the Pieter Botte Supersuite are more felsic than those of the Yates Supersuite. Plagioclase grains in the Nulbullulul Granite do not have highly calcic cores, in contrast to most units of the Yates Supersuite (Figure 30). They are normally zoned and have a relatively restricted compositional range — from $\sim An_{31}$ (core) to $\sim An_{13}$ (rim) (Bultitude & Champion, 1992). Some grains also have overgrowths of albite.

Age

The Nulbullulul Granite has yielded a SHRIMP age of 261±3Ma. This date is indistinguishable from the Rb–Sr age (259±1Ma) yielded by the Trevethan Granodiorite (Yates Supersuite), farther north, and is ~20 million years younger than most isotopic ages obtained from the S-type Whypalla Supersuite granites.

Chemical characteristics

Chemically, the members of the Pieter Botte Supersuite are distinguished from the Yates Supersuite granites by relatively high SiO_2, FeO*, K_2O, Rb, Th, Y, and Zr contents, and low Al_2O_3, CaO, and Sr concentrations (Figure 24). Rb content and Rb/Sr and Rb/Ba ratios are good discriminators (Figure 24). The granites of the Pieter Botte Supersuite are fractionated, with Rb contents ranging from ~360ppm to ~480ppm. In contrast, the Yates Supersuite granites are unfractionated and have Rb contents of <220ppm (Figure 24).

16 HREE = heavy rare earth elements (Gd–Lu)

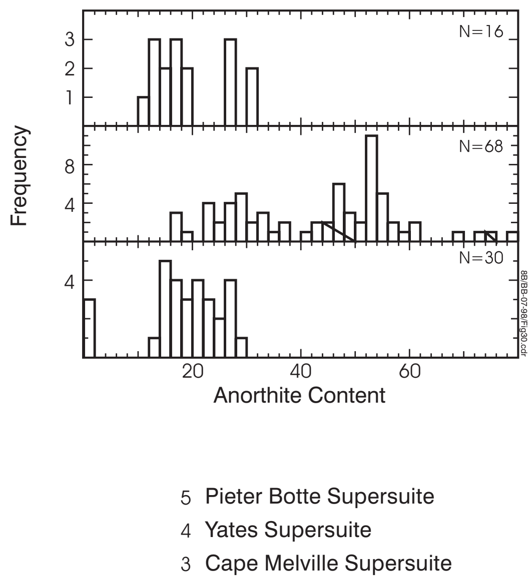


Figure 30. Plagioclase compositions (determined by electron microprobe) in Permian I-type granites of the eastern Cairns Region. The relatively mafic Yates Supersuite granites contain the most calcic plagioclases. N = number of determinations.

The Pieter Botte Supersuite granites are very similar chemically (and mineralogically) to the granites of the Cape Melville Supersuite, but are distinguished by relatively low Ba, and high Rb and U concentrations, as well as relatively high Rb/Sr and Rb/Ba ratios at similar FeO* or SiO_2 contents (Figure 24).

Shiptons Flat Supersuite

Granites of the Cooktown Supersuite are cut by dykes of aphyric to highly porphyritic microgranite and rhyolite. The dykes locally form small swarms in the Rossville–Shiptons Flat area, south of Cooktown. They pre-date the late Permian–Triassic Hunter–Bowen Orogeny and are commonly extensively deformed. One of the dykes cuts granite of the Yates Supersuite which has yielded a Rb–Sr age of 259±1Ma. The dykes were, therefore, most probably emplaced in the late Permian.

Chemical characteristics

The felsic dykes have many chemical similarities with the Cooktown Supersuite granites, whereas the relatively mafic dykes are similar in many respects to granites of the Whypalla Supersuite (*e.g.* Figure 29). The dykes are also similar chemically to the granitic rocks of the Bellenden Ker Supersuite (*e.g.* Figure 31). They do not show a significant increase in Rb contents with increasing SiO_2 content. However, Ba and Sr decrease significantly with increasing SiO_2, in a similar fashion to the granites of the other three supersuites.

Noteworthy characteristics of the Shiptons Flat Supersuite rocks include:

- their overall similarity with the Bellenden Ker Supersuite granites,
- Al_2O_3 contents tend to be lower in the dykes than in the granites of the Cooktown and Whypalla Supersuites,
- some of the more mafic dykes (~70% SiO_2) are enriched in MgO compared to the granites (with similar SiO_2 contents) of the other three supersuites listed above,
- the dykes are poorer in CaO than the Whypalla Supersuite granites (Figure 31),
- the more mafic dykes (~70% SiO_2) generally have higher Na_2O contents than the granites of the other three supersuites, at equivalent SiO_2 concentrations,
- P_2O_5 *decreases* with increasing SiO_2 in the dykes — as well as in the granites of the Bellenden Ker Supersuite and, to a lesser extent, in the Whypalla Supersuite granites,
- ASI decreases with increasing SiO_2 in the dykes, more or less paralleling the trend shown by the Bellenden Ker Supersuite granites,
- Ce contents decrease significantly in the very felsic dykes (>~74% SiO_2), paralleling similar trends in the Cooktown and Whypalla Supersuites (Figure 31); and unlike the Bellenden Ker Supersuite granites in which Ce contents do not change markedly with increasing SiO_2,
- the supersuite as a whole is characterised by relatively low Pb contents compared with the other three supersuites; Pb concentrations in the dykes do not change significantly with changes in SiO_2 contents.
- Rb contents are lower than those in the Cooktown Supersuite granites; furthermore Rb concentrations do not change significantly over the compositional range shown by the dykes,
- Th contents do not change markedly in the dykes with increasing SiO_2,
- Y contents increase with increasing SiO_2 in most samples (as they also do in the Bellenden Ker Supersuite granites), whereas they show an overall decrease in the Cooktown and Whypalla Supersuites with increasing SiO_2, and
- Zr contents decrease gradually with increasing SiO_2 in the dykes (also in the Bellenden Ker Supersuite granites; Figure 31); in contrast, most of the Cooktown and Whypalla Supersuite granites show much greater Zr depletions at high SiO_2 contents (Figure 31).

The rocks of the Shiptons Flat Supersuite are interpreted to be S-types, based mainly on their close spatial relationship to granites of the Cooktown Supersuite, their peraluminous character, and the absence of minerals such as hornblende.

Significance of the S-type granites in the eastern Hodgkinson Province

The presence of numerous plutons of S-type granite may have significant implications regarding the nature of the crust underlying the eastern Hodgkinson Province. The granites (both S- and I-types) of the eastern Hodgkinson Province have relatively primitive Nd (ε_{Nd} ranges from ~-2 to -6.4; Champion & Bultitude, 1994) and Sr isotopic signatures compared with those of the late Palaeozoic granites farther to the south-west (in the Chillagoe–Herberton area; Champion & Chappell, 1992; Champion & Bultitude, 1994). The isotopic data imply the granites of the eastern Hodgkinson Province were derived from relatively young (late Proterozoic–mid Palaeozoic?) supracrustal and infracrustal source rocks, which either underlie the exposed Hodgkinson Formation rocks or are interbedded with them.

Analysed samples of exposed Hodgkinson Formation rocks are isotopically too evolved to have been the sole source of the S-type granites (Champion & Bultitude, 1994). Only two of the Hodgkinson Formation samples studied by Champion & Bultitude (1994) have geochemical and isotopic characteristics which approach the compositional requirements for the protolith of the S-type granites of the eastern Hodgkinson Province. These volcanolithic rocks (from south of Cooktown) are both more immature and significantly more isotopically primitive than the typical, widespread, quartzofeldspathic arenites of the

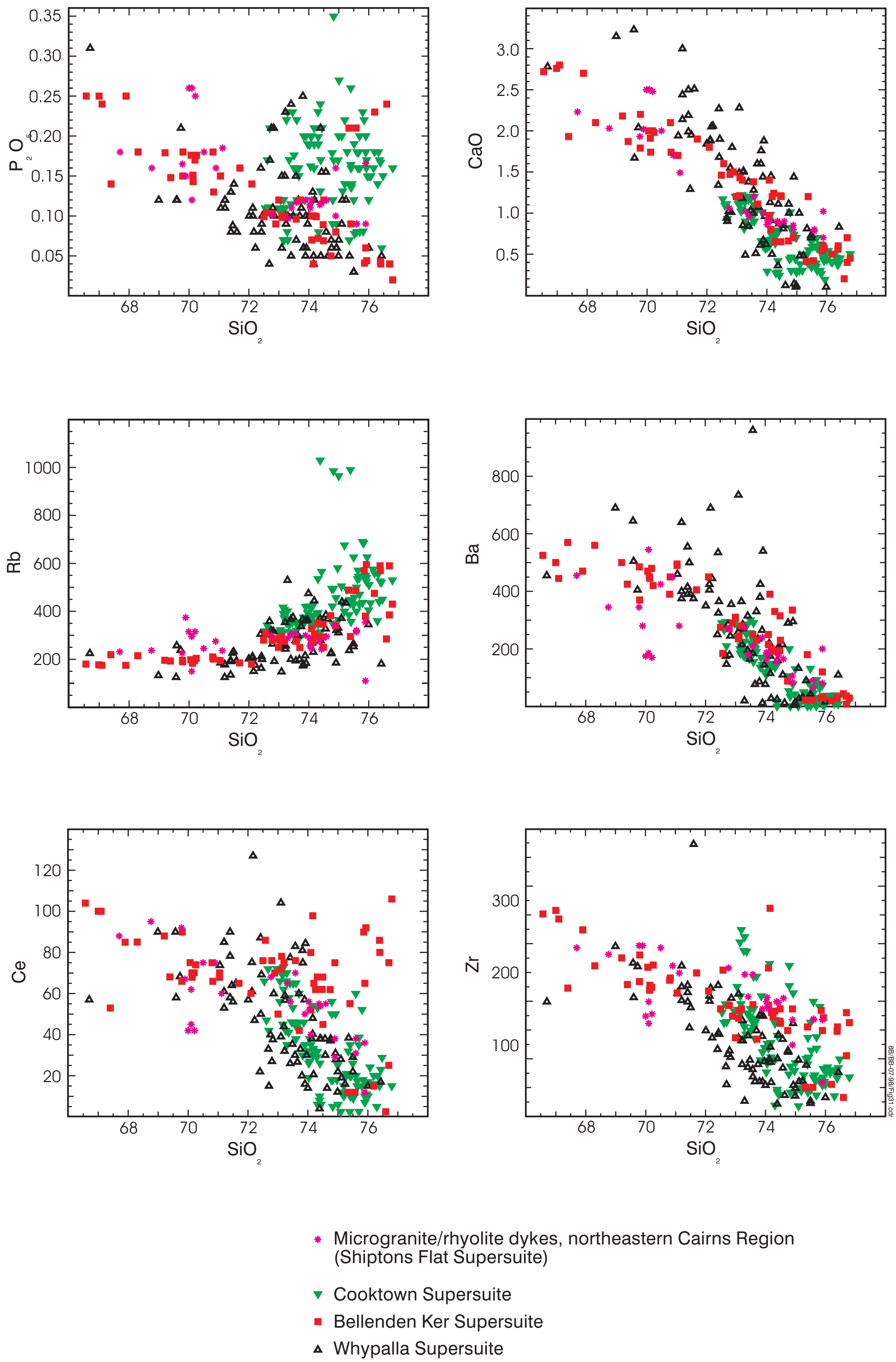


Figure 31. Chemical variation diagrams for microgranite and rhyolite dykes (Shiptons Flat Supersuite) from the north-eastern part of the Cairns Region. Also shown for comparison are the granites of the Bellenden Ker, Cooktown, and Whypalla Supersuites.

province. The data, therefore, imply that more immature, volcaniclastic? rocks are present in the eastern Hodgkinson Province — either at depth or within the exposed part of the Hodgkinson Formation (in which case they have yet to be delineated).

One of the Ordovician granites analysed from the Barnard Province (on the south-eastern margin of the Hodgkinson Province) during the study has a Sm–Nd isotopic signature (at 280Ma–260Ma) essentially identical to those for the Permian I- and S-type granites of the eastern Hodgkinson Province, in particular the Whypalla Supersuite granites (Champion & Bultitude, 1994). Two significant conclusions may be made from these results. Firstly, the supracrustal rocks of the Barnard Metamorphics must be older than the granites which intrude them and, therefore, older than probably all of the exposed Hodgkinson Province rocks (mainly Silurian–Devonian). Secondly, the presence of Ordovician granite with a ε_{Nd} value similar to the Permian S- and I-type granites of the eastern Hodgkinson Province implies they all may have been derived from similar-age (late Proterozoic–early Palaeozoic) sources. The data, therefore, support (but do not confirm) the hypothesis that continental crust of late Proterozoic–early Palaeozoic age is present beneath the rocks of the eastern Hodgkinson Province.

Ages of the source rocks for the granites of the eastern Hodgkinson Province based on zircon inheritance

U–Pb zircon (SHRIMP) dating of samples from selected granites in the eastern Hodgkinson Province indicates the widespread presence of inherited zircon components (mainly cores, but also entire grains; C.M. Fanning, Research School of Earth Sciences, ANU, written communication, 1992.

Inherited ages of ~440Ma–450Ma have been obtained from the Emerald Creek Microgranite, the Nulbullulul Granite,and the Cannibal Creek Granite. An inherited grain from a sample of the Bellenden Ker Granite has yielded an age of ~430Ma. Units in the far north-east of the province appear to contain even younger inherited zircons. A structurally distinct, inherited core and a zoned zircon grain analysed from the S-type Charlotte Granite (Cooktown Supersuite) and the I-type Nulbullulul Granite (Pieter Botte Supersuite), respectively, yielded ages of ~360Ma.

Preliminary results from the five samples analysed using SHRIMP, therefore, imply the S- and I-type granites of the eastern Hodgkinson Province were derived from relatively young sources of early–mid Palaeozoic age (post ~450Ma). Such a conclusion is essentially consistent with the Sm–Nd data presented by Champion & Bultitude (1994). Furthermore, there is evidence of widespread magmatic activity in the region at ~450Ma–460Ma. SHRIMP ages in this range have been yielded by a silicic volcanic clast from the Mountain Creek Conglomerate (in the far west of the Hodgkinson Province) and by a silicic volcanic clast from a conglomerate lens exposed south of Cooktown in the Hodgkinson Formation, as well as by a felsic I-type? granite in the Barnard Province to the southeast. The significance of the ~360Ma dates is uncertain. They are statistically indistinguishable from the age of the Mount Formartine Granite reported by Zucchetto & others (1998), but apart from that unit (and possible correlatives in the Broken River Province of the Clarke River Region) there is no known magmatic activity of that age in the Hodgkinson Province and adjacent areas.

It is stressed that the above results are of a preliminary nature. Clear, euhedral, elongate grains interpreted to represent simple igneous zircons were the main targets of the SHRIMP investigation — few structured grains were analysed. Furthermore, most of the work was carried out before cathodoluminescence images of the zircon grains were routinely taken to reveal internal boundaries between different zircon growth phases — although the normal transmitted and reflected light images were generally sufficient to indicate zoning and structured grains.

KENNEDY PROVINCE — TULLY–INGHAM AREA

Bedarra granite belt

The chain of islands, extending from Dunk Island in the north to the Brook Islands in the south, consist almost entirely of granite. South Island (Brook Islands group), at the southern end of the chain consists of olivine-bearing layered gabbro, of unknown age. The northern part of Dunk Island is made up of metamorphic rocks of the Barnard Metamorphics. The Bedarra granite belt consists of several plutons. Some of the islands (*e.g.* Dunk, North, and Wheeler Islands), despite their small size, consist of two or more distinct granites. In most places relationships between the various units could only be inferred or are unknown, because of poor outcrop and/or lack of detailed mapping.

Most of the named granites (Appendix 1) of the Bedarra belt are informal units; their extents and, in many cases, relationships with adjacent units are unknown.

Age

Recently obtained SHRIMP dates indicate at least some of the granites of the Bedarra belt are significantly older than the nearby late Carboniferous–early Permian granites of the Tully and northern Ingham Batholiths. Granite from Dunk Island (Woin–Garin granite) has recently yielded a SHRIMP age of 336±5Ma. Eleven of fifteen analyses (using SHRIMP) of zircons from the North Island granite (Brook Islands group, at the south-eastern end of the belt) have yielded an age of 335±6Ma — *i.e.* virtually identical to that obtained for the Woin–Garin granite. The zircons analysed are euhedral, with pyramidal terminations, and show simple magmatic zoning. They are typical of those found in high-level intrusives and appear to be recording a magmatic event at ~335Ma.

The granites of the Bedarra belt, therefore, are of similar age to the Kallanda Granite and Clemant Microgranite (330±4Ma and 337±6Ma, respectively; Gunther, 1993; Gunther & Withnall, 1995) of the Kangaroo Hills Mineral Field (south-western INGHAM, in the Charters Towers Region). These older granites of the Kangaroo Hills Mineral Field form part of a north-east trending belt dominated by fractionated varieties (*Oweenie Supersuite*).

In contrast, a sample of granite from Goold Island (to the north of Hinchinbrook Island, and south-west of the Bedarra granite belt) has yielded a SHRIMP age of 301±6Ma.

Mineralogical and chemical characteristics

The granites of the Bedarra belt are felsic (SiO_2>68%), with the exception of the Wheeler granite on Wheeler Island. Hornblende is very rare, having been detected in only one of the granites, and ilmenite is the main opaque mineral. Traces of tourmaline are present in Woin–Garin granite exposed on the south-western side of Dunk Island.

The Wheeler and North Island granites are distinct mineralogically (and chemically) compared with the other granites of the belt. Rare, relatively large, prominently zoned allanite grains are present in the Wheeler granite. The North Island granite also contains accessory allanite — and, in addition, sparse, interstitial grains of dark blue-green amphibole and rare small magnetite grains (mainly as inclusions in plagioclase grains), rather than ilmenite.

The granites are peraluminous in keeping with their felsic character and the absence or scarcity of hornblende. Rb contents increase with increasing SiO_2. However, all but one of the samples contain <300ppm Rb. The absence of significant Ba and Sr depletion in most samples is also consistent with the lack of extensive fractional crystallisation. The granite of Coombe Island (Coombe granite) is the most evolved (~75–76% SiO_2, 200–300ppm Rb, ~140–270ppm Ba, ~30–60ppm Sr). It and the felsic Brook and Toolgbar granites are the only granites analysed from the belt which show evidence of significant feldspar fractionation (Figure 32). The lack of extensive feldspar fractionation in the Bedarra belt granites contrasts with the trends shown by similar-age granites of the Kangaroo Hills Mineral Field (Oweenie Supersuite) and Ingham Supersuite granites (Figures 32 and 34).

Attempts to classify the granites of the Bedarra belt present the usual problems when dealing with unfractionated to only slightly fractionated, predominantly felsic rocks, most of which contain no diagnostic minerals. The lack of detailed mapping and, in some cases at least, an inadequate number of samples are also significant obstacles. A preliminary classification and subdivision of the granites are presented in Appendix 1.

Most of the granites define typical I-type trends, consistent with the rare presence of traces of allanite or hornblende in a few samples. P_2O_5 decreases markedly with increasing SiO_2 (Figure 32). K_2O, total alkalis, Pb, Rb, and Y contents increase with increasing SiO_2, whereas CaO, Sr, V, Ga, Nb, Zn, and Zr decrease significantly (Figure 32). La, Ce, Ba, Th, and U concentrations do not show any marked trends with increasing SiO_2 (Figure 32).

Most of the granites of the Bedarra belt and the I-type Oweenie Supersuite of the Kangaroo Hills Mineral Field define coherent trends on

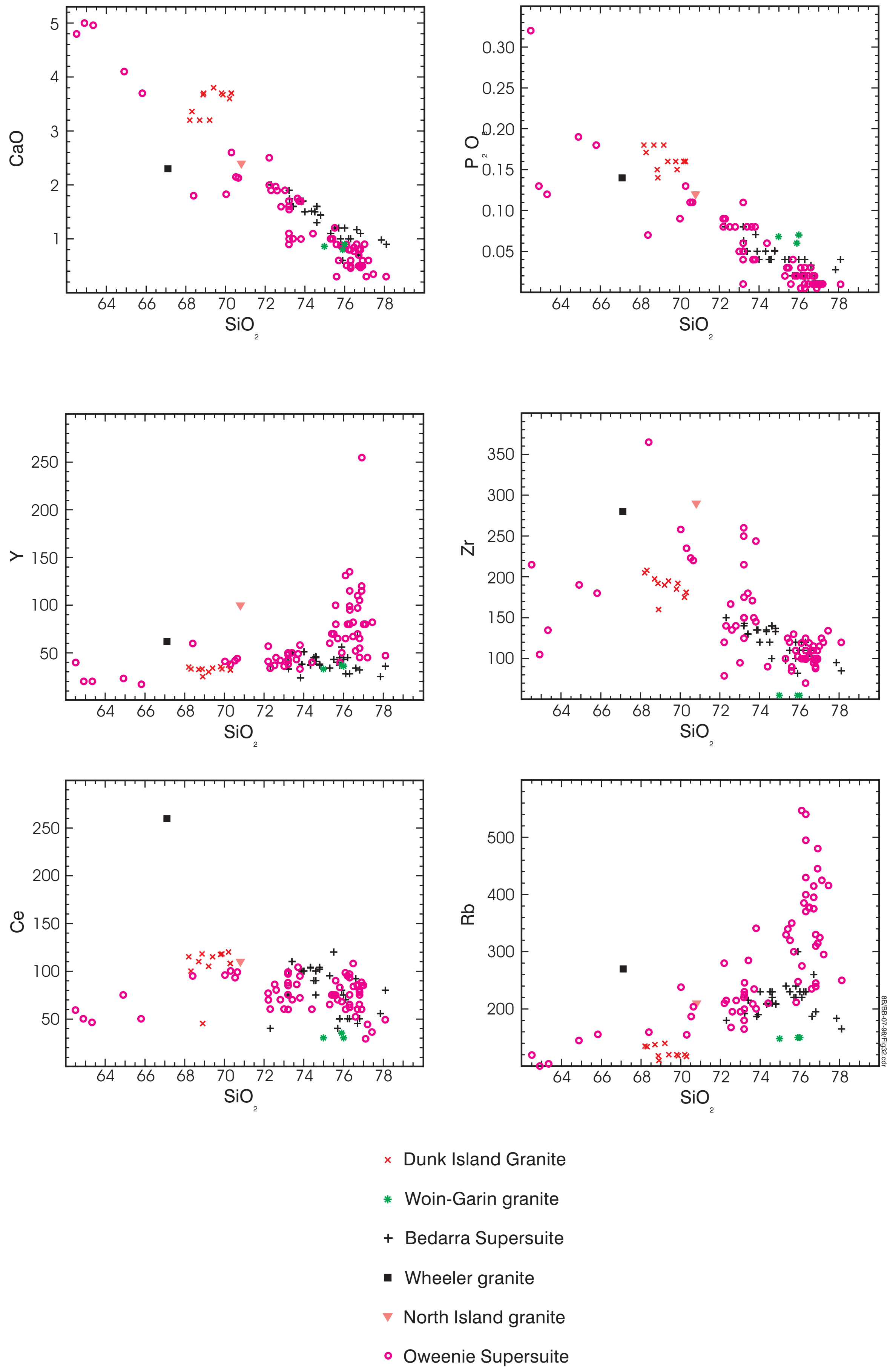


Figure 32. Chemical variation diagrams for the Bedarra granite belt. Analyses of granites from the Kangaroo Hills Mineral Field (Oweenie Supersuite, south-western Ingham Batholith) are also plotted on two of the diagrams for comparison.

most variation diagrams (*e.g.* Figure 32), implying derivation by similar processes, from sources of similar composition.

Presence of A-types

The Wheeler granite and, to a much lesser extent, the North Island granite are characterised by anomalous element concentrations compared to the I-type granites of the Bedarra belt (*e.g.* Figure 32). Other granites analysed from both Wheeler Island and North Island (Toolgbar and Brook granites, respectively) have much higher SiO_2 contents (~74–76%). There are no obvious differences between these and felsic I-type granites elsewhere in the belt (*e.g.* Figure 32).

The relatively SiO_2-poor Wheeler granite is characterised by anomalously high Zr, Ce, La, Y, Nb, Ga, and Zn contents, as well as Ga/Al ratios, compared with I-type granites of the belt. These chemical characteristics imply the Wheeler granite is an A-type. Anomalously high Nb, Y, Ga. Zr and Zn contents as well as relatively high Ga/Al ratios imply the North Island granite may also be an A-type. However, the granite has similar Ce and La abundances as the I-type granites. It, therefore, has been tentatively classified as an I-type.

Presence of S-types?

One of the most significant differences between the granites of the Bedarra granite belt and Kangaroo Hills Mineral Field are the significantly higher ASIs (~1.13–1.21) of the Dunk Island and Woin–Garin granites (Dunk Island) — particularly as they are relatively mafic (~68–70% SiO_2). Elevated ASIs can result from alteration involving partial removal of one or more of the relatively mobile elements, Na, K, and Ca. However, field observations and thin section studies indicate extensive alteration has not occurred.

Furthermore, biotites analysed from these samples plot with those from S-type granites of the Hodgkinson Province on a total Al versus mg-value diagram (Figure 33). Biotites analysed from other granites in the Bedarra belt plot either on the boundary between the fields defined by the I- and S-type supersuites of the eastern Hodgkinson Province or slightly in the S-type field. However, their total Al contents are significantly lower than those in biotites analysed from the Dunk Island and Woin–Garin granites (Figures 25 and 33).

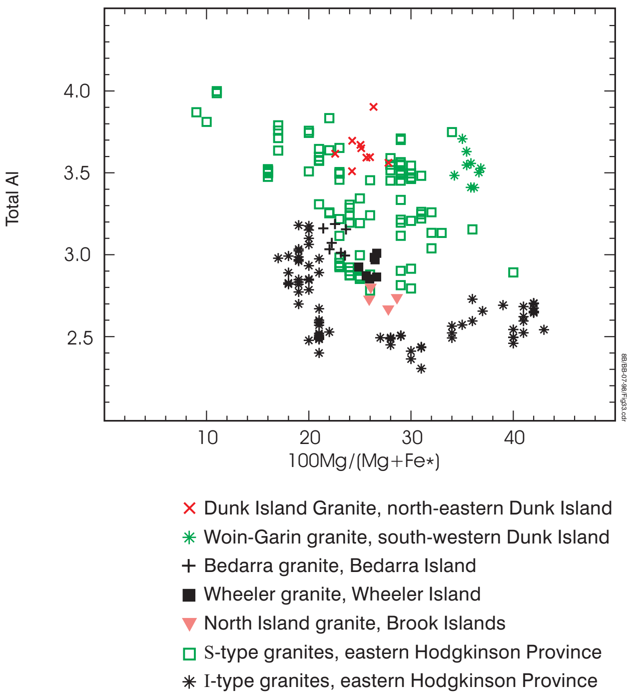


Figure 33. Total Al versus mg-value for biotites from selected granites of the Bedarra granite belt, and Permian I- and S-type granites of the eastern Hodgkinson Province.

In contrast, CaO (and Ce?) contents in the Dunk Island and Woin–Garin granites are too high for them to be typical S-types. In addition, these granites plot on extensions of trends defined by more felsic granites of the belt (Figure 32). Consequently, the granites have been tentatively classified as I-types.

The most likely candidate for an S-type is the foliated granite (Tapp–Ana granite) exposed on the southwestern side of Dunk Island (*e.g.* at GR 4123 80132). The granite is characterised by relatively high K_2O, P_2O_5, ASI, Ba, Pb, and Zn, and low CaO, Ce, La, Sr, and Zr contents.

Tully and northern Ingham Batholiths (Ingham Supersuite)

Biotite granite, hornblende–biotite granite to granodiorite and biotite–hornblende granodiorite are well represented in both batholiths. The range of compositions, textures, and magnetic susceptibilities indicate numerous plutons are present.

The Tully Batholith has a north-westerly to northerly elongation similar to that of the nearby Ingham Batholith to the south-west. The batholith crops out in INNISFAIL where it is separated from the Ingham Batholith by the Tully Fault and an elongate belt of silicic volcanic rocks (Glen Gordon Volcanics). The intrusive rocks of the Tully Batholith were delineated as the Tully Granite Complex by de Keyser (1964).

The northern part of the Ingham Batholith, with a well-defined north-north-westerly trend, occupies most of INGHAM and extends into the adjoining sheet areas to the west, north-west and north. It consists of late Carboniferous–Permian granites which intrude older granites (Visean; Gunther, 1993; Gunther & Withnall, 1995) to the south, in the Kangaroo Hills Mineral Field (Charters Towers Region). These Visean granites define a north-easterly trend and were presumably intruded under a different stress regime to the one which operated during the emplacement of the younger north-north-westerly trending part of the batholith.

Relatively mafic plutons (mainly of biotite–hornblende granodiorite, with some hornblende–biotite granite and diorite) of the Ingham Batholith were formerly mapped as part of the Almaden Granite (de Keyser & others, 1965). Champion & Heinemann (1994) included the units in the Dingo Mount granodiorite (informal name). Most of the batholith has been delineated as unnamed unit Cgb (de Keyser & others, 1965 — unit Pzg in INNISFAIL; de Keyser, 1964). This unit is made up mainly of hornblende–biotite granite and biotite granite (de Keyser & others, 1965). Pale pink, fine to medium-grained, even-grained to slightly porphyritic leucogranite crops out extensively in the far northern part of the batholith (mainly in INNISFAIL). The leucogranite contains disseminated molybdenite in the Koombooloomba area.

Age

A sample of granite from the Tully Granite Complex has yielded a SHRIMP age of 286±4Ma. Richards & others (1966) had previously obtained seven K–Ar mineral ages (corrected) ranging from 273Ma to 302Ma from rocks in the complex; the majority (4) of the ages are in the range from 279Ma to 288Ma. The three K–Ar biotite ages (corrected) obtained from the Ingham Batholith in the Cairns Region show a smaller range (296Ma–299Ma; Richards & others, 1966). Recent SHRIMP dating of hornblende–biotite granodiorite from north-west of Ingham (at GR 3612 79904, Kirrama 1:100 000 Sheet area) has yielded an age of 282±4Ma. In addition, granite from Goold Island (which forms an offshore part of the northern Ingham Batholith) has yielded a SHRIMP age of 301±6Ma. The available data, therefore, imply the granitic rocks of the Tully Granite Complex and northern part of the Ingham Batholith are mainly early Permian, but some units are as old as late Carboniferous.

Mineralogical and chemical characteristics

The Tully Granite Complex has an extended compositional range from gabbro to fractionated granite (Figure 34), whereas rocks containing less than ~63% SiO_2 have not been analysed from the northern Ingham Batholith. Most of the granites are I-types, based on the common presence of hornblende, titanite, and geochemical characteristics. The majority of the granites of both batholiths are characterised by decreasing abundances of TiO_2, FeO*, MgO, CaO, P_2O_5, Sr, Ga, and Zr, and increasing K_2O, Rb, Pb, Th, U, Nb, and Y with increasing SiO_2 (*e.g.* Figure 34). Both batholiths show well-defined trends towards highly fractionated compositions with high Rb abundances (>300ppm) and marked Ba and Sr depletion (Figure 34), implying feldspar fractionation played a significant role in the evolution of the felsic granites.

The intrusive rocks of both batholiths are very similar chemically and display similar trends on most chemical variation diagrams (*e.g.* Figure 34). Consequently, the I-types of both batholiths are assigned to the *Ingham Supersuite*.

Presence of A-types?

Some of the granites of the Ingham Batholith are characterised by anomalously high Zr contents (Figure 34). These granites, therefore, may have A-type affinities. However, unlike most A-types, they are not characterised by uniformly high abundances in all of the elements Nb, Y, Ce, La, Zn, and Ga (Figure 34). Possible A-types crop out south of Cardwell, on the mainland west of Hinchinbrook Island. Units with similar characteristics are also present in the western part of the batholith. These units have yet to be mapped in detail.

Comparison with the Glen Gordon and Wallaman Falls Volcanics

The Glen Gordon and Wallaman Falls Volcanics are very similar chemically to the majority of the I-type granites of the Ingham Supersuite (*e.g.* Figure 35); *i.e.* they appear to represent their extrusive equivalents.

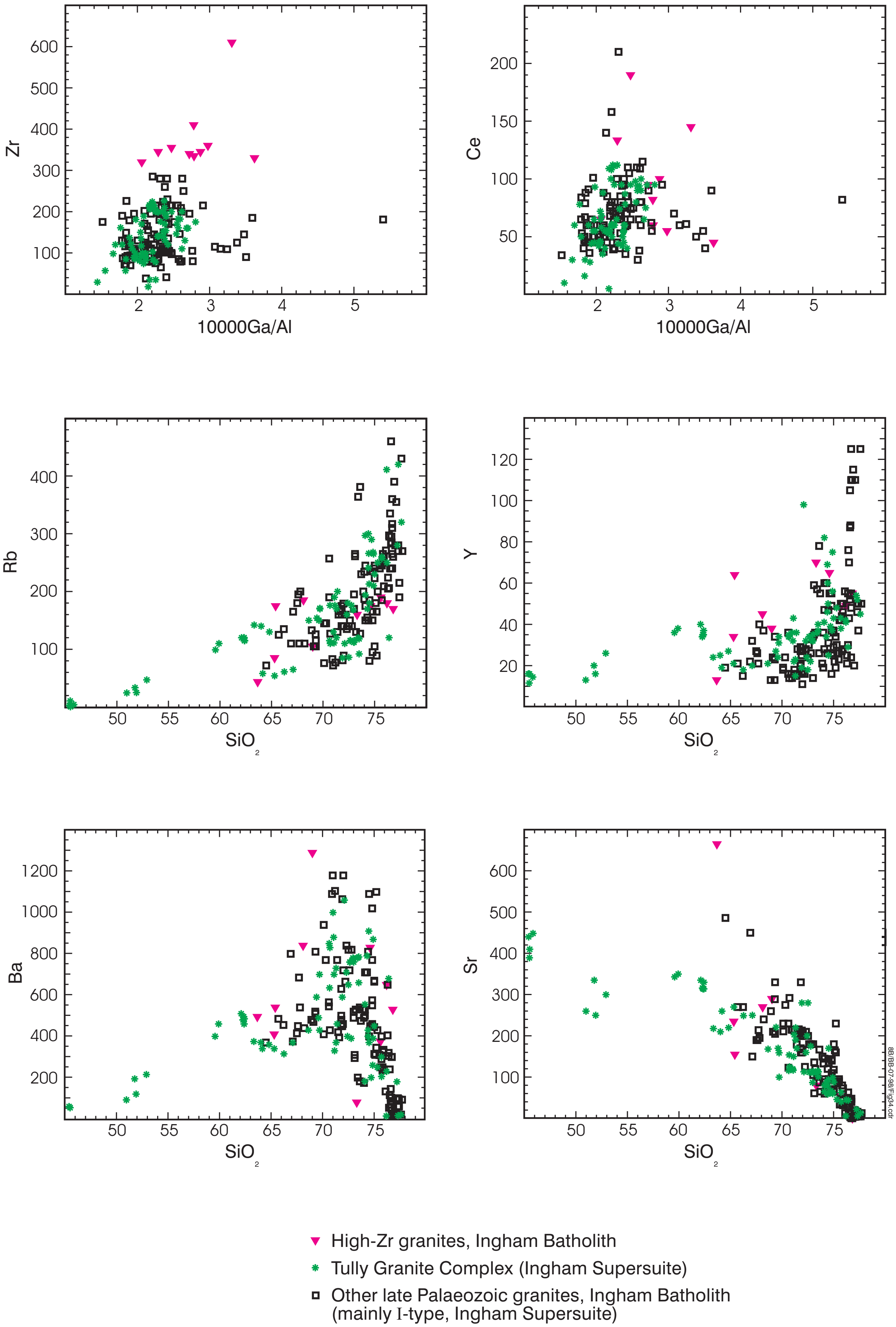


Figure 34. Chemical variation diagrams for the granitic and mafic intrusive rocks of the Tully and Ingham Batholiths (including rocks from Garden and Goold Islands). Trace element abundances are in parts per million, major oxides in weight per cent.

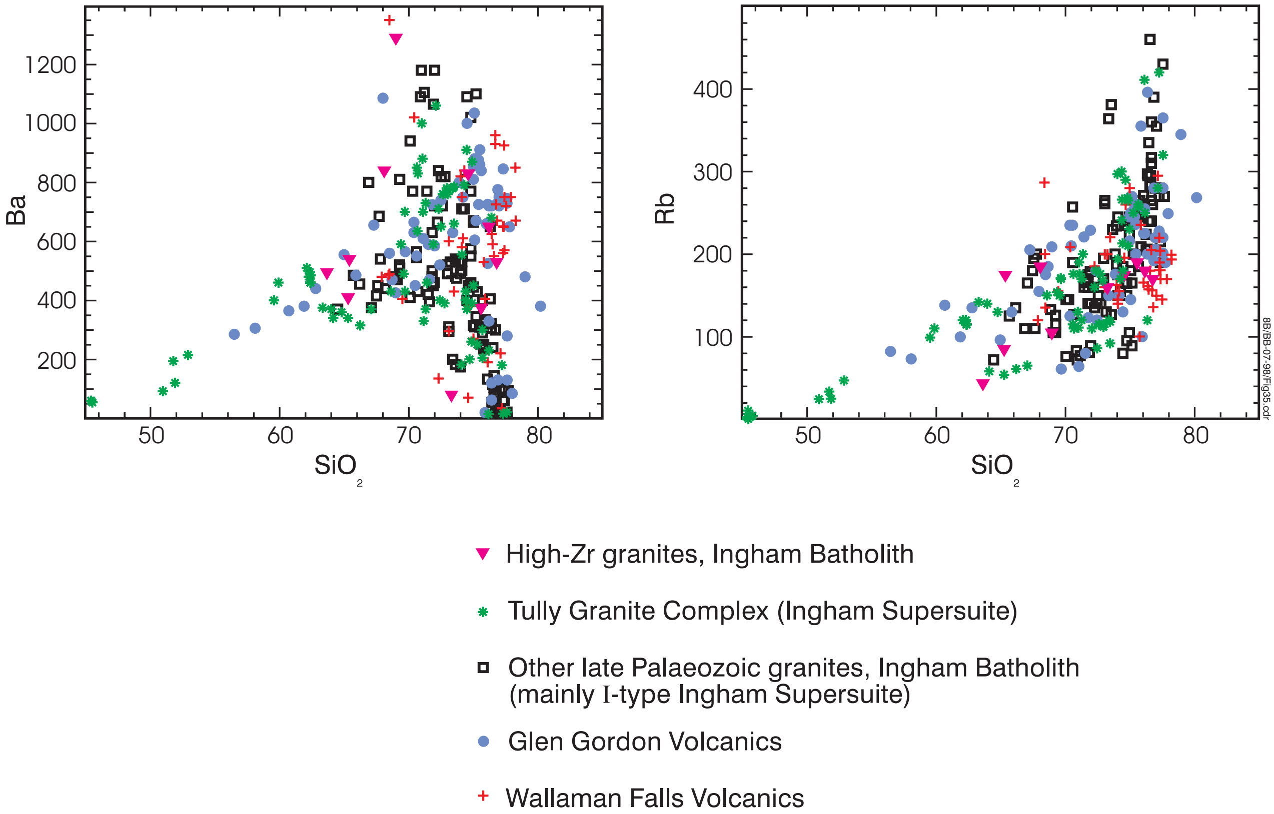


Figure 35. Selected Harker variation diagrams for the granitic and mafic intrusive rocks of the Tully and Ingham Batholiths (including rocks from Garden and Goold Islands), and the Glen Gordon and Wallaman Falls Volcanics. Trace element abundances are in parts per million, major oxides in weight per cent.

Comparison with the Almaden and Ootann Supersuites

The granites of the Ingham Supersuite display many chemical similarities with those of the Almaden and Ootann Supersuites (*e.g.* Figure 36). However, most of the more mafic granites (SiO_2<~70%) in the Ingham Supersuite are characterised by significantly higher P and Sr contents compared with the majority of the granites of the Almaden Supersuite. The more mafic rocks of these two supersuites define different trends for these elements on Harker variation diagrams. The trends converge towards felsic, SiO_2 -rich compositions (Figure 36).

Comparison with the main I-type supersuites of the eastern Hodgkinson Province

The main differences between the Ingham Supersuite granites and granites of the Cape Melville, Pieter Botte and Yates Supersuites are as follows:

- some of the granites of the Tully Granite Complex (Ingham Supersuite) are oxidised (magnetite and/or titanite bearing), whereas the I-type granites of the eastern Hodgkinson Province are invariably reduced (ilmenite bearing),
- the Tully Granite Complex contains more mafic plutons than the Yates Supersuite (Figure 36),
- Ingham Supersuite granites tend to be richer in Na_2O and Ba than the granites of the other three supersuites, although there is some overlap, and
- granites of the Pieter Botte and, to a lesser extent, Cape Melville Supersuites have higher Rb contents at equivalent SiO_2 contents than most Ingham Supersuite granites (Figure 36).

Granites of Hinchinbrook Island and the Palm Islands

Hinchinbrook Island, north of Ingham, consists mainly of granite and silicic volcanic rocks. Similarly, granite makes up most of the Palm Islands group, to the south-east. Pelorus and Curacoa Islands and the northern part of Orpheus Island consist mainly of silicic volcanic rocks (de Keyser & others, 1965). The granites were not examined during the recent GSQ survey. Consequently, the following descriptions are based mainly on reports by

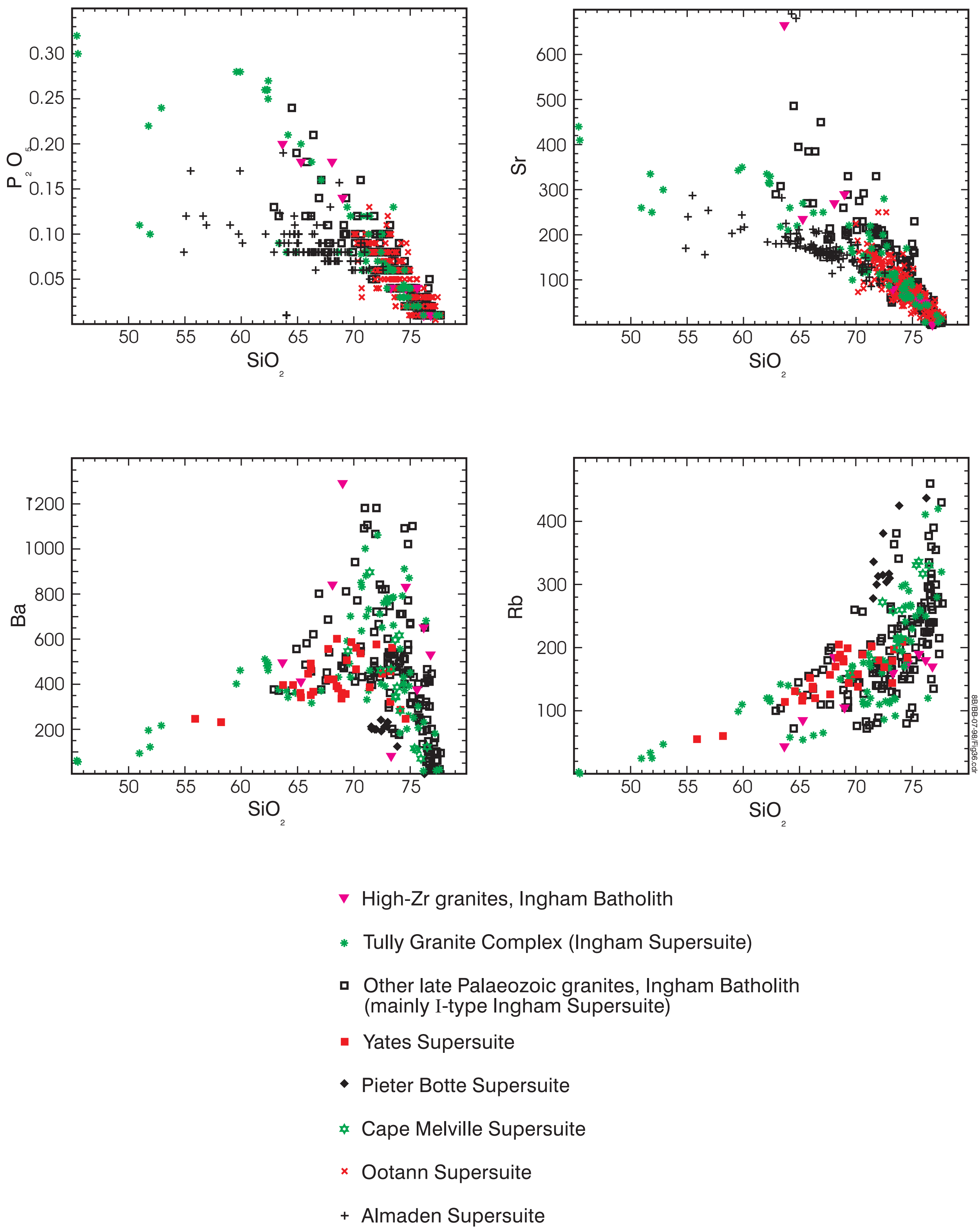


Figure 36. Selected Harker variation diagrams for the granitic and mafic intrusive rocks of the Tully and Ingham Batholiths (including rocks from Garden and Goold Islands), and the Almaden, Cape Melville, Ootann and Yates Supersuites. Trace element abundances are in parts per million, major oxides in weight per cent.

de Keyser & others (1965), Ewart (1978), Stephenson (1990, and unpublished data), and chemical analyses (of samples collected by Stephenson) supplied by Emeritus Professor B.W. Chappell (Australian National University).

Rock types

Stephenson (1990) divided the igneous rocks of Hinchinbrook Island into six main groups, namely (from youngest to oldest):

- felsic dykes, forming a swarm in the south-eastern corner of the island, with some outliers in the south-west,
- felsic granites (East Pluton of Stephenson, 1990; Hinchinbrook Granite of Champion & Heinemann, 1994), forming the mountainous spine of the island,
- enclave-bearing felsic microgranite/rhyolite, forming part of a ring-dyke complex,
- basic dykes, forming swarms with scarce associated felsic dykes,
- older granites and granodiorites, which crop out mainly in the north and south-west, and
- silicic volcanic rocks, exposed mainly in the northern part of the island.

The Hinchinbrook Granite consists mainly of very felsic, hypersolvus granite and microgranite which are relatively resistant to erosion. Noteworthy characteristics are the presence of arfvedsonite (de Keyser, 1966; Ewart, 1978; Stephenson, 1990), the presence of layering, and the widespread distribution of downward facing, unidirectional structures (Stephenson, 1990). The unit was emplaced at a high level in the crust and crystallised under relatively anhydrous conditions. Textures indicate the parent magma was essentially completely molten.

The granitic rocks of the Palm Islands consist mainly of (titanite–hornblende–) biotite granite and titanite–hornblende–biotite granite to granodiorite?. They may be similar in age to the older granites and granodiorites (terminology of Stephenson, 1990) on Hinchinbrook Island. The granitic rocks are cut by numerous basic to intermediate dykes — these may be equivalent to the older basic dykes on Hinchinbrook Island — as well as by some silicic dykes (Stephenson & Chappell, 1988). Some basic dykes also cut silicic volcanic rocks in the northern part of the island chain (de Keyser & others, 1965).

Age

The three youngest units are similar petrographically (Stephenson, 1990) and are probably all early Permian. The Hinchinbrook Granite has yielded a Rb–Sr isochron age of 275±5Ma (Stephenson & others, 1992). Richards & others (1966) had previously reported K–Ar mineral ages (corrected) of 262Ma and 267Ma (biotite), and 277Ma (arfvedsonite) for the unit. The three oldest units are mineralogically and chemically distinct from the youngest three, but their ages are uncertain. They are probably late Carboniferous. A sample of granite from nearby Goold Island has yielded a SHRIMP age of 301±6Ma. This granite is very similar chemically to the older granites and granodiorites of Stephenson (1990) on Hinchinbrook Island.

Stephenson & others (1992) produced an essentially identical isochron for the Rb–Sr isotopic data obtained from granites of the Palms Islands to that for the Hinchinbrook Granite. Consequently, they inferred the granites of the Palm Islands to be of similar age to the Hinchinbrook Granite — *i.e.* early Permian. Stephenson & Chappell (1988) had previously reported K–Ar biotite ages of 274Ma–281Ma for four different granites from the Palm Islands. However, the marked chemical similarities between the Palm Islands granites, the older granites and granodiorites of Hinchinbrook Island, and the granites of Goold Island may indicate all these groups are of similar age — most probably late Carboniferous in view of the recent results obtained from a granite on Goold Island (see above).

Chemical characteristics

The most noteworthy chemical feature of the granites in the Hinchinbrook–Palm Islands belt is the very felsic character of the Hinchinbrook Granite and the younger silicic dykes. They are A-types (Stephenson & others, 1992) and are characterised by relatively high SiO_2 contents and Ga/Al ratios. The Hinchinbrook Granite also shows marked enrichment in Zr, Zn, Nb, Ga, significant depletion in CaO, and very marked depletion in Sr (Figure 37). K_2O, Ce, La, Rb, Pb, Th, and U contents are also generally significantly higher in the Hinchinbrook Granite compared with the other granites and granodiorites of the Palm Islands and Hinchinbrook Island (*e.g.* Figure 37). The marked variation in Ba contents (from >550ppm to <20ppm), increasing Rb contents with decreasing K/Rb ratios, very low Sr concentrations (<20ppm), and high Rb/Sr ratios imply fractional crystallisation of feldspars (mainly K-feldspar) played a major role in the evolution of the unit. No consistent variations in trace element abundances with height (up to ~1100m) have been found (Stephenson & others, 1992). The felsic dykes which cut the Hinchinbrook Granite have

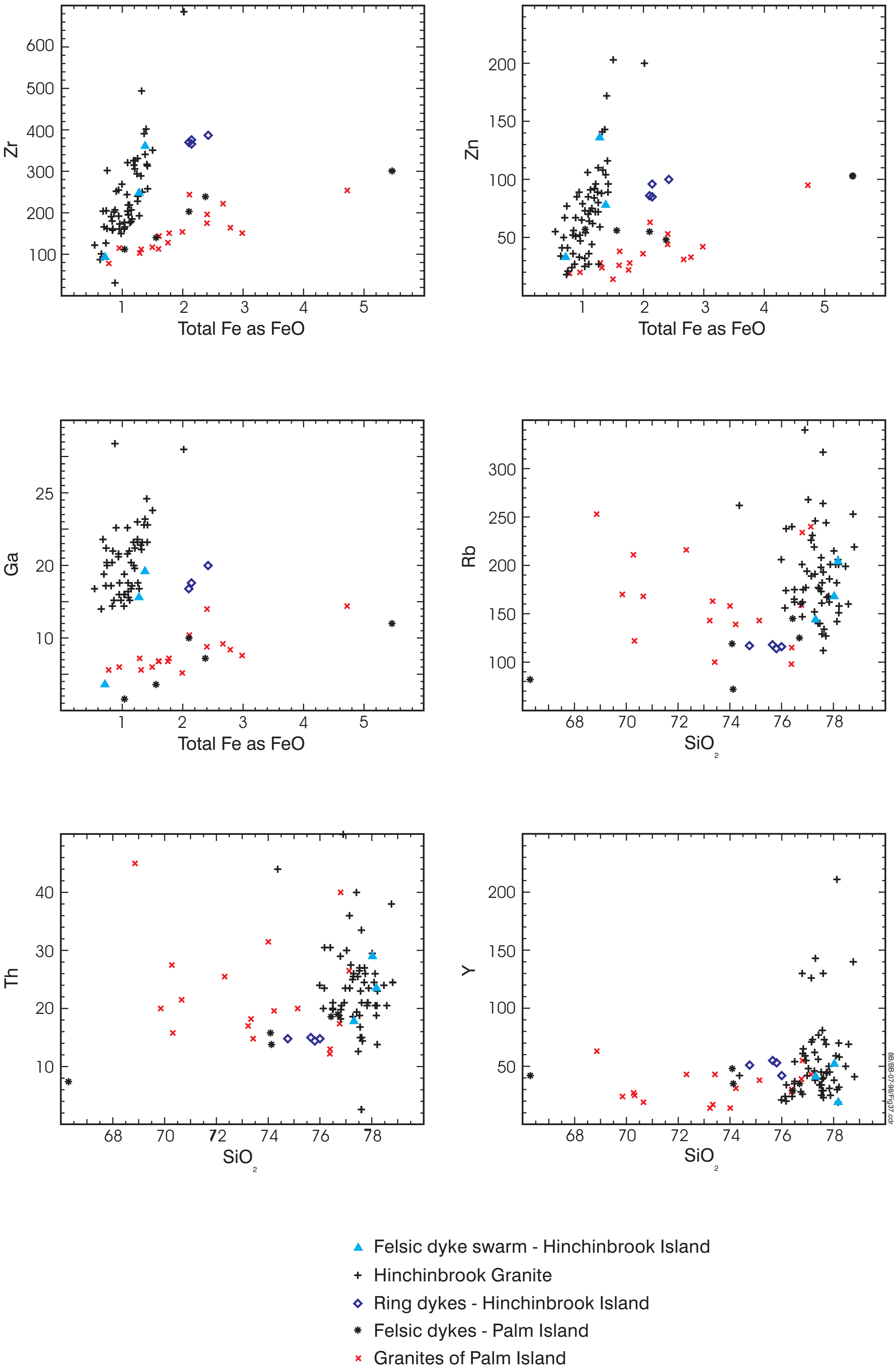


Figure 37. Zr, Zn, Ga, Rb, Th, and Y (ppm) versus FeO or SiO_2 (wt%) plots for the felsic intrusive rocks of Hinchinbrook Island and the Palm Islands.*

marked chemical similarities with the latter, implying the two groups are genetically related.

The rocks in the Hinchinbrook Granite are peraluminous but few are peralkaline — consistent with the low amounts of arfvedsonite present (<2% by volume; Stephenson & others, 1992). They are characterised by an extended range of Nd and Sm concentrations. ε_{Nd} values range from -1.3 to -8.0 (at 275Ma), all but one being <-3.0 (Stephenson & others, 1992; P.J. Stephenson, unpublished data). ε_{Nd} values (-1.4, -3.0; P.J. Stephenson, unpublished data) obtained on two samples of younger felsic dykes overlap with those for the Hinchinbrook Granite, consistent with the interpretation that the two groups were derived from source rocks of the same age and are genetically related. The two samples analysed from the Palm Islands granites have slightly more primitive ε_{Nd} values (-0.2, -0.9; P.J. Stephenson, unpublished data), implying they were also probably derived from a source of essentially the same age as that for the Hinchinbrook Granite.

The granites of the Palm Islands and older granites and granodiorites on Hinchinbrook Island contain hornblende in places and display a fractionation trend more typical of I-types than S- or A-types. P_2O_5 contents, for example, decrease markedly in these granites with increasing SiO_2 (or decreasing FeO*). Th contents generally decrease slightly with increasing SiO_2 (Figure 37), although two samples have anomalously high Th. Rb, K/Rb, Nb, Y, Ga, Ga/Al, ASI, Pb, La, Zr, Zn and Ce either do not change to any significant extent or slightly decrease with increasing SiO_2 (*e.g.* Figure 37); Ba increases slightly. Zr contents of these rocks decrease from ~260ppm in the most mafic representatives to <100ppm in some of the most felsic rocks (Figure 37). In contrast, Zr contents in the Hinchinbrook Granite range from ~600ppm to <150ppm over a very restricted SiO_2 range (~77–78% SiO_2). The contrasting trends displayed by the two groups are similar to those which characterise the late Carboniferous (I-types) and early Permian (A-types) silicic volcanic rocks of the Featherbed Volcanic Group (*e.g.* figures 6A–D, in Bultitude & others, 1996b).

The relationship (if any) between the ring dyke complex and the Hinchinbrook Granite is not as obvious as that between the Hinchinbrook Granite and the felsic dykes. The ring dyke complex has many of the characteristics of the Hinchinbrook Granite, such as elevated Zr, Zn, Ce, La, and Ga concentrations and markedly depleted CaO and Sr contents. However, FeO* contents are significantly higher and some trace element concentrations (*e.g.* Nb, Rb, Pb, Th, U) significantly lower in the rocks of the ring dyke complex. As a consequence they generally delineate fields distinct from those of the Hinchinbrook Granite when selected elements are plotted against FeO* on Harker-type diagrams. In contrast, the felsic dykes of the Palm Islands group have clearer chemical affiliations with the granitic rocks of the group and with the older granites and granodiorites of Hinchinbrook Island (Figure 37), implying they are all probably comagmatic.

KENNEDY PROVINCE — UNASSIGNED UNITS

Several small intrusions in the region (*e.g.* Table 4, Appendix 1) have not been assigned to formal units or supersuites, mainly because of their limited extent and a lack of analytical data.

KENNEDY PROVINCE — ULTRAMAFIC ROCKS

Basic and ultramafic/ultrabasic rocks (<5km^2) have been reported north-west of Black Mountain, at GR 3205 81585 and GR 3365 81585 in the central-east of the region (Rumula 1:100 000 Sheet area; Amos & de Keyser, 1964; Cranfield & Hegarty, 1989). Rock types include serpentinite, carbonate-talc schist, titanite–chlorite–epidote–albite schist, chlorite–magnetite–ilmenite rock, and variably altered gabbro/dolerite (Cranfield & Hegarty, 1989). The rocks are generally extensively sheared.

Another lens of mafic–ultramafic rocks (*Cowley Ophiolite Complex*; Bultitude & others, 1998a) is poorly exposed in the Cowley area, in, or adjacent to, the Russell–Mulgrave Shear Zone. Farther south, serpentinite has been quarried ~3.5km south-east of Silkwood (at ~GR 3976 80366, Innisfail 1:100 000 Sheet area). The ultramafic complex at Cowley consists of metamorphosed serpentinite, talc schist, (talc–) tremolite schist, (tremolite–) chlorite schist and talc–magnesite rocks containing relict peridotite, as well as some gabbro, and basaltic or andesitic dykes (Jones, 1978; Rubenach, 1978).

Small lenses of ultramafic rocks have also been reported on Dunk Island and the North Barnard Islands (Rubenach, 1978). The ultramafic complexes are thought to have been tectonically emplaced in the late Permian–Triassic during the Hunter–Bowen Orogeny. Their age of formation is unknown.

KENNEDY PROVINCE — DYKES

Numerous basic to intermediate and silicic dykes cut the Palaeozoic and older rocks of the region (*e.g.* Bultitude & others, 1993a, 1995, 1996b). Dyke frequency ranges from isolated individuals to numerous closely spaced bodies, forming swarms. The Hodgkinson Formation, in particular, is cut by numerous small swarms of dolerite dykes. The Nychum Volcanics are cut by the Ticklehim Creek Dyke Swarm (Morgan, 1968a) and a smaller swarm of basic to silicic dykes in the eastern part of the Kum Kum Range. Several dykes of distinctive, highly porphyritic to even-grained hornblende basalt/dolerite cut the Barnard Metamorphics and the Tully Granite Complex (Bultitude & Garrad, 1997).

The dykes are typically simple and, in most places, form vertical or sub-vertical tabular bodies ranging from <1m to ~50m in thickness. Some dolerite dykes have been traced for up to 20km on aerial photographs (Halfpenny & Hegarty, 1991). Rare multiple dykes of porphyritic microgranite are present locally, in ring fractures bounding the early Permian volcanic rocks of the Featherbed Volcanic Group.

Most dykes have north-westerly trends, parallel or subparallel to the strikes of beds, prominent foliations, and major faults in the enclosing rocks (Bultitude & others, 1993a).

The ages of the dykes are poorly constrained. None of the dykes has been isotopically dated. The dykes are essentially unmetamorphosed, and the majority cut early to middle Palaeozoic rocks of the Hodgkinson Province. Some intrude late Carboniferous–Permian igneous rocks of the Kennedy Province. No dykes have been found in the Mesozoic rocks in and adjacent to the region. The majority of the dykes, therefore, were most probably intruded in the Carboniferous and Permian.

The range in compositions, textures, and degree of alteration imply several episodes of dyke emplacement. Some younger (Cainozoic) basic dykes are associated with the Cainozoic basalts of the region. The pyroclastic deposits on Stephens Island, for example, are cut by several well exposed olivine basalt dykes, up to ~2m thick.

KENNEDY PROVINCE — INTRUSIVE BRECCIAS

Several small breccia pipes are exposed in the central-west of the region (Bultitude & others, 1993a, 1995, 1996b). They form circular to elliptical pods ranging from a few metres in diameter to ~500m in length, in mainly Hodgkinson Formation rocks.

The breccia pipes are generally located on faults or are exposed adjacent to small granite stocks (in particular, those of the Prices Dam Igneous Complex); rarely, the zone of brecciation cuts a granite pluton.

The breccias are thought to have resulted from explosive hydrothermal activity related to the extensive late Carboniferous–early Permian magmatism which took place in the south-western part of the region. The breccias are of interest to the mineral exploration industry because of their potential to contain anomalously high metal concentrations. Similar breccias are also present west of the Palmerville Fault (*e.g.* Bultitude & others, 1998b).

MESOZOIC SEDIMENTARY ROCKS

Pepper Pot Sandstone

The Pepper Pot Sandstone (Ball, 1917; de Keyser & Lucas, 1968), of probable early Triassic age , is a spectacular cliff-forming unit of mainly lithofeldspathic to quartzose sandstone, and subordinate conglomerate and conglomeratic sandstone (Table 1). The conglomeratic rocks contain unsorted, subrounded to well-rounded granules to small boulders (in the lower part) of quartz, quartzite, chert, jasper and arenite, most of which have been derived from the Hodgkinson Formation. Rhyolite clasts of Featherbed Volcanic Group type, with minor dacite? and other igneous fragments (including a range of granite types) are very common in conglomeratic units in the lower part of the sequence. In contrast, igneous clasts are relatively rare in the upper part of the unit, although scattered pebbles and small cobbles of rhyolite were invariably present in the conglomeratic rocks examined on top of the mountain (*e.g.* at GR 2668 81399, GR 2672 81407). Maximum clast size decreases (to an average of medium to large pebbles) upwards. The ratio of sandstone to conglomerate also increases with height in the section. The rocks, particularly the sandstones, commonly have a haematitic cement which imparts a purple to brick-red colour. Contacts between the purple to red rocks and white, brown or grey rocks transgress bedding planes in places (Oversby & others, 1997). The haematitic cement therefore appears to have resulted from weathering-induced leaching rather than representing an original depositional feature.

The presence of plant fossils, of conglomerate and pebbly sandstone lenses delineating stream channels and washouts, and coarse torrential current bedding, indicate a fluviatile depositional environment. Descriptions of core from DDH1 by McElroy & Bryant (1981) with fining upwards sandstone layers in a predominantly fine-grained sequence implies a meandering stream-dominated environment — the thicker mudstone layers representing lake deposits.

According to Ball (1917) the Pepper Pot Sandstone overlies the Mount Mulligan Coal Measures in the State mine with a slight angular discordance. De Keyser & Lucas (1968) also noted that the wedging out of the underlying Permian strata to the south may indicate a slight angular unconformity. However, Oversby & others (1997) reported that the contact appears to be gradational in core examined from a hole drilled (at GR 2670 81407, Mount Mulligan 1:100 000 Sheet area) through the contact and in some outcrops in the north. They postulated that the basal part of the Pepper Pot Sandstone may belong to the same depositional cycle as the coarse upper part of the underlying Mount Mulligan Coal Measures. Rocks of the former at the contact are everywhere coarser than the adjacent underlying rocks and are commonly purple (Oversby & others, 1997). The main distinguishing features, other than colour, between sandstones of the two units are higher quartz, lower lithic, and much lower detrital muscovite contents, together with the absence of carbonate cement and coal and carbonaceous fragments in the rocks of the Pepper Pot Sandstone (Oversby & others, 1997).

Kondaparinga Formation

More than 200m of interlayered claystone, mudstone, siltstone, sandstone and minor granule conglomerate were intersected in the upper part of a hole drilled at GR 2609 81366 (Mount Mulligan 1:100 000 Sheet area), on top of the Mount Mulligan massif (McElroy & Bryant, 1981). Palynological studies indicate at least the upper part of this sequence, which has been informally referred to as the Kondaparinga Formation, is middle Triassic (Price, in McElroy & Bryant, 1981). The sequence overlies coarser grained, more massive sandstone and conglomerate of the Pepper Pot Sandstone in the southern half of the mountain. The relationship between the two sequences is uncertain.

Development of the Pepperpot Basin

The most likely setting for deposition of the sedimentary rocks forming Mount Mulligan is a rift (Pepperpot Basin). The presence in the Mount Mulligan Coal Measures of a coarse-grained basal sequence dominated by locally derived clasts deposited in alluvial fan and mass-flow deposits, overlain by meandering stream/lacustrine deposits indicating possible axial palaeoflow, and a subsequent return to coarser grained braided-stream deposits is typical of deposition in grabens and half-grabens (Blair & Bilodean, 1988).

The depositional environment of the Pepperpot Sandstone differed little from that for the Mount Mulligan Coal Measures. However, deposition extended farther south. The rift may also have controlled deposition of the Triassic sediments or, alternatively, they may have accumulated in a sag basin.

Other units

Rare small residual mesas of Mesozoic sandstone, conglomeratic sandstone and conglomerate cap the multiply deformed

Hodgkinson Formation rocks north-east of Maytown. These outcrops are erosional outliers of the nearby *Laura Basin* succession (Bultitude & others, 1998c,d).

Small, scattered outcrops of sandstone and conglomeratic sandstone also unconformably overlie Chillagoe Formation rocks south of the Palmer River (Bultitude & others, 1998d). The rocks are commonly extensively ferruginised and, unlike those north-east of Maytown, have little or no topographic relief — in fact, they generally crop out at lower levels than the nearby limestones of the Chillagoe Formation.

Mesozoic rocks of the *Carpentaria Basin* succession crop out east of the Palmerville Fault in the central-west of the region. They have been mapped as part of the *Gilbert River Formation*, of late Jurassic?–early Cretaceous age (Bultitude & others, 1995). The outcrops consist mainly of clayey quartzose sandstone, and minor interlayered conglomerate, conglomeratic sandstone, glauconitic sandstone, siltstone, mudstone, and shale.

Clasts in the conglomeratic lenses consist mainly of angular to rounded fragments of quartz, chert, silicic volcanic rocks, quartzite, arenite, and gneiss. The sediments were deposited in a fluviatile (lower part) to shallow-marine (upper part) environment (Smart & others, 1980).

CAINOZOIC VOLCANIC ROCKS

The Cairns Region contains three Cainozoic basalt provinces and part of a fourth, namely (from north to south) the Piebald, McLean, Atherton and Wallaroo Provinces (terminology of Stephenson, 1989), as well as the small Mount Fox volcanic field. All are *lava field* provinces. Their age distribution does not show any relationship with the northward motion of the Indo–Australian plate over a mantle plume. The common presence of mantle xenoliths and high-pressure megacrysts indicates the primitive or near-primitive character of many of the basaltic rocks.

Piebald Province

The Piebald Province consists of several relatively small areas of basalt north-west of Cooktown — namely, at the head of the Starke River, in the valley of the Morgan and McIvor Rivers (McIvor River Basalt, Bultitude & others, 1991), and to the west of Hope Vale. The volcanic rocks overlie Mesozoic sandstone of the Laura Basin, as well as younger (Cainozoic) sediments. Fourteen volcanic vents have been recognised, scattered over an area of ~$140km^2$. They include some highly dissected pyroclastic cones and residual basalt hills (which may represent remnants of small shield volcanoes; Stephenson, 1989; Bultitude & others, 1991). Aeromagnetic data indicate a close correlation between volcanic vents and magnetic highs (Bultitude & others, 1991). The absence of known vents associated with several of the magnetic highs implies either (1) the presence of unmapped vents or, (2) the presence of sub-surface pipes and/or dykes. Two K–Ar whole–rock determinations indicate a limited age range from ~1.6Ma to 1.2Ma (Stephenson, 1989). Other age estimates range from >3.0Ma to 0.2Ma (Bultitude & others, 1991).

Bultitude & others (1991) subdivided the Piebald Province of Stephenson (1989). The McIvor River Province consists mainly of valley-fill lava flows with very minor pyroclastic deposits. In contrast, the remaining part of the Piebald Province is dominated by numerous pyroclastic and composite vent-type deposits.

Most of the basaltic rocks in the Piebald Province contain phenocrysts of olivine and subordinate clinopyroxene. Analysed rocks include basanite, hawaiite, mugearite, and olivine tholeiite (minor). Most are nepheline normative, with SiO_2 contents <51%, and a range of Mg-values[17] from ~65 to ~47. The abundance of lherzolite inclusions is highly variable, ranging from absent to ~20% (by volume). Xenocrysts of spinel, olivine and pyroxene have also been reported; they probably resulted from the disaggregation of peridotite xenoliths (Bultitude & others, 1991). Upper-crustal 'basement' debris, such as sandstone, chert, quartz, quartzite, conglomerate and shale, are common in some pyroclastic deposits (Bultitude & others, 1991).

17 Mg-value = [100MgO/40.32]/[FeO/71.86 + MgO/40.32]

McLean Province

The McLean Province is centred on Lakeland Downs where the volcanic rocks extend over ~96km^2 (Domagala & others, 1993). The province also includes several small isolated lava fields and other volcanic remnants. It contains eighteen recognised vents, including scoria and lava cones and two maar-like structures (Morgan, 1968b; Robertson, 1993). The close association of many of the eruptive centres with faults and shear zones implies their locations are structurally controlled (Morgan, 1968b; Stephenson, 1989; Robertson, 1993).

K–Ar whole–rock age determinations indicate two periods of cone-building volcanic activity, namely between 6.29Ma and 5.12Ma and between 3.6Ma and 3.08Ma — although some undated cones (of mainly scoria) are probably <1Ma (Stephenson, 1989; Robertson, 1993). Zircons from the Mount McLean vent have yielded fission-track ages of 104Ma, 38Ma (considered to represent the age of an early shield-building volcanic event), 9Ma and 3.6Ma. A zircon from nearby Hoskin's vent yielded a fission-track age of 2.6Ma (Robertson, 1993).

Robertson (1993) reported that the older shield lavas consist mainly of transitional basalt, with minor mugearite. These are medium to fine-grained rocks with olivine and less prominent plagioclase and clinopyroxene phenocrysts. Rocks produced during the younger, cone-building activity include nephelinite, analcimite, leucitite, basanite, alkali basalt, hawaiite and mugearite. Many are vesicular and glassy, and olivine is the main phenocryst phase.

Most of the volcanic rocks of the McLean Province have Mg-values between 70 and 58 (Robertson, 1993). Volcanic activity since ~9 million years ago was dominated by eruptions of highly ne-normative, primary or near-primary lavas with Mg-values >65 (Robertson, 1993). The province is characterised by the presence of some highly undersaturated rocks. A small remnant lava flow preserved on the lower western flank of Mount Walker (Annan River valley) contains <40% SiO_2.

Megacrysts and spinel lherzolite inclusions are relatively abundant in the younger ne-normative lavas and pyroclastic deposits. Pyroxenite and granulite inclusions are rare. Clinopyroxene is the most abundant megacryst phase; phlogopite, zircon and anorthoclase megacrysts have also been reported (Robertson, 1993). Alluvial zircon, garnet and rare sapphire have been retrieved from the drainage system of Bull Hollow (a possible maar). Alluvial diamonds have been recovered from the drainage systems of the East and West Normanby and Laura Rivers (Robertson, 1993). The primary sources of these minerals are unknown.

Atherton Basalt Province or Atherton Province

The Miocene–Holocene Atherton Basalt Province (Best, 1960; de Keyser & Lucas, 1968; Denmead, 1971; also referred to as the Quincan Province by Morgan, 1968b, and as the Atherton Province by Stephenson & others, 1980, Stephenson, 1989) extends from north of Mareeba south to the Tully River and from the Mount Garnet area in the west to Stephens and Sisters Islands (South Barnard group), off the coast. The province has an area of ~1760km^2. Fifty two eruptive centres have been identified so far (Stephenson, 1989). The majority of these are located on the Atherton Tableland, but several are in the coastal lowlands. Most investigators have included the products from all these centres in the Atherton Basalt. Willmott & others (1988) defined some discrete areas of basalt in the northern and north-eastern parts of the province as separate formations.

Volcanic landforms

The Atherton Basalt Province contains a range of volcano types including lava shields, composite cones, cinder cones, maars, and one diatreme (Hypipamee Crater). The eruptive centres for most of the lava flows are concentrated in the southern and western parts of the province, the cinder cones in the northern part (de Keyser & Lucas, 1968). The maars occupy a central belt.

The province is characterised by broad lava plains on the Atherton Tableland, which are abruptly terminated in the east by a steep escarpment. Extensive lava flows travelled down several valleys from the tableland. Some of the basalt flows in the valleys of the Mulgrave and Russell Rivers, for example, were erupted from volcanic centres on the Atherton Tableland and descended the 400m-high escarpment (Denmead, 1971; Stephenson & others, 1980; Whitehead &

McDougall, 1991). Another flow, from the small volcano ~1km south of Maalan, travelled down Cochable Creek to reach the Tully River gorge (Stephenson & others, 1980). The relatively young cones at Bones Knob, west of Tolga, produced flows which extended to Mareeba, ~30km to the north.

The maars are relatively young features and have a reported age range from ~200 000 to ~10 000 years B.P. (Stephenson, 1989). Several contain sediments recording significant vegetation changes (Kershaw, 1970). The high rainfall and groundwater conditions are most likely to have been key factors in determining this eruptive style, rather than the presence of abnormally explosive magmas (Stephenson & others, 1980).

Rock types

The volcanic rocks include lava flows and coarse to fine-grained pyroclastic deposits, locally underlain by lacustrine and fluviatile sedimentary rocks (de Keyser & Lucas, 1968; Denmead, 1971). They are generally deeply weathered, particularly in the high rainfall areas where the lava flows are commonly difficult to distinguish from pyroclastic deposits.

The very well-exposed pyroclastic deposits (of mainly coarse to fine tuff, lapilli tuff, volcanic breccia, and scoria) on Stephens Island (one of the few localities in the province where pyroclastic deposits are well exposed) contain numerous angular fragments of metamorphic rocks (mainly biotite-muscovite schist, biotite gneiss and amphibolite) and quartz (up to ~30cm; Bultitude & Garrad, 1997). Jones (1978) also reported fragments of hornblende gneiss. Amphibolite is by far the most abundant exotic rock type represented in the fragments. The amphibolite fragments also tend to be the largest; exceptional examples are up to ~3m across (most <1m).

Elsewhere, columnar jointing is very common in the massive parts of lava flows; good exposures can be observed at the many waterfalls (*e.g.* Millaa Millaa Falls, Mena Creek Falls) for which the eastern part of the Atherton Tableland is renowned.

Some of the lava flows contain small (generally <5cm across), scattered ultramafic inclusions. Localities where numerous xenoliths have been found include Lakes Eacham and Barrine, Mount Quincan, and Gillies Crater. Host rocks are mainly stratified scoria — *e.g.* the Mount Quincan basanite. Mantle-derived peridotite inclusions up to ~30cm across dominate. Inclusions of pyroxenite (several types), as well as scarce granulite and schist have also been reported (de Keyser & Lucas, 1968; Stephenson, 1989). Megacryst species include pyroxene, amphibole, spinel, and anorthoclase (Stephenson, 1989).

Composition

Hawaiite, *ne*-hawaiite, alkali basalt and basanite are the most common rock types represented (Bultitude & Garrad, 1997). More highly undersaturated representatives are very rare. A few samples contain more than 10% normative hypersthene and are *ol*-tholeiitic basalts. None of the samples analysed contain normative quartz.

The rocks have a restricted range of Mg-values which do not extend to low values (Bultitude & Garrad, 1997), in contrast to many other Cainozoic provinces in eastern Australia (particularly the central-type complexes). $^{87}Sr/^{86}Sr$ ratios and ε_{Nd} values range from 0.70391–0.70429 and from 5.2–3.9, respectively (O'Reilly & Zhang, 1995). The relatively restricted range of Mg-values is consistent with the restricted ranges of SiO_2 contents and DIs[18] shown by the lavas (Bultitude & Garrad, 1997). Ewart (1989) noted that the mafic magmas of north Queensland have been less modified by fractional crystallisation processes than many of those elsewhere in eastern Australia, the trends apparently being controlled by augite fractionation.

Age

Basalts from the Lamins Hill volcano range from 1.4Ma (in the valley of the Russell River) to 0.9Ma (on the upper slopes of the volcano; Whitehead & McDougall, 1991). There are also several small, relatively young volcanoes and lava fields in the coastal belt, east of the Atherton Tableland. These include Green Hill (0.986Ma; Muller & Henry, 1982), near Gordonvale and three dated volcanoes in the Innisfail district ranging from 0.803Ma–0.645Ma (P.J. Stephenson, Townsville, written communication, 1996).

One volcano at Bones Knob (GR 3345 80956, Atherton 1:100 000 Sheet area) has been dated at 1.7Ma and the partly enclosing older one at

18 DI = Differentiation Index

1.8Ma (Stephenson, 1989). One of the flows in the Millstream Falls area (in ATHERTON) has yielded an age of ~1.2Ma (Stephenson, 1989). The Fisheries Basalt (Willmott & others, 1988) has yielded a K–Ar isotopic age of 2.2Ma (Whitehead & McDougall, 1991). The Malanda cone is the oldest eruptive centre dated in the province (3.1Ma and 2.9Ma; Stephenson, 1989).

A 7.1Ma-old lava flow is preserved in the catchment of the Wild River (in ATHERTON), at a level well above the 100m-deep Wild River gorge (Stephenson, 1989). This flow is the oldest known in the province, but its source is unknown. Many of the older flows in the Mount Garnet district (south-western ATHERTON), are overlain by up to ~35m of alluvial deposits. The presence of pebbles of Cainozoic basalt in the gravels underlying the lateritic duricrust in Return Creek implies the volcanicity associated with the Atherton Basalt Province may extend back to at least the middle Tertiary (Stephenson & others, 1980).

Wallaroo Province

The small Wallaroo Province is located ~50km south of the Atherton Province and straddles the boundary between the Cairns, Clarke River, and Georgetown Regions. The lavas (maximum thickness of ~50m) flowed down a former valley of the Herbert River (Stephenson, 1989). Four volcanic centres have been identified, three of which have yielded ages ranging from 6.04Ma to 10.3Ma (Stephenson, 1989, personal communication 1996; Withnall & Grimes, 1995). Petrographic criteria indicate most of the lavas are alkali basalts. However, the Wallaroo Province is the only Cainozoic basaltic province in north Queensland in which tholeiitic rocks containing phenocrysts of hypersthene have been found (P.J. Stephenson, Townsville, personal communication, 1996).

Mount Fox volcanic field

The Mount Fox volcanic field is on a dissected plateau ~45km south-west of Ingham. The field, which has been described by Sutherland (1977), includes plugs (two of which have yielded ages of ~22Ma and 21Ma) and undated flow remnants in the same area (Stephenson, 1989). Mount Fox volcano is a much younger pyroclastic cone, more than 120m high, containing a shallow infillled crater from which a lava flow extends south-westwards from the southern base of the cone. Older flow remnants overlie Tertiary sediments, including stanniferous gravels, and mainly form ridge cappings defining former drainage channels (Stephenson, 1989). Young (1.5Ma) lherzolite-bearing basanite flows descended the coastal escarpment into the Stone River valley (Stephenson, 1989).

CAINOZOIC SEDIMENTS

Cainozoic units in the region consist mainly of:

1) coastal deposits,

2) dune fields which have developed adjacent to the coast,

3) colluvial and residual deposits derived from the local bedrock, and

4) deep weathering profiles and duricrusts (ferricrete, minor silcrete), probably of several ages.

The deposits are most extensively developed along and adjacent to the coast, particularly in the north-east and south-east of the region. None, except for those in the Cairns and Cooktown areas (Willmott & others, 1988; Bultitude & others, 1991) has been examined in any detail.

The oldest deposits in the Cooktown area consist of deeply weathered (mottled and ferruginised), poorly sorted mudstone, fine-grained sandstone, and minor conglomerate (Bultitude & others, 1991). They are mainly thick-bedded to massive and moderately to highly indurated. Younger (late Tertiary–Quaternary) sediments are interbedded with basaltic rocks of the Piebald Province. These sediments, which are similar to those described above, also show some mottling and ferruginisation (Bultitude & others, 1991). The two groups are commonly difficult to distinguish.

Elsewhere, volcanic rocks of the Atherton Basalt Province overlie poorly exposed, deeply weathered Tertiary sedimentary rocks and younger alluvium in many places south and east of Malanda (*e.g.* near the head of the North Johnstone River; de Keyser & Lucas, 1968). Stephenson & others (1980) reported occurrences at the North Johnstone River 6km east of Malanda, in the Jaggan–Tarzali area, and in West Butcher Creek (at the end of Lud Road) ~12km north-east of Malanda. The main rock types are shale and sandstone, but some thin beds of waxy to dull black lignite, impure coal, and thicker beds of low-grade oil shale have been reported (Denmead, 1947a; Stephenson & others, 1980). The oil shale contains well-preserved dicotyledonous leaf impressions and plant pollens (Kershaw & Sluiter, 1982). Auriferous gravels (deep leads) beneath basalt in the upper Russell River (Boonjie) area were mined in the mid 1880s–early 1900s.

The youngest fluvial deposits form floodplains and terraces along major watercourses. They comprise unconsolidated to firm mud, sand, and gravel. Older beds locally show some mottling. More steeply sloping alluvial-fan deposits have developed on the sides of valleys. In places they grade upslope and laterally into poorly sorted talus deposits.

There are aprons of *alluvial and talus deposits* on the lower slopes of the main ranges. These grade upslope into exposed bedrock and downslope into alluvial fans and flats. The composition of these deposits is controlled by the parent bedrock. The older colluvial slope deposits are deeply weathered, partly indurated, and dissected so that they form ‘flatirons’ above the modern-day slopes.

The onshore coastal deposits have resulted from the interaction of sediment supply from rivers and fluctuations in sea levels since at least the late Pleistocene (Bird, 1970, 1971, 1972a, b, 1973; Jones & Stephens, 1983, 1984; Jones, 1985). They have been subdivided into several morphostratigraphic units. Sandy beach ridges are present in some bays. Sandy and muddy coastal swamps are present between and behind the beach ridges. Tidal flats of mud and sand are developed in the major estuaries and between the younger beach ridges.

The extensive coastal plain in the Ingham district represents a delta built up by the Herbert River. The deposits consist mainly of clay, sandy clay, mud, sand, gravel, and conglomerate (de Keyser & others, 1965). They attain a maximum thickness of more than 96m (de Keyser & others, 1965). The age of the alluvium probably ranges back to the Pleistocene, or possibly even late Tertiary at the base. The alluvial deposits, except for the most recent ones, are commonly mottled and cemented (de Keyser & others, 1965).

Fossil beach sands are extensively developed south-east of Mourilyan, where they extend up to ~10km inland (de Keyser, 1964). The deposits originally formed sand spits and bars, behind which former lagoons have been silted up. The deposits grew and shifted northwards under the influence of long-shore currents caused by the prevailing south-easterly trade winds.

Dunes are present along parts of the coastal belt. Extensive dunefields have developed between Cape Bedford and Cape Melville; smaller deposits are present along Ramsay Bay on Hinchinbrook Island, as well as elsewhere. The deposits in the Cape Flattery area have been divided into three age groups, based on the degree of degradation and the depths of the soils developed on them. All consist of well-sorted, fine to locally medium-grained quartz sand.

The oldest (Pleistocene) dunes are characterised by rounded ridges (crests) and deep soils. The soils have leached A2 horizons >7m deep, and thick, deeply coloured B horizons.

The intermediate dune unit is characterised by long, straight ridges with moderately sharp crests. These ridges are the trailing arms of large parabolic dunes. Some extend inland for more than 20km. Observed soil depths range from 2m to 3.4m (Bultitude & others, 1991).

The youngest dunes are of Holocene age and include those which are currently active. They have sharp-crested ridges — both long and straight, and smaller complex parabolic types. Soils are poorly developed. These dunes probably developed under the influence of the strong prevailing south-easterly winds which buffet the exposed parts of the coast line. The winds have reworked an abundant supply of sand by blowing out pre-existing beach ridges which are now destroyed.

The silica mine at Cape Flattery is working mainly blowouts and Holocene dunes which have formed from the reworking of older leached A2 intervals of Pleistocene dunes. This process has yielded deposits of much higher purity than those in dunes derived directly from present-day coastal sands.

CORRELATIONS — INTRA AND INTER-REGIONAL

The oldest rocks of the region are in the Barnard Metamorphics. The formation is intruded locally by the Tam O'Shanter Granite which has yielded a U–Pb zircon (SHRIMP) age of 486±10Ma. The enclosing supracrustal rocks are, therefore, older than early Ordovician; they are currently thought to be most probably Neoproterozoic to Cambrian?.

The Barnard Metamorphics, therefore, may correlate, at least in part, with metamorphic rocks thought to be of similar age (early Palaeozoic or late Proterozoic) poorly exposed farther south in the Charters Towers (Wyatt & others, 1970; Paine & others, 1971; Withnall & McLennan, 1991)and Belyando (Withnall & others, 1996) Regions. In particular, the Argentine Metamorphics and Anakie Metamorphic Group are similar lithologically to parts of the Barnard Metamorphics, consisting of metapelite and quartz-rich metapsammite (Withnall & others, 1996). The Cape River Metamorphics, in the western part of the Charters Towers Region, also contain abundant quartzite. The Barnard Metamorphics may, in fact, represent the northern extremity of a Neoproterozoic–early Cambrian? orogenic belt which extended from the Transantarctic Mountains for almost the entire length of eastern Gondwana.

The unfossiliferous (apart from abundant radiolarians in chert lenses) Mulgrave Formation is thought to be the oldest unit in the Hodgkinson Province. The unit is characterised by distinctive quartzose arenite as one of the major rock types. It has been correlated with the lithologically similar Judea Formation of the Broken River Province (Bultitude & others, 1993a), the sedimentary part of which has been dated as early Ordovician (Withnall & Lang, 1993; Withnall, 1997a). The unit may also correlate with Ordovician quartzose turbidite deposits in the Lachlan Fold Belt of south-eastern Australia (*e.g.* Crook & Powell, 1976; Fergusson & Colquhoun, 1996).

The overlying Mountain Creek Conglomerate contains lenses of late Ordovician (Ashgill) limestone in its lower part (Bultitude & others, 1993a). The unit is, therefore, of similar age as the Carriers Well Limestone in the Camel Creek Subprovince (Broken River Province), the Fork Lagoon beds in the Anakie Province, and the Rosenthal Creek Formation of the Silverwood Group in the Warwick–Stanthorpe area (Wass & Dennis, 1977; Palmieri, 1978). Late Ordovician strata are also exposed farther south in the Tasman Fold Belt in northern and southern New South Wales and Victoria (Philip, 1966; Beavis, 1976; Cawood, 1976).

The early Silurian (late Llandovery)–early Devonian (early Emsian) Chillagoe Formation of the Hodgkinson Province correlates, at least in part, with the Graveyard Creek Group (late Llandovery–Lochkovian?) and Kangaroo Hills Formation (Silurian?–early Devonian) of the Broken River Province to the south.

Whether or not there was a significant break/unconformity between the Chillagoe Formation and Mountain Creek Conglomerate is uncertain. Bultitude & others (1996b) postulated there may have been an erosional break, corresponding with uplift related to the intrusion of the Nundah Granodiorite in the nearby Etheridge Province (Georgetown Region) to the south-west. The juxtaposition of the east-younging Mountain Creek Conglomerate against west-younging rocks of the Chillagoe Formation is consistent with such an interpretation.

The Nundah Granodiorite has yielded a U–Pb zircon (SHRIMP) age of 434±10Ma. It, therefore, may predate the Chillagoe Formation and correspond to an unconformity at its base. Furthermore, Withnall (1997c) postulated a significant deformational event in the late Ordovician or early Silurian which produced mylonite zones and thrust faults in the eastern Georgetown Region prior to the commencement of deposition of the Graveyard Creek Group in the Broken River Province (in the late Llandovery). The presence of a foliation in some middle Palaeozoic granites of the eastern Georgetown Region, now known to be ~425Ma and older, is also consistent with a very late Ordovician or very early Silurian deformation.

There was a major change in the style of sedimentation in the Hodgkinson Province in about the late Pragian–early Emsian (at

~400Ma). Uplift of basement blocks to the west and extensive granite emplacement approximately coincided with a marked deepening of the basin to the east, resulting in the deposition of coarse conglomerates along much of the western part of the province.

Granites of the Cape York Peninsula Batholith have yielded a pooled age of ~407Ma (Black & others, 1992a, b). Isotopic ages in the range from ~380Ma to ~420Ma are also common in the granitic and metamorphic rocks of the Etheridge Province (Georgetown Region), and in the granites of the Charters Towers Region (*e.g.* table 6.8 in Hutton & others, 1997; Bain & others, 1997).

The Carboniferous–Permian intrusive and volcanic rocks of the Cairns Region form part of a very extensive late Palaeozoic igneous province (Kennedy Province) developed throughout much of north Queensland. A noteworthy feature of this province is the dominance of felsic, commonly fractionated, compositions.

MINING HISTORY

P.D. Garrad

Detailed mining histories are given in Idriess (1938), Kerr (1979, 1989, 1991), Lam & others (1988, 1991), Culpeper & others (1990, 1994), Bruvel & others (1991), Dash & others (1991), Denaro & others (1992, 1994a), Dash & Cranfield (1993), Garrad (1993), Hooper (1993), Lam (1993), Lam & Genn (1993), Dash & Morwood (1994), Garrad & Rees (1995) and Morwood & Dash (1996).

GOLD

William Hann's expedition of 1872 discovered gold on the **Palmer River**. The following year a group of prospectors led by James Venture Mulligan explored along the Palmer and its tributaries and recovered 102ozs of gold, leading to probably the greatest gold rushes ever seen in Australia. The Palmer Gold Field was gazetted in 1873. Maytown sprang up and quickly became the administrative centre for the whole of Cape York Peninsula. Numerous small outlying settlements such as Echo Town, Revolver Point, German Bar, Stonyville, Byerstown, Groganville and Uhrstown were established. Cooktown was established at the mouth of the Endeavour River to service the gold field and, within months, became one of the busiest ports in Queensland.

By 1875 the population in the Palmer River area was about 20 000 with many outlying creeks and gullies being worked as the shallow alluvial gold deposits of the main river became depleted.

Mining of the auriferous reefs in the Maytown district commenced soon after the discovery of alluvial gold, output peaking in 1888–1889. Very little lode mining was carried out after 1893. Cyanide treatment of tailings met with some success in 1898. From the early 1900s to the 1980s many attempts were made by companies and syndicates to de-water and reopen the mines but they all failed.

Alluvial gold was discovered in the **Hodgkinson Gold Field** between 26th January and 7th February 1876 by two separate parties of prospectors. The first was led by the well-known explorer, James Venture Mulligan, and the second comprised McLeod, Sefton, Kennedy and Williams. A rush of miners soon followed and about 2000 men were soon working the meagre alluvial deposits. Many of the men left the field soon after, disillusioned and regarding the field as a 'fizzer'.

Although geologically similar to the Palmer Gold Field, the Hodgkinson Gold Field was primarily a lode mining area. The only recorded alluvial production figures are for 1876–1879 when 1 088kg gold were won with an additional 120.3kg gold obtained between 1881–82 for the whole field (Denmead, 1923). The Gold Field was proclaimed on 15th June, 1876. Crushing machines were quickly brought to the field. The Glen Mowbray machinery site was the first established, with crushing commencing on the 1st December, 1876. Eight machines were operating on the field within a year of its discovery and another four arrived the following year. By 1877, the township of Kingsborough had a population of 1100 and Thornborough 1000. A network of rough tracks provided access from Cairns, Port Douglas and Smithfield. Intensive mining activity continued until around 1897. Alluvial and near-surface lodes were mined at first, and only the larger reefs were being worked past the turn of the century. Intermittent alluvial and small-scale lode mining operations have occurred since these early boom times.

Beaconsfield also known as 'Beaconville', is located in the eastern part of the Hodgkinson Gold Field. The largest mine (the Monarch) was discovered in 1876 by W.M. Thompson. The first machinery reached the Monarch mine late in October 1877. The area was worked from 1877–1900 and subsequently only intermittently. The most recent mining occurred in 1992 when ~0.33kg of alluvial gold was mined from a gully draining the lode.

Mining of quartz–stibnite–gold reefs in the **Northcote** area commenced as early as 1877. By 1892 the Emily lode in the area was being worked for gold, while the Ethel lode was the main antimony producer. Two towns were established to accommodate the miners. Northcote was the main centre from 1877–1887, and provided access to the gold mines to the west of the main Northcote area. New Northcote, the other centre, was close to the Emily mine and antimony smelter. Production continued in some of the mines up to 1927, most of the production occurring in the period from 1878–1900. Production recommenced briefly between 1940–1942. Intermittent mining took place up to 1991.

The Moxham brothers discovered gold in several quartz reefs in the Minnie Moxham area soon after the rush to the Hodgkinson Gold Field. The first recorded crushing was in July 1878. Most of the gold was produced between 1878–1886 and between 1893–1895. Production continued at a slower rate from 1897–1902, from 1911–1940, and from 1949–1950. The total gold production up to 1987 was ~700kg . Although stibnite is a common accessory mineral in the quartz reefs, no antimony production was recorded from this mine. In 1988 a decline was constructed to access the old workings at the 69m level and open-cutting commenced to the east and west of the main shaft. A 100 000t per annum carbon-in-leach (CIL) plant incorporating a gravity recovery section was built on site and treated ore until mid-1990. About 110kg of Au bullion were produced in the two year period. The operation was not economic and the company went into liquidation. The mine and plant were placed under care and maintenance and later sold to Nittoc International Co Ltd. The plant was reopened in 1991 to extract gold from ore mined in the nearby Northcote area.

Very little has been written about the **Mulgrave Gold Field** other than brief descriptions in ARDMs and reports published by Jack (1893) and McConnell & Carver (1984b). The earliest report of alluvial gold workings for the Mulgrave River is 1879. Dempsey (1980) reports the discovery as October 1879. These activities encouraged prospectors to explore the area now known as the Mulgrave Gold Field. This gold field was proclaimed on 1 July 1880 and encloses a large tract of mountainous country bordering the Mulgrave River. There were three main centres; Goldsborough (Lower Camp or Fanning Town), Top Camp (Upper Mulgrave) and Kraft Creek (also informally called the Bartle Frere Gold Field). The total gold production from 1879–1942 (from both reef and alluvial sources) was 206kg of gold, made up of 130kg derived from alluvial sources and 76kg from auriferous quartz reefs.

The Goldsborough area is located on the western bank of the Mulgrave River at its junction with Toohey Creek. The Chance group of workings is located on the largest and richest deposits. In 1880, a Cairns syndicate installed the first mining plant on the field, a five head battery called the General Roberts Mill.

The area referred to as 'Upper Camp' is located about 7km south of Goldsborough, in rugged country between Butcher and Machinery Creeks. The area was first mentioned in the 1881 ARDM and by 1888 the area was being actively mined. The Upper Camp area contains mainly hard-rock mines, the Walter Hodgson and Orient-Mowbray being the largest workings. The first battery in the area, called the Mowbray Mill, was established in 1882 (later referred to as the Mount Orient battery). This battery was situated on Toohey Creek below the Orient-Mowbray mine, the ores being transported down the steep rugged slope by a rail bucket system. These operations were abandoned in 1897 because of poor grades. The Walter Hodgson mine, discovered in 1887, was the longest operating mine in the Mulgrave Gold Field. The reef was worked via several adits to a depth of 90m.

The main production of alluvial gold in the Mulgrave gold field has been from the Swipers Flat area. The area was the site of a small gold rush in 1890. In 1934 the area was worked by sluicing but no production was recorded.

In 1884, the Palmer Gold Field boundary was expanded to include the lodes in the **West Normanby River area**, located approximately 80km south of Cooktown. Some of the leading gold mines in the West Normanby field at that time were the Monte Christo, Star of Normanby, Isabella, Edna, Emily, Poverty and Zig-zag. By 1898, most of the miners had left the field and did not return until The Brothers deposit was discovered around 1900. From 1916 onwards, virtually no mining was carried out in the area, until increasing gold prices in the 1970s revived exploration interest in the field.

The discovery of gold in the **Sandy Creek/North Johnstone River** area was first reported in the Cairns Post on 18 December 1884. This report precipitated a rush of prospectors to the area known as the '**Johnstone diggings**' in the following year. This rush included three to four hundred Chinese. This mining activity was short lived as the gold grades in the alluvium were poor.

The **Russell River Gold Field** was worked intermittently between 1887–1959, 680.4kg of Au and possibly as much as 100t of cassiterite concentrates being produced; 586kg of gold were extracted between 1891–1901. This figure is too low due to the practice of not tabulating alluvial production figures in the earliest ARDMs and the lack of regulatory bodies to monitor production. Dempsey (1980) quoted a figure of 3 000kg of gold produced from the Astronomer mine alone (the largest workings on the field) whereas de Keyser (1964) recorded 833kg as the estimated gold production for the entire field.

The region was discovered in 1886 by Christie Palmerston and a colleague, Svenson, who decided to investigate the area to the north of the North Johnstone River. On a second visit to the area, Palmerston met Clarke and Joss (an old colleague) who prospected the discovery area but moved into Coopooroo Creek where most of the deep leads occur (the Boonjie Terraces). News of the discovery prompted a rush of miners in 1887. The gold field was proclaimed in September 1887. In 1890 two smaller rushes occurred in the field; these were in the Five-Mile and Nine-Mile areas. They were short lived, the deep-lead deposits being of limited extent.

Alluvial gold in deep-lead deposits was the primary target. Cassiterite was also obtained as a by-product of some mining operations. Minute flakes of platinum have also been found in the gold bearing alluvium in places. The principal method of mining the deep leads was by tunnelling below the basalt capping and following the auriferous wash. This method was eventually replaced by larger-scale sluicing. The water for these operations was channelled to the faces being worked along a total of 64km of races. Faces up to 20m high were worked using this method.

Gold-bearing quartz reefs were discovered at Cocoa Creek in 1890 but were abandoned by 1893. This area became the **Starcke No. 1 Gold Field** and was gazetted in 1895. Stibnite-bearing lodes were found in 1893 but no antimony production was recorded.

The reef-gold deposits of the **Towalla** area were first mentioned in 1892 by the local Mining Warden. The area has also been referred to as the **Russell Extended Gold Field**. After 1907, the area was incorporated into the Russell Gold Field. The total production from this gold field is 155kg of gold, obtained between 1889 and 1907. Lode gold mining contributed 137kg, alluvial gold making up the remaining 18kg . It was not until 1893 when a gold rush occurred to the area that the main period of mining commenced. The rugged, often inaccessible, rainforest-covered region forced most prospectors to leave by 1898. The creeks and gullies of the area were also worked for alluvial gold. Mining activity had ceased by 1900 and the gold field lay abandoned until 1941 when the Python mine commenced processing ore from extensive underground operations at Towalla. Operations ceased in 1943 due to a shortage of manpower as a result of World War II. The area was never reopened.

The **Clohesy River** deposits were first reported in 1891. Most recorded production came during the period 1894–1898, when a 5 stamp battery and 3 berdans (grinding) pans were in operation. Intermittent mining occurred between 1905–1951. The most recent attempts to reopen this deposit were between 1983–1990. The total production was at least 40.242kg of Au from 2453t of ore. The main mines were the Waitemata, Black Snake, Black Bear and Hill Top. The Golden Mile and Thirty Three Mile Creek were the main alluvial workings. The Waitemata was the largest mine in the Clohesy River area and accounted for about 70% of the total production.

In 1896, payable alluvial gold was discovered in Kitty Gully, 7.5km west-north-west of the Old Starcke Camp. The new discovery was known as Munburra, and the **Starcke No. 2 Gold Field** was proclaimed in 1898. Gold-bearing quartz reefs were discovered in the same year. Several companies worked the reefs up until mining ceased in about 1913.

The **Jordan Gold Field** (which includes the Johnstone diggings) was proclaimed on the 18th March 1896 and includes the area between the Beatrice and South Johnstone Rivers. The total amount of gold produced from this gold field is 401kg, obtained between 1898–1981. The reef-gold production was 158.5kg, most of the remaining 242.547kg probably being derived from alluvial operations.

The area around Jordan Creek, the main mineralised area, was discovered by two prospectors, McNeil and Donaldson, during 1897–98 (Dempsey, 1980). The main workings were concentrated about Henrietta and Jordan Creeks (tributaries of the North Johnstone River) where several batteries were constructed in about 1900. Initially, the easily won alluvial deposits were mined, most of the gold before 1903 being extracted by sluicing. Activity on the field dwindled as the alluvial and lode deposits were worked out, and the field was virtually abandoned by 1918. The Wyreema mine was the only lode mine operating between 1904–1918. Mining activity resumed in 1931. Both the lode and alluvial operations were concentrated around the Wyreema mine and in the Little Beatrice River area. This activity ceased in 1943 because of a shortage of manpower as a result of World War II. The region lay abandoned until 1949 when small-scale gold mining commenced at several of the historic mines. This low level of activity continued until the 1980s when most of the area was World Heritage listed.

The **Mount Peter Provisional Gold Field** is located in Sawmill Pocket, in the ranges behind Edmonton. Peter Petersen, after finding traces of gold in his cultivated paddock, prospected the adjoining hills for the source and discovered the Mount Peter reef in 1913. Other reefs were discovered soon after and the Mount Peter Provisional Gold Field was proclaimed two years later on 16 July 1915. The total gold production from the Mount Peter Provisional Gold Field is 314kg. The largest deposit (accounting for one third of the field's total production) and deepest workings occur along the Talisman reef. Initially ores won from the various reefs were crushed at a five head battery erected near the Mount Peter mine. With increasing depth sulphide-rich ores were produced and these were taken to the Chillagoe State Smelters or Venus battery (Charters Towers) for treatment. Mining occurred in three main periods, namely: 1915–1925, 1931–1943 (the main period of activity), and 1946–1970s. The last phase of mining was dominated by small operations on the historic workings centred around the Talisman and a new deposit called the Lady Lyn.

Small gold mining operations have taken place at the **Culpa diggings**, **Freshwater Creek**, and **Eubenangee** area. The Culpa diggings are situated on the Tully River, upstream from Koombooloomba Dam. Mining operations concentrated on gold-bearing alluvial terraces along Culpa Creek. Alluvial gold has been reported in the headwaters of Freshwater Creek, located several kilometres west of Edmonton. The area was the site of a small alluvial gold rush prior to 1919. The Eubenangee area was first mentioned in 1924 when alluvial gold was found on Portion 12, Parish of Glady. This discovery was shortlived and the area abandoned by 1926.

The **Kraft Creek** area was also locally called the **Bartle Frere Gold Field**, although it was not a gazetted gold field but part of the Mulgrave Gold Field. It was discovered in about 1931 by W. Kraft and S. Wilkie (Tramp, 1937), who traced alluvial gold found in the Mulgrave River upstream to its source. The gold was found to be shedding from quartz reefs located on the northern slopes of Mount Bartle Frere in 1936. The discovery attracted considerable attention, with more than 100 leases being pegged by the middle of 1937 over the ten major reefs and alluvial/eluvial deposits. The inaccessible nature of the area and steep topography hampered mining operations. The total gold production for the area is ~14kg. The gold was produced between 1937–1942 and represented the only production from the Mulgrave Gold Field for that period. The main method of mining was by hand-picking quartz floaters from the creeks and hillsides in the area of the original discovery. The Mount Morgan Development Company investigated two of the most promising reefs (Key of the Hills and Krawil) during 1937 and 1938 by driving adits. The results of this work were disappointing and the area was abandoned by the company.

Initially the ore was packed by horse to Babinda and then forwarded to the Chillagoe State Smelters, a costly exercise, which attests to the rich nature of the ore. In 1939 a five head battery and several smaller batteries were erected in the area. These had all been abandoned by 1942.

In the late 1970s, several companies commenced mining alluvial gold in the Mammoth Bend and Four Mile Bend areas of the Palmer River and in the West Normanby River. Alluvial tin production increased significantly in the 1970s, following rising tin prices, and peaked in the mid-1980s. Interest in alluvial gold mining increased significantly in the early 1980s as the result of a sharp increase in the gold price and falling tin prices in the mid-1980s. The Palmer River and its tributaries, especially McGann, Stony and Sandy Creeks, and the gullies draining Mount Madden were all worked. Fine Gold Creek, a tributary of the Saint George River was also the focus of extensive alluvial mining. Small-scale mining is currently being carried out in the Palmer, North Palmer, South Palmer, and Little Palmer

Rivers areas, particularly along small gullies draining the old lode workings.

Recently, a revival of lode gold mining in the West Normanby area was signalled by the opening of Maddens mine.

Open-cut mining of gold–stibnite–quartz lodes in the **Northcote** area was carried out from October 1991–July 1992 by Nittoc International Company Ltd. The main deposits worked were the Emily, South Emily, East Leadingham, Ethel and Black Bess. The total production from these mines during this period was 383kg of gold bullion from 75 145t of ore, at an average grade of 5.10g/t. The ore from these mines was treated in the CIL plant at the Minnie Moxham mine, 3km to the north-east. Antimony was not recovered from the ore. Investigations into the possible treatment of the sulphide ores are continuing.

TIN

Alluvial gold and tin were discovered in Cannibal and Granite Creeks, south-east of Maytown, in 1873 and 1874; mining commenced in 1876. In 1879, extended areas were opened to the alluvial tin miners and production continued up until 1884.

James Venture Mulligan discovered alluvial cassiterite in the Wild River district during a gold prospecting expedition in 1875. As gold was of paramount importance in those times, there was little initial interest in the discovery. However, as the gold boom in north Queensland eased, many prospectors turned from mining gold to mining tin, silver and copper (Kerr, 1979). Local pastoralist, John Atherton, sparked interest in the region's tin deposits when he found tin at **Tinaroo Creek** in 1878 and on the **Wild River** near one of Mulligan's camps the following year. He guided a party of prospectors comprising Messrs. Brown, Brandon, Jack and Newell to the Wild River find, which they soon abandoned for Tinaroo Creek. During 1879 the group extracted 95t of tin and 4.6kg of gold from the alluvium. The Tinaroo area later became part of the **Tinaroo Mineral Field**.

Alluvial cassiterite was mined mainly from Tinaroo, Douglas, Black Rock and Deception Creeks and their tributaries. Black Rock Creek has been extensively reworked in recent times. Small-scale lode mining occurred around the turn of the century in scattered locations throughout the field, the Glen Atherton and United (Robson's) mines being the largest.

In May 1880, Messrs. Brown, Brandon, Jack and Newell returned to the Wild River and discovered a huge deposit of lode tin mineralisation which could be traced for ~3km in outcrop. They confirmed that their discovery was extremely rich by crude smelting. This area was to become known as the **Herberton Mineral Field.**

News of the Great Northern discovery, as their mine was known, brought into existence the town of **Herberton** on the banks of the Wild River. By December 1880, 24 parties were working tin deposits within a radius of two miles from Herberton.

The absence of crushing machinery meant that only the richest ore could be economically transported by pack-horses to Port Douglas. Jack and Newell invited John Moffat to join the Great Northern syndicate, on the proviso he erected crushing machinery. In June 1881, Moffat's ten-head battery commenced crushing. Moffat's policy of crushing public stone, in addition to the output of the Great Northern, ensured a new stability on the tin field.

By 1881, discoveries of tin mineralisation at **Watsonville** encouraged Moffat to purchase disused machinery from the Hodgkinson Gold Field to erect at Watsonville in mid-1882.

Tin in the **Coolgarra** area was discovered in 1882 and a battery was operating by 1884. **Brownville**, located to the west of Coolgarra, was also being developed around this time, but battery facilities were not constructed until 1931. This battery operated until 1962.

In July, 1882, Messrs Gibbs, Thompson and McDonald discovered several large tin deposits at Gibb's Creek, in rough country, ~16km west-south-west of Watsonville. In 1884, a battery and smelters were erected at the confluence of Gibb's and McDonald Creeks, the growing village was named **Irvinebank**, and the mill was named the Loudon Mill. During the first year, the Loudon Mill crushed 3 900t of ore for 660t of cassiterite, yielding 445t of metallic tin after smelting. By 1906 a network of tramways had been built to connect the major mines in the area to this facility. The mill was purchased by the Queensland Government in 1919 and operated as the State Treatment Works until the mid-1980s.

Prospecting was widespread during the late 1800s and ensuing discoveries of alluvial and lode tin deposits initiated rushes to **Emu, Return, Battle and Nettle Creeks**. In May 1883, the **Herberton Deep Lead** was discovered by J. MacDonald, who found tin-bearing wash under basalt at Chinamans Creek (about 3km south of the Herberton Post Office; Cuttler, 1972). The **Cassowary Creek** and **Bradlaugh Creek Deep Leads**, offshoots of the Herberton Deep lead, were discovered soon after. It was not until 1884 that the first production (10 tons of cassiterite concentrate) was recorded. Production quickly rose to 100 tons over the next two years. Probably more than 4 000 tons of cassiterite concentrates have been won from the deep leads.

Tin was discovered in the **Ord** district in the 1880s but operations were not viable until a railway line was built to the area in 1901. The two largest deposits worked were the Gladstone (4 000t of ore for a yield of 200t tin concentrates) and Gilmore (26 000t of ore producing 2 000t of tin concentrates) mines. Alluvial tin mining in the area concentrated on the headwaters of the **Tate River**, **Fulford Creek** and **California Creek**.

In 1884, tin lodes were discovered at Eureka Creek, later called **Stannary Hills**. A battery on Eureka Creek was crushing ore by 1888. The main mining period was between 1899–1907, when tramways were constructed to Boonmoo siding on the Chillagoe rail line, and a large battery was constructed at Rocky Bluff, on the Walsh River. This battery operated between 1903–1925 (Blake, 1972). Another, smaller battery at the You and Me mine operated between 1921–1924.

Alluvial cassiterite deposits were found in Wallaby Creek and the upper Annan River valley, south of Cooktown, in 1885. Within a year, alluvial tin was being mined at several localities between Mount Amos and Mount Romeo, in the **Cooktown** or **Annan River Tin Field**, and lode mining had commenced at Mount Amos. By 1887 the main mining centres of Rossville, Helenvale, Shipton's Flat, Tabletop, Little Tableland, Big Tableland, Mount Leswell, Mount Hartley, Mount Amos, Mount Finlayson, Mount Romeo, Mount Poverty, and Slaty and Granite Creeks, were established. The main centres for lode mining were at Mount Amos (Phoenician and Dreadnought mines), Big Tableland (Lion's Den mine), Mount Leswell and Collingwood.

Production reached a peak in 1888, when 1034t of cassiterite concentrates were won by 800 miners. The **Cooktown Mining Field** was gazetted in 1889. Dredging was attempted in 1892, but this and later attempts were unsuccessful. Most of the tin was obtained by hydraulic sluicing of alluvium, colluvium and decomposed (altered) granite. The Annan River Company NL and other companies commenced large-scale sluicing operations in 1905. The largest mines were the Collingwood Face, Daly's Face and Home Rule. Water was obtained by elaborate systems of water races. Annual production steadily declined and by the early 1960s averaged 20t of cassiterite concentrates.

Alluvial cassiterite was also discovered in the **China Camp** area (southern extremity of the Cooktown Mining Field) in 1885 and at **Mount Spurgeon** (outside Cooktown Mining Field) in 1886. Most of the production from the China Camp area occurred between 1908–1920. Three main mining areas constitute China Camp; Lode Hill, Roaring Meg and Pocket. These areas were all worked by sluicing alluvial and eluvial deposits. Mining of alluvium on Mount Spurgeon was short lived and by 1909 diminishing grades and water shortages had reduced operations significantly.

By 1888, tin mining at Irvinebank was at a low ebb, the only highlight being the Vulcan mine. The Vulcan produced ore containing up to 20% cassiterite, compared to the 9.1% average for the other mines in the area (Kerr, 1979). The Vulcan produced more ore than any other lode tin mine in Queensland — 184 000t of ore yielding 13 961t of cassiterite (Mason, 1953). It was also the deepest tin mine in Australia, being worked to a depth of 453m.

By 1890, Irvinebank had surpassed Herberton as the main lode tin mining centre of the Herberton Mineral Field, a position it has maintained ever since. Prospecting in the area continued to locate more deposits. The Smiths Creek deposit at Nymbool was discovered in 1901. A battery was erected in 1903 but the mine closed in 1909.

Alluvial cassiterite was discovered on the **Mount Windsor Tableland** in about 1890. Mining was carried out by sluicing the large volumes of granitic alluvium in tributaries of Piccaninny Creek. Alluvial cassiterite was also found in Campbell and Flaggy Creeks. Mining has been sporadic since 1932. The Stephanie Mine, on Lang Creek, was worked in the 1960s.

The tin boom of 1906 resulted in the introduction of the first tin dredges to north Queensland at the Annan River, south-east of Cooktown, and at Glutton's Gully close to Return Creek dam at Mount Garnet (Kerr, 1989). The Mount Garnet Hydraulic Tin Sluicing Company in the first six months of 1908 produced 34t of cassiterite but this was not economical to support the operations. The dredging operations on the Annan River were proving more successful. This plant operated until September 1916 when it was removed to Cooktown where operations recommenced in 1917 and continued until 1922 (Kerr, 1989).

A collapse of the tin market in 1907 led to a marked reduction in wages and conditions provided by companies in the Herberton–Irvinebank area resulting in union-organised strikes in 1907 and 1908. Also at this time, the average grade and output of ore from the Vulcan mine dropped to about half that of the previous year. Capital outlay on a tramway linking Stannary Hills with Irvinebank drained the resources of the main mining company in the area, the Irvinebank Mining Company. More industrial trouble around 1909 forced the temporary closure of the Rocky Bluff battery at Stannary Hills. Another market collapse in Europe in 1917 resulted in the closure of the Irvinebank battery. In 1919, the Irvinebank smelter, battery and tramway were bought by the State Government.

After World War I, intermittent mining on a small scale continued in the Herberton Tin Field. Improved transport facilities enabled the working of lower grade ore. Many of the old mine dumps, which were estimated to average 2% tin, were retreated — in some cases they were completely removed.

After 1925, little activity occurred in the mining field until the late 1960s when Metals Exploration NL, North Broken Hill Ltd, and Hopetoun Minerals NL engaged in prospecting and exploratory diamond drilling. From 1971–1979 Nickleseekers Ltd explored the field under mining lease and worked some of the old mines including the You and Me. Tributers worked alluvial deposits in this area in the late 1970s and early 1980s.

Bucket dredging was begun on Return Creek by Tableland Tin Dredging Ltd in 1939 and on Battle Creek by Ravenshoe Tin Dredging Ltd in 1957. The first large-scale alluvial stationary washing plants were introduced in 1965. From 1939 to December 1978, 32 100t of cassiterite concentrates were won by these two companies (Robinson, 1980).

In the 1960s, world production of tin failed to meet demand, and the slow response by producers to increase production resulted in a the steady price rise (Raggatt, 1968). The rising price of tin encouraged companies such as Loloma Mining Corporation to move into the field. In 1966, three batteries were crushing ore in the tin field. These were the Great Northern Battery at Herberton, the State Battery at Irvinebank and Green's Battery at Emuford.

The Jumna Mill at Jumna Creek (between Bakerville and Irvinebank) was subsequently constructed by Loloma Ltd to treat ores from numerous mines around Irvinebank, Stannary Hills and Herberton, and to treat the tailings accumulated in the Irvinebank dam.

The Herberton–Irvinebank area supported numerous small-scale tin mines during the buoyant period from 1960–1983, as well as small to medium size operations by companies such as Great Northern Mining Corporation and Mareeba Mining and Exploration Pty Ltd.

Old mines were accessed by larger adits that permitted the use of modern mining equipment. Some new orebodies were worked, such as in the Arbouin and Tommy Burns mines, and some new deposits were discovered, such as the North Hope mine north of the Jumna Mill. The Tommy Burns was the third largest producer in the Herberton Mineral Field (behind the Vulcan and Great Northern) and was owned and operated by R.B. Mining Pty Ltd.

In the period 1976–1981, all major tin-bearing creeks in the field were worked by machines (predominantly hydraulic excavators). The Emuford district was a significant producer of alluvial cassiterite and peak production was of the order of 600t of concentrates per year (Pollard, 1984).

A rapid oversupply of tin on the world market caused a price slump around 1983, and as a result mining activity decreased significantly and is currently at a low ebb.

In the late 1970s and early 1980s, small-scale mining also recommenced throughout the Cooktown Tin Field, together with moderately large-scale alluvial operations by Terrax Resources NL at Rossville and Serem Australia

Pty Ltd at Lee Creek. Production rose significantly to peak at 250t in 1981. There has been little mining carried out since the dramatic fall in tin prices in the mid-1980s.

TUNGSTEN, BISMUTH AND MOLYBDENUM

The Cairns region during the 1900s was a significant world producer of tungsten. In 1904 production from north Queensland was 1 564t of wolfram ore, elevating the region to the worlds largest producer. This position was held until the outbreak of World War 1. This production was in response to commodity demands from European steel makers. The early mining history of the tungsten, bismuth and molybdenum industry in the Cairns region is documented in detail by Kerr (1991).

The **Wolfram Camp** deposits were discovered in 1893 and have been mined almost continuously until the late 1970s. The importance of this deposit is illustrated by the production of 2 540t of wolfram in the ten years prior to World War 1, which was equal to the size of the world market in 1905 (Kerr, 1991). The majority of this production was exported to Germany and Britain. The area was subsequently reworked for eluvial material. Limited underground mining has occurred since this time. The main mines worked were the Avoca, Enterprise, Larkin, Forget Me Not, McIntyre, Mulligan, Murphy & Geany, Pepper, Tully and Victory.

Very coarse wolframite, native bismuth and molybdenite occur in vughs in pipe and sheeted vein deposits along the contact of the James Creek Granite with adjacent metasedimentary rocks of the Hodgkinson Formation. The deposit is renowned among the gemological community for the spectacular quartz crystals commonly encrusted with native bismuth crystals and rosettes of molybdenite. Specimens from this area can be found in many museums throughout the world. The total production of concentrates from these deposits is approximately 5 400t of wolframite, 1 455t mixed wolframite and native bismuth, 135t molybdenite, and 80t bismuthinite.

Bamford Hill like Wolfram Camp was first mined in 1893. Mining continued until 1981, punctuated by brief periods of inactivity. The extensive mineralisation is contained in the Bamford Granite, in sheeted veins and pipes, and as disseminated ore in endogreisens.

The mineralised vein swarm forming the **Mount Carbine** deposit was discovered on Carbine Hill in 1883 (Dash & Cranfield, 1993). Small-scale mining commenced in 1894. Initial activity concentrated on eluvial and alluvial deposits. The scheelite component of the ore was not wanted in the early days and miners roasted the ore in charcoal furnaces to break it down. Carbine Hill became ‘honeycombed’ with underground workings, most of which were only two or three man operations.

The Irvinebank Mining Company conducted large-scale underground mining of the deposit from 1906–1917. A new mill was commissioned on 30th May 1911. The mill processed ore at the rate of 50t per day, using a ten-head battery. In 1917, the operation was sold to the Thermoelectric Ore Reduction Company, which was also working the Wolfram Camp and Bamford Hill tungsten deposits. Operations ceased at Mount Carbine in 1919 because of a price collapse, due to the end of World War I. Small war-related production peaks occurred from 1937–1942 and 1950–1952.

Prior to 1969, lode mining was restricted to individual quartz veins and was predominantly underground. R.B. Mining Pty Ltd (later a subsidiary company called Queensland Wolfram Pty Ltd) acquired the leases over the Mount Carbine deposit in 1969 and, by 1974, had mined 400 000t of eluvial/alluvial scree. In 1974, open-cut mining of the main ore zone at the southern end of Carbine Hill commenced. A total of about 19Mt of rock was extracted from the pit. Mount Carbine was one of the largest, lowest grade operating wolframite mines in the world (Wolff, 1980).

Underground mining, with decline access, was initiated in 1986 but, due to a depressed tungsten market, all mining operations ceased in September 1987 and the mine was placed under care and maintenance. In mid-1993, a decision was made to auction most of the plant and equipment and rehabilitation and revegetation has commenced on the mine site. Total production was approximately 16 400t of wolframite and scheelite concentrates, and at least 7.8t of cassiterite concentrates.

The Glen deposits located near Emu Creek, north of Mount Garnet, was first mined in 1905. The concentrates initially incurred a penalty because of their bismuth content, but by 1909 hand-dressed ores consisting of bismuth carbonate (bismutite) with specks of metallic bismuth were being produced in commercial quantities. Mines in the area include, Gows, Simpsons, Byrnes or Manaposa, Dredges, and Toogoods, all of which produced tungsten and bismuth. The ores are generally associated with sulphides (mainly molybdenite), in flat-lying lodes occupying horizontal joints in the Emuford Granite. The 30mm thick veins have the shape of inverted saucers and the associated gangue is mainly topaz. Production from these mines was small, the ores containing up to 30% Bi and 35% W.

The **Koorboora** area, located 12km east of Almaden, has produced significant quantities of tungsten and tin from intermittent mining between 1888 and the late 1960s. The deposits in this area are very rich but of limited extent. The richness of the ore from the Neville mine influenced many in 1909 to consider it the greatest single wolfram mine in the world (Dash & others, 1988). The Neville produced 559t of wolfram from 8 230t of ore between 1904–1911 (Kerr, 1991). The lodes were mainly ferruginous and chloritic with the massive tin and wolfram being confined to fault and fracture zones.

At least 304.8kg of bismuth concentrates were also produced from the Alhambra mine in the **Coolgarra** area in 1908 (Blake, 1972). This mine was predominantly a tin producer with bismuth as a by-product.

Tungsten was discovered at **Dingo Mountain**, located north of the Herbert River gorge, in about 1910. The deposits were worked intermittently up until the 1970s. Workings comprise two main areas on the north-western side of the mountain, about 700m apart. The mineralisation is in the Dingo Mountain granodiorite (informal name, Champion & Heinemann, 1994), which intrudes rhyodacitic ignimbrite (Wallaman Falls Volcanics). Considerable unreported production has taken place over and above the 30t of wolframite concentrates recorded for the period 1910–1970 (Morris, 1991).

In 1917, scheelite was found in the foothills of the Burton Range. This area became known as **Lode Hill**. The mineral had until then been erroneously identified as quartz (Rudd & Pike, 1978). The Lode Hill group of deposits extends from 2.0–5.5km south-east of the Mount Carbine tungsten mine. The total length of discontinuous workings is 3.6km but the main area of workings is 1.5km long. A peak annual production of 15.5t of scheelite concentrates occurred in 1918. Production increased again during the early 1940s when the main opencuts were excavated. Minor production from small shafts occurred in the early 1950s.

The **Mount Perseverance** lodes, located in dense rainforest ~2km north of the Mossman–Mount Molloy road, were discovered in November 1917. The total officially recorded wolframite concentrates production from 1917–1920 was 26.42t. However, Morton (1938) noted that information from local miners indicated approximately 45t of wolframite and 1.75t of cassiterite concentrates were actually produced.

The main method of mining was by driving adits into the soft, decomposed granite forming the hillsides. In 1920 the area was virtually abandoned due to devastation from a cyclone and collapse of the metals market. Intermittent mining occurred between 1928–1934. Mining recommenced in earnest in about 1937 and by 1938, the total production (1917–1938) was approximately 74t of wolframite concentrates. From 1938–1950, mining continued intermittently.

A sharp rise in the price of tungsten towards the end of 1950 resulted in almost all quartz vein outcrops being pegged by the beginning of 1951. Mining continued steadily until about 1955, after which activity decreased, and records show that it had ceased by 1974. Production for the period 1951–1974 was conservatively estimated to be 53t of wolframite concentrates.

In 1971, R.B. Mining explored the Mount Perseverance area by costeaning, trenching and drilling. Resources in the order of 13Mt containing 0.025–0.038% WO_3 were delineated but were considered uneconomic.

A total of about 17t of wolframite concentrates with an approximate tungstic oxide content of 72% has been produced from the area. In addition, about 1.75t of cassiterite concentrates have been extracted from watercourses in the area.

Scheelite floaters were found in creek beds about 15km south of Palmerville in the early 1900s. No other tungsten discoveries were made in the Palmer River area until 1968, when Frost Enterprises Pty Ltd discovered scheelite lodes at **Spring Creek** and **Mount Hurford**. The

Spring Creek deposit (Keddie's Workings) was mined in 1969 and 1970 for a yield of 5 966.7t of concentrates.

Wolframite has been produced from two mines in the **Cooktown Tin Field**. A lode discovered at Mount Hartley in 1889, yielded 1.2t of wolframite concentrates. H.C. Worrall worked the Bonny Boy claim at Clearwater (Romeo area) from 1955–1957 producing 7.1t of wolframite concentrates.

Molybdenum has largely been derived as a by-product of mining operations for wolfram in the Wolfram Camp and Bamford Hill areas.

BASE METALS

The **Dianne Copper** deposit was probably discovered by prospectors in the early 1880s. The lode was mined from two shallow shafts and an adit but no production was recorded for this early mining period. Uranium Corporation carried out exploration work to assess the deposit in 1958 with inconclusive results. In 1968, North Broken Hill Pty Ltd drilled the deposit on behalf of the lease holders and calculated reserves of approximately 451 000t of oxidised copper ore containing 0.86% copper. No mining was carried out. Kennecott Exploration Pty Ltd carried out further drilling in 1969.

Mareeba Mining and Exploration Pty Ltd subsequently calculated reserves of 90 000t of supergene ore containing 24% copper. The company acquired the deposit in 1979 and commenced developmental work. Production from 1979–1983 was 69 820t of direct shipping grade ore assaying 18–26% Cu and 359g/t Ag (Wallis, 1993). The secondary copper ore was mined to a depth of more than 90m, below which it graded into primary massive sulphide ore. Most of the ore was not treated at the mine site, but trucked by road to Cairns for shipment overseas. Because of a fall in world copper prices in 1982 and depletion of reserves, Mareeba Mining decided to terminate the operation, leaving 20 000t of unrecovered ore.

James Venture Mulligan discovered the silver–lead–tin deposits along the Dry River (Silver Valley area) in 1881, and the town of **Newellton** was established in response to the influx of miners to the area. A smelter was constructed at Newellton in 1883 but only operated until 1886.

Significant quantities of copper ore were mined from the **Silver Valley** area, located 9km SE of Irvinebank. The main producers were Lancelot, Lanette (342t Cu), Westward Ho (202t Cu), and Battery (199t Cu). The Lancelot mine, discovered in 1891, was one of the largest tin, bismuth, copper, lead and silver workings in the Silver Valley area. This deposit was a 60–90cm wide complex sulphide lode that trended for hundreds of metres. The mine closed in 1915.

Kerr (1991) has compiled a detailed account of the history of the Lancelot mine that was the most significant pre-World War 1 German development undertaken in north Queensland. The Lancelot Tin Mining Company was purchased by Clotten of Frankfurt in 1899 and proceeded to reopen the Silver Valley mines. He invested heavily in the Lancelot and Magnum Bonum mines. The complexity of the ore and scarcity and expense of charcoal for smelting led to the collapse of at least four companies associated with mines in this area.

In 1883, prospectors discovered rich silver lodes at Mount Albion, later called **Montalbion**. They sold their interests to John Moffat's company in 1884. In 1885, spectacularly rich discoveries of horn silver (cerargyrite) assaying 45 920–61 227g/t were reported. The establishment of smelters at Montalbion in 1886 encouraged the development of other silver–lead deposits in the area such as the Orient Camp group (Kerr,1979). The Montalbion lodes had by 1895 produced 49 258kg of silver from 39 799t of ore (Blake,1972). Production had ceased by about 1924. The slag dumps were removed and retreated at the Chillagoe Smelters in the 1920s.

The **Mount Molloy** copper deposit was discovered in 1882 by Pat (Paddy) Molloy, a teamster, while looking for his bullocks. From 1883–1902, oxidised ore was mined by various owners and shipped to Europe for sale. In 1902, the then owners, J.V. Mulligan and J. Forsayth, sold the mine to John Moffat who formed the Mount Molloy Syndicate. The syndicate commenced mining in 1903 — smelting commenced on 25/11/1904, producing blister copper that was 90% pure. Large-scale mining took place from 1905–1910, during which time 43 600t of copper ore was treated to extract 3 900t of copper.

The average ore grade was 8.7% Cu, and production was largely from supergene and oxidised ores. Minor amounts of gold were recovered from the oxidised zone. A peak work force of 250 men was employed at the mine in 1907. In 1908, the rail link to Mareeba was completed but the smelter closed down soon after (Dash & Cranfield, 1993). Operations had ceased by 1910, due to depressed copper prices.

The most valuable individual copper deposit, however, was found near **Mount Garnet** in 1882. The Mount Garnet Freehold Silver and Copper Mining Company commenced mining and smelter construction in 1898. The deposit was worked most intensively from 1898–1902 producing about 4 415t of copper and 29 500kg of silver. Attempts were made between 1915–1917 to reopen the mine as a zinc producer but failed. The deposit is currently being reappraised.

Base-metal deposits in the **Chillagoe–Mungana area** had been known since 1888, but little activity occurred until the district was promoted by the mining entrepreneur, John Moffat. In 1894, Moffat erected a smelter at the Calcifer mine, followed by another at the Girofla mine in 1896. However, it was not until 1901, when Moffat and his partners established a large smelter at Chillagoe, that significant mining activity commenced throughout the area. Most of the lodes proved to have only limited reserves, and production difficulties severely hampered the profitability of the Chillagoe operation. In 1919, the struggling smelting venture was taken over by the Queensland Government. In succeeding years, poor management of the smelting operation compounded the difficulties of the small miners in the area, and in 1943 the smelters were finally closed.

The major copper producers in the Chillagoe–Mungana area included the Zillmanton, Shannon and Ruddygore mines, the groups of mines around Calcifer, Redcap, and Mungana (most notably the Girofla and Lady Jane). Some of the Mungana lodes are breccia pipe deposits in the Chillagoe Formation, but the majority are skarn deposits.

The Ruddygore is an exception and represents a porphyry copper stockwork deposit in the Ruddygore Granodiorite. The mines around Mungana accounted for about one-third the total production of copper from the field. Supergene enrichment was a critical economic factor in the economic mining of these deposits, operations commonly ceasing just below the base of the enriched zone.

Descriptions of most of the Chillagoe–Mungana mines are in Jensen (1941a); production figures for many have been recorded by de Keyser & Wolff (1964). Total recorded copper production from the Almaden–Mungana district was >21 000t of copper, with a peak production of 2 204t of copper in 1908.

The **Tartana area** of mineralisation was discovered in 1899, the Tartana Hill, King Vol and Montevideo mines being the largest. Production data for this area are incomplete. The ore was processed at the Chillagoe State Smelters mainly for lead, copper and silver; minor amounts of gold were also recovered.

Copper was discovered in the **O.K.** area during 1901, production commencing in 1902. The O.K. mine was the largest copper producer for the Chillagoe–Mungana area and the first copper mine in north Queensland to pay dividends. The mine was prematurely abandoned by 1912. The closure of operations was the result of falling ore grades and a costly lawsuit in 1909. Intermittent attempts to reopen the deposit occurred in 1930–31, and between 1937–1942. The mine is estimated to have produced 81 544t of ore for a yield of 7 800t Cu, 102kg Ag and 12kg Au (Culpeper & others, 1990).

Copper mineralisation was discovered at the **St George Copper mines**, north of Palmerville, in 1905. The St George Copper and Coal Company prospected for copper and mercury and produced ~8t of 30% copper ore from 1905–1907.

Copper-stained outcrops in the **Glenroy area**, north of Palmerville, were first worked between 1906–1907. Shallow prospecting shafts were excavated but there is no record of any production.

Numerous small scattered copper mines occur in a belt north and west of Herberton, known as the '**Copper Firing Line**'. Collectively, the lodes produced the most copper in the Herberton area. The major mines included the Captain, Empress, Anniversary, and Yellow Jacket. Blake (1972) estimated this area produced several thousand tonnes of copper between 1909–1943. The copper occurs in association with tin in complex sulphide minerals in shear-related veins.

Several mines in the Emuford area (such as the **Mount Babinda** and those on the **Siberia lode**) produced copper and associated metals. At the Siberia Lode, 6km east of Emuford, copper and silver were mined from several subparallel, east-trending, fracture-controlled quartz veins, up to 5km long. Total recorded production from this group is >366t of copper; 117.5kg of silver; 28t of lead; and 21 grams of gold. The first leases were pegged in 1900, the main productive years being from 1909–1916. Copper–tin lodes near Watsonville (such as the Consolation and the United North Australian (UNA) Group) produced small quantities of copper and associated metals.

The **Wambanu copper mines**, situated in Dells Creek on the south-western rim of the of the Herbert River gorge, were first worked in 1909 and then in 1913–1914, 1935–1937 and 1942. The main mine is called the Wambanu. This area now forms part of the Lumholtz National Park.

The **Nightflower mine** is located south of Big Watson Creek. This deposit was discovered in 1923 by two aborigines, Archer and Stewart. It was later pegged by a syndicate of Chillagoe and Mungana interests and the Chillagoe State Smelters, to supply ore to the Chillagoe Smelters. The Nightflower mine is recorded as having produced 305t lead, 1 123kg silver and 624g gold from 1 234t of ore between 1923–1930.

Production from base metal deposits in the Cairns region had virtually ceased by 1943, when the Chillagoe smelters were closed. An exception was the **Baal Gammon** mine (part of the United North Australian (UNA) Group) which was worked intermittently during the 1970s and early 1980s, bringing its total copper production to >2 480t (as well as 23 485kg of silver). Copper was also produced as a secondary product from the Red Dome gold mine near Mungana.

ANTIMONY

After gold was discovered in the Hodgkinson Gold Field in 1875, antimony ore was found at **Woodville** (located south of Mount Mulligan) and **Northcote** (located farther east). Mining commenced as early as 1877. The first recorded production was from the Emily lode in 1881. In response for a demand for a reduction works, the Northcote Antimony Smelting Company commenced smelting in late 1883 (Wallis, 1993). In 1883, approximately 406t of ore were smelted and in 1884 559t. Financial mismanagement and low yields forced the smelter to close by the end of 1884 (Kirkman, 1982).

The town of Northcote existed for no more than ten years — 1877–1887. Smelting recommenced at New Northcote, farther upstream on Leadingham Creek, near the Emily mine, in the 1890s. By 1892 the Emily was being worked for gold and the Ethel lode was the main antimony producer.

Intermittent production continued at low levels until the late 1960s. Interest in antimony was reawakened in the late 1960s and early 1970s by abnormally high prices. Between 1970–1973, Queensland Antimony NL carried out development work at the Tunnel lode and Black Bess mine, and reopened the main Ethel shaft. A crushing and liquating plant to extract antimony was planned at New Northcote but never eventuated.

Mining by Nittoc International Company Ltd of gold-stibnite ore from the Emily, South Emily, East Leadingham, Black Bess and Ethel lodes recommenced in 1991. Gold was extracted from the ore at the CIL plant at the Minnie Moxham mine, 3km to the east. The antimony was not extracted during this process. The operation ceased in June 1992.

Total production of antimony metal and concentrates from the Northcote area is approximately 2 362t. The area was the largest antimony producer in Queensland, accounting for approximately one third of the state's production (Wallis, 1993).

Woodville is estimated to have produced about 1 266t of ore (probably containing 2% stibnite), with maximum production during 1906. In 1907, the Jackson mine at Woodville was reported to be working a lode 0.6m thick grading 50% antimony at 20m depth. The annual production for 1906–1907 exceeded that of the Northcote area. During 1915 and 1916 production recommenced in the Woodville area and the owner of the nearby Home Rule battery installed a plant to treat low-grade antimony ores.

Although the **Mitchell River** orebody (**Retina** mine) was being worked from 1890, official production records for this deposit only commence in 1905. Production continued at low levels until 1907 when the Mitchell River Gold and Antimony Company Limited constructed a mill with a capacity to treat 40t of auriferous antimony ore per day (ARDM, 1907). The mill was designed to recover both antimony and gold. The extraction process performed well in the laboratory but the venture proved unsuccessful on a larger scale.

Smaller deposits along the **Saint George River** were also discovered during the 1890s. The main deposits were the Saint George, Lincoln and Poppy which were probably opened up prior to 1892 (Lam & others, 1991). The Saint George and Lincoln workings were reopened in1971 by Nickelfields of Australia NL when an estimated 60t of ore were treated at a nearby plant (Siemen, 1973). The venture ceased shortly afterwards because of a shortage of ore.

Limited production occurred in the Mitchell River and Woodville areas between 1940–1952. The escalation in the price of antimony in the late 1960s encouraged company exploration of the main antimony prospects and limited mining was carried out. In addition, subeconomic gold resources have been defined at many of the known antimony occurrences. The most significantly of these is the Tregoora prospect.

COAL

Coal deposits have been reported in several Permian units of the Cairns Region. The most extensive of these deposits and the only one mined is at Mount Mulligan. Coal was first discovered at Mount Mulligan in 1907 but it was not until 1914 that production began. Operations commenced initially at the Mount Mulligan State mine, the King Cole mine being opened in 1941.

Three coal seams were worked at the Mount Mulligan mine, the No. 3 seam (0.6m thick) having the most extensive workings. The King Cole mine worked only one seam. One million tonnes of coal were mined from the Mount Mulligan area, mainly from the Mount Mulligan mine. Peak production was in 1924 when 45 109t were extracted; the average annual production was about 20 000t (CR 11519).

The Mount Mulligan mine was the site of Queensland’s worst mining disaster when in late September 1921 an underground explosion caused the death of 76 miners. The cause appears to have been careless mining practices and poor management.

The coal from this area was mainly used locally to fire the furnaces of the Chillagoe State Smelters, in steam locomotives, and to generate electricity to power mining machinery in the Herberton–Mount Garnet area. These markets were lost in 1957 with the development of coalfields in the Bowen Basin, the completion of the Tully hydro-electric scheme, and the introduction of diesel locomotives. Overheating in the State mine also contributed to its closure. The King Cole mine had closed two years earlier (1955) after a large rock fall.

FLUORITE

Fluorite is a common accessory mineral in many of the ores produced from the Herberton Mineral Field and adjacent areas. The Cairns Region was the largest producer of fluorite in Australia at one stage. The first major deposit discovered in the region was the **Mistake**, located north-west of Emuford, in 1917. This deposit was worked for both fluorite and wolfram. The largest deposit was the **Perseverance** near Fluorspar (north of Almaden), which yielded 9 272t of fluorite. This deposit is notable for being the only substantial fluorite lode associated with gold mineralisation.

Total fluorite production from the whole region is approximately 32 000t.

IRON

Small iron deposits, locally referred to as ironstone are common in the Chillagoe district. The deposits are mainly in limestone lenses of the Chillagoe Formation which have been metasomatised by adjacent igneous intrusions. The ores commonly comprise magnetite, hematite, and garnet.

A few of the larger ironstone deposits have been worked in the past to provide flux for the Chillagoe State Smelters. The most significant of these was **Mount Lucy**, a low hill 5km west of Almaden, from which 45 344t of magnetite–haematite–garnet ore were mined early this century. This deposit produced nearly 60% of the recorded production from the Chillagoe district.

LIMESTONE

The largest deposits of limestone occur in the Chillagoe area, south of the Mitchell River around Bellevue, and between the Mitchell River and Palmer Rivers. Variably recrystallised limestone and marble occur in a north-west-trending belt extending for about 30km north and south of Chillagoe. Large quantities of limestone have been extracted from this area in the past for use as flux in the Chillagoe State Smelters. More recently, lime has been produced for chemical and agricultural purposes (Ootann and Chillagoe areas). Limited marble production has also occurred from numerous deposits, mainly south of Chillagoe.

Small limestone lenses in the Hodgkinson Formation in the Silver Valley area were worked to provide flux for local smelters which operated in the early 1900s.

A deposit of recrystallised limestone (ML 32 Birthday) was mined (for agricultural lime) in the Mount Peter area from 1960–1963. These operations (by North Queensland Marble Pty Ltd) produced 203t of crushed lime which was used on the surrounding cane fields.

In the Little Mulgrave River valley agricultural lime has been extracted from two deposits, called Little Mulgrave No. 1 (ML 40) and Little Mulgrave No. 2 (ML 40). Between 1962–1971 >3 000t of lime was produced from these deposits for use in agriculture.

MANGANESE

Manganese ores are widely scattered in the Hodgkinson Formation, along the coastal ranges of the Cairns Region. A comprehensive review of these deposits is contained in Jensen (1941b). The deposits are of limited extent and have not produced large quantities of ore. The deposits are commonly interlayered with chert beds. They are probably of synsedimentary origin, the manganese being derived from submarine volcanogenic exhalations. The main minerals present are psilomelane, pyrolusite, rhodonite and rare braunite (Dash & Cranfield, 1993).

In the Innisfail area the largest deposit is at Mount Martin, located about 3km north-west of Edmonton. The deposit was worked periodically from the 1900s–1940s. The operations were only on a small scale with approximately 1 117t of 40–50% manganese ore produced. The Weekend Stunt was worked intermittently prior to 1919. The deposit was again worked in the 1940s but the poor grade of the ore and discontinuous nature of the lodes made operations uneconomical.

The Mount Beaufort and Victorian mines (both located in the Cassowary Range, west of Mossman) are recorded as having produced approximately 60t of manganese ore containing between 15–50% manganese.

CLAY

Clay was mined from a pit at the Silkwood brickworks, south of Innisfail, from 1952–1975. During this period 17 100t of clay was extracted and made into bricks for the region.

EXPLORATION REVIEW

The results of company exploration in much of the Cairns Region have been tabulated and described by Lam & others (1988), Lam & others (1989), Dash & others (1991), Lam & others (1991), Denaro & others (1992), Garrad (1993), Dash & Cranfield (1993), Lam (1993), Lam & Genn (1993), Culpeper & others (1994), Dash & Morwood (1994), Denaro & others (1994a), Denaro & others (1994b), Garrad & Rees (1995), and Morwood & Dash (1996).

These references describe activities in most of the region except the Mungana, Chillagoe, Lyndbrook, Bullock Creek and Ravenshoe 1:100 000 sheet areas.

Exploration activity within the Hodgkinson Province has experienced several cycles in response to fluctuations in market demand. Most exploration has concentrated on gold, tin and tungsten and to a lesser extent, base metal mineralisation.

The gold prospectivity of the region has been reviewed by numerous companies, mainly since the 1970s. The most intensively explored areas are the Chillagoe–Mungana district, the Hodgkinson Gold Field and the Palmer Gold Field. Persistent exploration in the Chillagoe district in the 1980s resulted in the discovery of the Red Dome deposit. Several other prospects in this district are currently under evaluation. Exploration in the Hodgkinson Gold Field in the last 20 years has only yielded several small hard rock resources in the Northcote district. The oxidised portion of these has since been mined. Exploration activity defined large alluvial resources in the Palmer River district which were also subsequently mined.

Exploration for bulk-tonnage, low-grade stockwork deposits of the slate-belt type in the Hodgkinson Formation has had limited success. Mineralisation located to date is in rich shoots of limited extent. The small size and absence of associated disseminated mineralisation has prevented the definition of a mineable resource.

Tin has been produced in large quantities from the region for more than 100 years. Exploration in the 1970s and 1980s led to the delineation of several major lode and alluvial prospects. The Herberton Mineral Field and Cooktown district were the focus of the majority of this exploration activity. The collapse of the tin market in the mid-1980s halted development of these prospects. Major deposits discovered include the Collingwood, Jeannie River and Kings Plains prospects. Large tracts of prospective country such as Mount Lewis and Mount Spurgeon now form part of the World Heritage listed Tropical Rainforests Reserve.

Tungsten exploration was carried out throughout the Mount Carbine area in the 1970s and 1980s. Small to medium sized deposits were defined at Lode Hill, Pom Pom and Cumble Cumble but were considered uneconomical. Large low grade resources were also delineated at Mount Perseverance and Watershed Grid. Poor commodity prices have discouraged further activity.

Base metal exploration concentrated in areas around the centres of historic production such as Mungana–Chillagoe, Mount Molloy, O.K., Hannabelle and Dianne. Smaller scattered occurrences have also been tested. All areas have generally yielded only small low-grade resources peripheral to that previously worked. The O.K. mine, south of the Mitchell River, is currently being explored for gold–copper mineralisation. The O.K. and adjacent mines were the main copper producer in the Chillagoe district for a brief period in the early part of this century. Drilling of anomalous zones was completed in November 1995.

Coastal areas have been investigated for silica sand and heavy minerals associated with both modern and ancient beach sediments. This activity has defined large and extensive silica sand resources in the Cape Flattery (currently being mined) and Cape Melville regions and a moderate resource south-east of Innisfail. The percentage of heavy minerals in the deposits is low and of limited extent.

The Featherbed Volcanic Cauldron Complex and adjacent zones have been explored for uranium by numerous companies mainly prior to the mid-1970s. Mineralisation was detected at Doolans Springs, in the Fishermans Waterhole area, and at Pinchgut Pinnacle. These prospects are small and subeconomic.

Nickel exploration has targeted laterites developed over mafic to ultramafic bodies located in the Cassowary Ranges, south-west of Mossman, and in the Gunnawarra area. Drilling has indicated that the laterite profile is thin and of limited extent. The deposits are uneconomic.

The region is also considered by some to contain the primary source of the diamonds periodically found in the O'Briens Creek Gemfield. Reconnaissance geochemistry has so far failed to locate any pathfinder elements and no anomalous areas have been defined. One 0.166 carat diamond, showing marks of vigorous and lengthy transport, has been identified from tin-bearing deep leads near Herberton.

The possible presence of gemstones associated with the basalts and pyroclastic deposits of the Atherton Basalt Province was tested in the late 1980s. The venture did not locate any sapphire-anomalous regions. Sapphires and zircons have been recently found at three separate locations in the Lakeland Downs area associated with vents and pyroclastic deposits of the Cainozoic McLean Basalt Province.

KNOWN MINERALISATION AND RESOURCES

Mineralisation in the Cairns Region has been described in detail by Dash & others (1988, 1991), Lam & others (1988, 1991), Culpeper & others (1990, 1994), Bruvel & others (1991), Denaro & others (1992, 1994a), Dash & Cranfield (1993), Garrad (1993), Lam (1993), Lam & Genn (1993), Dash & Morwood (1994), Denaro & Ewers (1995), Garrad & Rees (1995), Morwood & Dash (1996) and Plimer (1997). The information contained in these reports has been summarised, revised, and updated to form the basis of the following section.

The enrichment of economic minerals to form ore bodies has occurred throughout the tectonic history of the region. However, most economic deposits are related to Carboniferous–Permian deformations and granite intrusion. There is a strong ore metal association with the different supersuites, in particular O'Briens Creek Supersuite with Sn–W, Ootann Supersuite with W–Mo, and Almaden Supersuite with Cu–base metal Au. These relationships are more complex in detail.

Fissures and faults produced during crustal extension were pathways for contemporaneous tholeiitic basalt, manganiferous exhalative chert (some with anomalous gold) and small, volcanogenic massive sulphide lenses, the main deposits are the O.K., Mount Molloy and Dianne copper mines.

Slate belt type gold-bearing quartz veins were deposited during one or more of these deformation events. The mineralising fluids were probably generated during regional tectonism and channelled to dilational sites within shear zones. The main gold fields of this type are the Palmer Gold Field (46t gold, mainly alluvial) and the Hodgkinson Gold Field (11t gold production, mostly lode), where mineralisation has been dated as late Carboniferous (Morrison, 1988). Other major areas with similar gold-bearing veins are the West Normanby, Mareeba and Starke Fields, and numerous gold fields in the Innisfail area.

Tectonism produced regional faulting into which gold–antimony mineralisation was channelled in the Hodgkinson Gold Field (Peters & others, 1990). Antimony was introduced into vein deposits at Northcote (the source of approximately one third of Queensland's antimony production), Cocoa Creek and Mount Mulligan area. Studies indicate that antimony mineralisation in both the Hodgkinson Gold Field and the Northcote area was probably introduced at a later stage than the gold (Peters & others, 1990).

Dykes, veins, greisens and skarns related to two north-west-trending belts of S-type granites extending from Innisfail to Barrow Point contain: tin mineralisation near Cooktown (*e.g.* Collingwood prospect, 4Mt @ 0.7% Sn), Mount Holmes, Mount Lewis, Mount Spurgeon; scheelite in skarns, of which the Watershed prospect is the largest; and tungsten mineralisation in vein swarms at Mount Perseverance and Mount Carbine (which has produced 16 400t of wolframite and scheelite concentrates and contains a remaining resource of 28Mt @ 0.1% WO_3–cutoff 0.03% WO_3). The granites were emplaced in the early–late Permian. The granites of the Cooktown Supersuite are associated in places with extensive tin mineralisation.

In the Herberton Mineral Field extensive tin mineralisation characterises the O'Briens Creek Supersuite. More than 150 000t of tin concentrates have been produced from greisens, breccias, pipes and veins. Alteration accompanying this tin mineralisation includes chloritic, sericitic, albitic, potassic, greisen and quartz-tourmaline. Near Mount Garnet, skarns developed adjacent to O'Brien's Creek Supersuite granitoids contain subeconomic fluorite and tin deposits, such as the wrigglite skarn deposit at the Gillian prospect.

At Wolfram Camp and Bamford Hill, coarse-grained wolframite–molybdenite–bismuthinite mineralisation occurs in vuggy pipes, veins and sheets in closed-system endogreisens formed in cupolas of highly fractionated Ootann Supersuite granites (Blevin, 1990).

In the western part of the region, limestones of the Chillagoe Formation have been intruded by late Carboniferous I-type Almaden Supersuite granitoids, creating extensive skarns locally containing gold, silver, base metals and minor tin mineralisation. The recently closed Red Dome gold–copper mine is of this type. These discontinuous skarn deposits were a major source of copper, lead and zinc in Queensland in the early part of this century.

Nickeliferous, serpentinised, ultrabasic bodies near Julatten and Gunnawarra are probably fault-emplaced along major crustal sutures. Lateritic deposits developed on these bodies are subeconomic.

ANTIMONY

Antimony mineralisation is developed in the Northcote area, Hodgkinson Gold Field, Mitchell River deposits, Starcke Nos. 1 and 2 Gold Fields, at Six Mile Creek and other minor scattered occurrences.

Numerous antimony ± goldbearing quartz veins are localised in north-west trending shear zones which cut the Hodgkinson Formation in the Hodgkinson Gold Field and nearby Mitchell River region. Buck and ribbon quartz together with local comb quartz are the main types represented (Golding & others, 1990). The quartz veins, especially those associated with the higher grade pods of stibnite, tend to be discontinuous with well-developed pinch and swell structures. Preferential but erratic enrichment is localised in receptive sites, such as dilation zones, tension gashes, cross fractures, and shear zones which cut more competent rock types such as massive arenite. The veins are generally steeply dipping and range in length from a few tens of metres to ~4km (Garrad, 1993).

Recent oxygen isotope studies by Golding & others (1990) and Peters & others (1990) indicate the antimony-gold-bearing quartz veins are characterised by distinctive, mainly heavier O^{18} values compared to those obtained from the gold-bearing quartz and barren quartz veins. These differences may reflect more enriched fluids and/or deposition at lower temperatures from fluids of similar oxygen isotopic composition (Golding & others, 1990). In either case, the differences support separate flow paths or a distinct and separate source for the antimony-bearing ore fluids.

The antimony mineralisation has a marked preference for regionally significant shear zones throughout the study areas (*e.g.* see Peters & others, 1990). It is generally discrete from the main gold mineralisation and not associated with melange zones. Surveys of the antimony deposits of the Hodgkinson Province (Jensen, 1939, 1941c; Aerial, Geological and Geophysical Survey of Northern Australia, 1941) indicate that, in general, the massive antimony ore contains little gold, whereas arsenical ore has a significantly higher gold content. In the Mitchell River area, for example, there is generally a positive correlation between pyrite and arsenopyrite contents and gold grades (Reisgys, 1986). Mineralogical studies indicate these sulphides have been commonly replaced by stibnite (Woodcock, 1958). The truncation of gold-bearing quartz veins in places by stibnite-bearing veins also indicates the antimony mineralisation was a later event.

Hodgkinson Gold Field

Peters (1987) and Golding & others (1990) recognised two distinct quartz vein associations in the Hodgkinson Formation, namely, Au-quartz veins and Au-Sb-quartz veins. The Au-Sb-quartz veins tend to be located in separate domains from the Au-quartz veins, or on domainal boundaries which truncate the Au-quartz veins. The stibnite is commonly altered to cervantite and stibiconite at the surface.

Stable isotope studies by Golding & others (1990) have indicated that, although distal magmatic fluids cannot be ruled out, it is more probable that these deposits were precipitated from deeply sourced metamorphic fluids.

In the **Northcote area**, mesothermal quartz veins containing antimony and, in most cases, gold, are postulated to have been precipitated from upwardly migrating metamorphic fluids generated during regional tectonism and deposited in favourable structural sites (Golding & others, 1990).

The main mines in the area were the Flottershow, Lone Hand, Jacobsen, Tunnel, Craigs, Emily, Emily South, East Leadingham, Ethel, Black Bess, and Edith to the Northcote Group, and the Belfast Hill deposits. These lodes occur in a major north-west-trending structural ‘corridor’ (see Figure 38). The main feature of this corridor is a large, north-west-trending, west-dipping, brittle reverse fault with a slightly oblique sinistral component of movement (McConnell, 1992). Subsidiary structures have a range of orientations from east-west (Craig’s Lode) to north-south (Black Bess).

Mineralisation is localised in dilational sites in shear zones, the stibnite forms massive pods and lenses in the quartz veins. The quartz veins consist mainly of ribbon and buck varieties, with fragments of country rock on

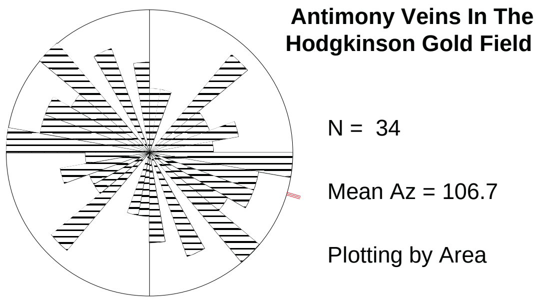


Figure 38. Orientation of Antimony mineralised reefs in the Hodgkinson Gold Field (Northcote and Woodville areas).

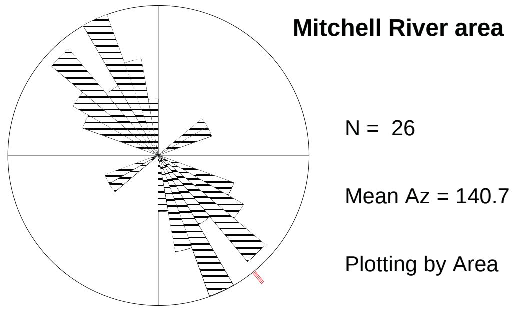


Figure 39. Orientation of Antimony and Gold reefs in the Mitchell River area.

the margins. Minor comb quartz is present locally. Veins characterised by milled breccia textures have been reported by Nittoc (Kinnane, 1985).

Geological and petrographic studies of the veins at Northcote by Western Mining Corporation Limited and Nittoc International Company Limited (Ichikawa & McConnell, 1992; Kinnane, 1985) indicate:

- the gold is invariably associated with fine-grained acicular arsenopyrite, disseminated pyrite, and minor chalcopyrite, pyrrhotite and galena,
- stibnite is a common associate of gold but occurs along the margins of gold-bearing veins, and
- stibnite has overprinted hydrothermal pyrite and arsenopyrite and completely enclosed some gold grains, clearly indicating that the stibnite is a late phase.

No gold–antimony alloys were identified. At the Emily deposit, a rhyodacite dyke cuts the gold mineralisation. This dyke has been brecciated and contains antimony mineralisation, further indicating the stibnite is a late phase.

In the **Woodville** area, located south-east of the abandoned township of Mount Mulligan, stibnite mineralisation is localised in lenses which appear to be controlled by the intersection of minor and major shears. A gradual reduction in antimony content in the quartz veins is observed away from the main area of antimony mineralisation to the north through the Home Rule–Dagworth group of mines to the Stuartown mines where antimony is accessory, and also to the south-east (Garth, 1971).

Mitchell River Deposits

The Mitchell River area is located on the Retina Fault, a major shear zone, and related structures. Antimony is also present south-east of these mines, where numerous small deposits of limited economic value occur along the same structure.

Small deposits of antimony are also present to the south-west of the Mitchell River mines. These include the **Pillidge**, **Antimony Hill**, **Jestah**, and **Current Creek Group** lodes, as well as the Fence Antimony prospect. These deposits are all structurally controlled and may be related to dilational structures or shear zones (see Figure 39) which cut the Hodgkinson Formation (Culpeper & others, 1990).

The most significant deposit in the Mitchell River area is the **Retina lode** where stibnite, with associated gold, is concentrated in several lenses, over a strike length of ~350m. The fault gouge associated with the main shear zone (Retina Fault) is the host of the antimony and gold mineralisation (Garrad, 1993). The Retina mine attracted significant attention in the 1970s as a moderate-tonnage low-grade prospect.

The eastern (footwall) margin of the shear zone at the Retina mine is defined by a prominent 15cm-thick lens of pale grey, kaolinitic fault gouge. The shear zone is bounded to the east by a zone of intense wallrock alteration. This zone is white, very friable, and consists of euhedral quartz and feldspar grains in a kaolinitic matrix. The country rock was probably a felsic dyke. The mineralised zone extends to the north-north-west (Retina North prospect) and south-south-east (Retina South prospect), and has an overall strike length of ~2km.

Located east of the Retina Fault and north of the Mitchell River, is a large anomalous gold concentration within a 1.5km-wide deformed zone, bounded to the west by the Retina Fault. The main prospect in this zone is the **Tregoora deposit** (also known as the Black Knight–Rim Fire deposit) which is located within a larger gold-anomalous zone termed the Sleeping Giant. Antimony is associated with this large low-grade gold deposit. The antimony is hosted by quartz and occurs within shears and associated structures. The age of mineralisation is considered to be early Carboniferous.

Saint George River Area

Antimony-bearing quartz lodes associated with north-easterly to south-easterly-trending conjugate fractures occur as discontinuous, north-trending, *en echelon* mineralised lenses in the Hodgkinson Formation near the confluence of the Saint George and Mitchell Rivers. There are 16 occurrences within a 5km by 2km area. Within the lenses, mineralised quartz veins (100–500mm wide) strike north-east and south-east and barren veins (100–300mm wide) strike east. Some mineralised veins are lightly iron-stained and brecciated on the margins, with strongly slickensided surfaces. In places, the veins swell to form large outcrops of white ‘buck’ quartz. Elsewhere they thin out to form quartz veinlets, or pinch out completely in the country rock.

The lodes commonly consist of a dominant quartz vein containing multiple stibnite-rich lenses, ranging from 10–50mm wide, and stockworks. In some lodes, stibnite occurs preferentially along the vein margins and narrow zones of anastomosing stibnite veinlets occur within the adjacent wallrock. Where oxidised, these veinlets are difficult to distinguish from the host rock. Stibnite typically forms 10–30% of the lodes. Selected stibnite samples assayed up to 40% antimony. Channel samples indicated that antimony and traces of gold are present in both the lodes and in the adjacent wall rock.

Starcke Nos. 1 and 2 Gold Fields

The only antimony mineralisation in the Starke No. 2 gold field occurs in a Sb–Au-quartz vein at the **Uncle Sandy** mine. The lode is a 100–300mm-wide quartz fissure vein in silicified siltstone and mudstone. The vein comprises cherty quartz with pyritiferous host rock inclusions to 20mm across. Stibnite appears to be associated more with sheared/brecciated host rock than with quartz and may be concentrated on the vein margins. The only recorded production was 9t of 9% Sb ore and 0.3kg of gold.

Cocoa Creek (Starke No. 1 gold field) situated 45km north-west of Cooktown consists of two lodes which are up to 0.8m thick. The lodes consisted entirely of stibnite and quartz (plus traces of visible gold). The mineralisation has formed at relatively high-levels in the crust but has no epithermal signature (Derrick & Ogierman, 1988). The tailings dump at Cocoa Creek contains 1395t at an average grade of 5.2% Sb (Denaro & Ewers, 1995).

Six Mile Area

Antimony mineralisation occurs in gold-bearing quartz veins in a north-north-east-trending belt of acid to intermediate volcanic and intercalated sedimentary rocks of the Normanby Formation in the Six Mile area, 8km west of Cooktown. The main mines are the Good Luck, Thunderbolt and Mundic King. Stibnite occurs in small, discontinuous lenses which grade about 38–60% Sb. Gold contents are generally low in the stibnite-rich quartz.

Current Prospects and Main Known Resources

The **Black Sparkle** deposit located 4.8km south-south-east of Irvinebank was evaluated by Allegiance Mining NL under option from Great Northern Mining Corporation NL. The company believed the deposit had a potential resource of ~600 000t of open pittable antimony ore (Register of Australian Mining 1996/97, page 310). A drilling program is planned to investigate the resource in more detail.

The main prospects in the **Northcote** area are the Ethel, Ethel Extended, Emily, Tunnel, Tunnel Extended, Antimony No. 2, and Black Bess. Gold is contained in highly sheared, wide zones of quartz vein stockworks which were ignored by the early antimony miners. A resource of 230 000t @ 5–6g/t Au is reported to remain at the Ethel Extended prospect. Previous exploration had identified an oxide resource of 164 000t @ 1.9g/t Au, a sulphide resource to 50m depth of 399 000t @ 4g/t Au with an additional 272 000t @ 4.7g/t Au to 100m (Register of Australian Mining 1996/97, page 170). Some of this oxide resource has been mined by Nittoc International Ltd. Western Metals Ltd currently own the prospects and may continue exploration in this area.

The Tregoora, Retina and Black Knight deposits are currently being worked by Soloman Mines. These deposits are principally being worked for the associated gold present in the oxide portion of the deposits but antimony concentrates are being recovered as a byproduct of treatment and stockpiled. Refer to the 'Gold' section of this report for more information on the Mitchell River region.

BASE METALS

Chillagoe Area

Numerous mineralised skarns have formed in the Chillagoe area where Permo-Carboniferous granitoids intruded metasedimentary rocks of the Chillagoe and Hodgkinson Formation. The granites are mainly I-type and intruded at shallow depths (Rubenach, 1994). This area contains the recently closed **Red Dome** mine as well as the abandoned base metal mines at **Redcap, Zillmanton, Mungana,** and **Calcifer**. Red Dome is discussed in more detail in the 'Gold' section of this report.

The **Penzance**, **Queenslander** and **Morrison** mines are the most extensively worked of the **Redcap group** of mines, located to the north-east of Mungana. The ores from these mines averaged 1–5% Cu and 31–155g/t Ag. The Morrison orebody also contained up to 22% Pb.

The mineralisation is developed in large-scale high-temperate skarns. Rubenach & Cartwright (1994) and Paverd (1971), attributed the formation of the endoskarns and exoskarns of the Redcap Creek area to the interaction of fluids from the Belgravia Granodiorite (Carboniferous) with limestone of the Chillagoe Formation. The depth of intrusion of the granodiorite was estimated as 3.5km by Rubenach & Cartwright (1994). They have proposed two stages of skarn formation:

- Stage 1; exoskarns consisting of an inner melilite skarn zone and an outer massive tilleyite skarn zone (formed at above 700°C). Mineral assemblage is tilleyite, mellilite, wollastonite, monticellite, and spurrite.
- Stage 2; vesuvianite-rich and wollastonite-rich skarns, replacing in part the stage 1 skarns (formed at around 550–600°C).

Garnet-rich endoskarns are commonly developed along fractures, commonly located close to granitoid/marble contacts. Some of these endoskarns are replacement rather than infill with extensive 'bleaching' (replacement of biotite and hornblende by diopside) haloing these deposits (Rubenach, 1994). Stable isotope studies indicate magmatic fluids were dominant, so the extensive endoskarn development demonstrates significant circulation from the marble contacts back into the solidified granitoids. Rubenach (1994) has found dramatic isotopic fronts at skarn/marble contacts in the large Redcap Creek skarns which he considers indicates fluid flow parallel rather than normal to skarn zoning.

This area has received considerable attention from mineral exploration companies due to its proximity to the Red Dome mineralisation.

The **Zillmanton group** is a small collection of mines located 5.5km west of Chillagoe. The **Zillmanton lode** was the main producer. Other workings included the Shannon, Shannon East, Shannon West, Zillmanton North, Zillmanton Extended and McMillans Lode. The only recorded production is for the period 1910–1911 when 8 700t ore yielded 347t Cu and 370kg Ag.

The mineralisation is hosted by siliceous haematitic garnet skarn and is a similar mineralisation style to much of the Mungana area.

The main historic workings in the **Mungana group** were the **Girofla** and **Lady Jane** which were also the outstanding producers. Other important mines included the Griffiths, Magazine Face and Dorothy. Production figures for individual mines in this group are incomplete, Ishaq & others (1987) estimated the total production from this group prior to the opening of the Red Dome mine to have been 367 000t of ore for a yield 8 700t Cu, 35 000t Pb, and 100400kg Ag.

The recently completed operations at **Red Dome** are located south-east of the old Lady Jane and Girofla workings. The mineralisation for the Red Dome deposit is described in detail on page 163 of this report and is characteristic of the mineralisation in this area.

Table 6. Known total production for the main mines near the Chillagoe township.

Mine Name	Ore	Known Production
Chillagoe Consols	30 500t	13 950kg Ag, 6 500t Pb, 400t Cu
Christmas Gift	8 500t	858.7kg Ag, 500t Pb, 85t Cu
Lyonite Hills	~2000t	~190t Pb, 201.5kg Ag
Titree	32 000t (1932–42)	400t Cu, 564kg Ag, 52.8kg Au
Wilson's Lease	1 050t	168kg Ag, 139.4t Pb, 4.55t Cu

Numerous mines have been worked in the area surrounding the Chillagoe township and extending to the south-east for ~5km. These mines have exploited skarn mineralisation developed in the Chillagoe Formation adjacent to granite contacts (mainly Almaden Supersuite granites). The main mines in this area are the **Chillagoe Consols**, **Christmas Gift**, **Lyonite Hills**, **Macrossan**, **Titree**, and **Wilson's Lease** (Table 6).

The mineralisation in the Christmas Gift mine typifies the style of mineralisation in this area. The iron–garnet orebody has developed at the contact between granite and calcareous rocks of the Chillagoe Formation. The north-dipping lode varied greatly in composition from siliceous ore high in silver to manganiferous or sideritic ore; some ore contained cupriferous garnet rock. The mineralisation was commonly patchily developed. The orebody is capped by massive brecciated limonitic and haematitic gossans. Rich sphalerite ore containing up to 40% zinc was occasionally encountered during mining but was discarded due to a lack of demand and smelting facilities. Jensen (1941a) reported the presence of antimony in a complex antimony–lead ore at the Hensey Upper mine in this area.

The main sulphides present are chalcopyrite, pyrite, galena, sphalerite, arsenopyrite, with rare bismuthinite and molybdenite. The supergene enrichment zone was the main focus of mining operations.

Verwoerd & Sargeant (1971) postulated a ~600°C temperature of formation for the Hensey skarn. Tremolite, diopside, garnet, wollastonite, chondrodite, and clinozoisite are the dominant skarn mineral assemblage.

The **Calcifer group** of mines is located 8.2km south-east of Chillagoe. The main mines are the **Boomerang**, **Five Chain Bend**, **Harpers**, **Hobsons**, **Holiday**, and **Sonya Hills**. The main historic mine was the Boomerang which produced 6 972t of ore for 57.12kg Ag, 106.1t Cu, 2t Pb but the group as a whole is estimated to have produced ~26 450t of ore for a yield of 1 555t Cu, 400t Pb, 744kg Ag. The Harpers deposit displays a massive ferruginous and argillic alteration assemblage and is currently being reappraised for its gold potential by Niugini Mining Ltd. They have completed an extensive drilling campaign which has indicated the presence of low grade gold mineralisation plus sporadic base metal concentrations.

The deposits in the Calcifer group are principally high-temperature skarns which developed in roof pendants of Chillagoe Formation rocks. The presence of irregular intrusive contacts and of fractures striking north and north-west have influenced the distribution of the ore forming fluids (Rubenach, 1994). The general style of mineralisation and mineral assemblage is similar to those in the Chillagoe area described above.

Torpy's Crooked Creek (also called **Torpy's Lead Mines**) is located ~28km south-east of Chillagoe in a north-west-trending lens of conglomerate. Mineralisation is concentrated along several fracture planes. Production figures are incomplete, but the total recorded production was ~6000t of ore which yielded 920t Pb and 2 604kg Ag (Dash & others, 1988).

An extensive gossan is developed on the deposit and evidence of brecciation and 'rehealing' by silica is present. The orebody has a maximum width of 10.6m (carrying 30% Pb) in the upper levels of the workings. It narrows to 3.9m at the 38m level and to 0.6m (carrying 22% Pb, 18% Zn, 558ppm Ag) at the 91m level. The zinc content of the ore increased with depth. Very little geological information is available for this deposit.

The **Ruddygore** mine is located 3km north-east of Chillagoe and was the first porphyry copper deposit found in Queensland. The deposit is a porphyry copper and weak porphyry tin deposit hosted by metasomatised Ruddygore Granite. Mineralisation is associated with an inner, sericitic alteration halo. The main ore minerals are pyrite, chalcopyrite, bornite, arsenopyrite, cassiterite and tetrahedrite. Mining was principally via extensive underground workings and two large open cuts. In 1980 AOG found that copper contents were inversely proportional to those of tin. Horton (1982) considered this deposit to have formed in a Continental margin setting during the Permo-Carboniferous.

Debrah Prospect

Copper mineralisation has been found in several places adjacent to the Palmer River east of Maytown. The largest deposit is the **Debrah** prospect. The host rocks like those at the Dianne mine (see below) comprise mainly chert/quartzite beds/lenses interlayered with basic (spilitic) lava flows or sills. The tabular-shaped orebodies are >100m long and are capped by ferruginous gossans. The sulphide zones contain pyrite partly replaced by chalcopyrite, sphalerite and galena (Fe>>Cu>Zn>>Pb and Ag>>Au). Past mining has been confined to secondary enrichment carbonate zones with grades of 2–25% Cu. This deposit is probably a Besshi–Kieslager type of volcanogenic massive sulphide.

Dianne Deposit

The **Dianne** deposit is a stratiform Cu- and Zn-rich massive sulphide body (Besshi–Kieslager type of volcanogenic massive sulphide) which forms a small, steeply pitching lens in an overturned sequence of interbedded shale and greywacke. The tabular orebody is >150m long and is capped by a ferruginous gossan. Along strike, the massive sulphides grade into a thin pyritic chert layer and, locally, stratabound pyrite-rich zones. Chalcopyrite and minor sphalerite also occur in the enclosing sericitic shale. Supergene enrichment has occurred to approximately 100m depth. No stockwork or feeder mineralised zone has been identified. Past mining concentrated on the supergene enriched zone, which contained ores assaying up to 25% Cu. About 18 000t of copper were produced from the deposit.

Gregory & Robinson (1984) concluded from sulphur isotope studies that the ore fluids were mainly of magmatic origin. Decreasing temperature and mixing of the fluid with seawater probably initiated precipitation of the ore minerals. No stockwork mineralisation is evident, apart from minor sulphide-rich veins in chert lenses in the footwall. The deposit may have formed at a significant distance from the source of the ore fluids.

This mineralisation and other VMS deposits in the Hodgkinson Province is considered by Nethery & Barr (1996) to be related to Silurian submarine tholeittic volcanic centres spaced approximately 25km apart. This submarine volcanism was coeval with the intrusion of the ~435Ma Nundah Granodiorite (Nethery & Barr, 1996).

Whittle (1968) examined the copper ores of the Dianne deposit in detail and postulated that the copper mineralisation was epigenetic and not a VMS. The introduction of ore-bearing solutions was partly structurally controlled by the presence of brittle fractures and partly by the presence of relatively permeable greywacke. The primary mineralisation was of hydrothermal origin, in the form of quartz–pyrite–chalcopyrite seams and veinlets. Secondary enrichment took place in the upper, more permeable weathered greywacke and in shale partings. Secondary ore minerals include malachite, azurite, cuprite, digenite and native copper.

Glenroy Creek and St George (Fairlight) Copper Mines

These two groups (12km apart) of copper–mercury deposits are located north of Palmerville. The mineralised zones are in narrow, discontinuous lenses of basic volcanics and breccias interbedded with silicified sediments of the Chillagoe Formation. The main ore minerals are chalcopyrite, chalcocite, malachite, native copper, and cinnabar which have several modes of occurrence, namely

- as disseminated grains,
- as fracture infillings, and
- in quartz and calcite veins.

Ball (1909) estimated the ore mined from the **St George workings** to contain at least 30% Cu and 5–6% Hg. Only ~8t of ore were mined. In 1982, CSR Ltd considered the St George area to be prospective for Carlin-type gold deposits. The results of subsequent stream-sediment, soil

Table 7. Recorded total production from the main base metal mines in the Herberton Mineral Field (based on Dash & others, 1991; Bruvel & others, 1991).

Mine Name	Copper Conc. (tonnes)	Silver (kg)	Lead (tonnes)	Locality
Mount Garnet	4415			1km SSW of Mt Garnet
UNA Group	2480	23 485		6.2km W of Herberton
Silver Valley area	>780	3 948	118	9km SE of Irvinebank
Consolation (Devonean West)	694.20	1 809.1		5.8km W of Herberton
Copper Firing Line area (including Empress)	>530.00			~2km NE of Herberton
Siberia Lode Group (mainly from Mount Volk and Morning Star)	366.00	~117.5	~28	Emma Creek, 5km E of Emuford
Lanette (Lenette)	342.00			9.0km ESE of Irvinebank
Westward Ho	202.60			7.8km SE of Irvinebank
Battery	199.60			9.3km ESE of Irvinebank
Montalbion Group–Rio Tinto	100.60	47 492	1038	7.1km WNW of Irvinebank
Orient Camp West group		9 100	2 640	8.8km NNW of Irvinebank

and rock chip sampling indicated there was no potential for significant gold deposits.

Hannahbelle, Red Hill and Mitchell Surprise

These three mines are located west of Groganville in an approximate north-south alignment. They are considered to be Besshi–Kieslager type volcanogenic massive sulphide deposits hosted by the Hodgkinson Formation.

At the **Hannahbelle**, malachite and cuprite were mined from three closely spaced lodes. Channel samples, collected in 1943 from the lodes exposed in the walls of the adit, averaged 2.5% Cu, 6.2g/t Ag and 0.62g/t Au.

Red Hill is on a ridge of metasiltstone near the contact with a thin lens of chloritised basalt or andesite. A 1.5m wide gossanous zone, sampled at a depth of 25m assayed 0.7% Cu, 0.6g/t Au and 40.4g/t Ag.

The **Mitchell Surprise** deposit is in a south-east-trending shear. Mineralisation comprises pyrite, chalcopyrite (after pyrite) and, in places, sphalerite (mainly as exsolved star-shaped grains in chalcopyrite). Diagenetic sulphide-bearing quartz veinlets occur in the sulphide zone and the adjacent wall rocks. A 1m wide, steeply south-west-dipping, oxidised enrichment zone was mined. Four channel samples collected in 1943 over a 7.5m wide gossanous zone in the bottom crosscut averaged 4.37% Cu, 46g/t Ag and <0.6 /t Au.

Herberton Mineral Field

The main deposits/centres from which base metals have been produced in the Herberton Mineral Field are **Mount Garnet**, **United North Australian (UNA)**, **Silver Valley**, **Copper Firing Line**, **Siberia Lode**, **Montalbion group**, and the **Orient Camp East** and **West groups**. Most of these deposits are in sedimentary rocks of the Hodgkinson Formation.

The main copper minerals are malachite, azurite, chalcocite, tenorite, chenevixite, cuprite, chalcopyrite, bornite, covellite, and native copper. Supergene enrichment was a critical factor in forming economic deposits, mining generally ceasing at the base of this zone.

At least 10 110t of copper were produced from the Herberton Mineral Field (see Table 7). This figure is very conservative as the production figures for the region have been poorly documented, particularly for the Copper Firing Line.

The **Mount Garnet** mine is located at the south-western extremity of the Herberton Mineral Field. The deposit occurs in a subvertical calc-silicate skarn. The mineralisation is developed at the faulted contact between Palaeozoic sediments of the Chillagoe Formation and probable Precambrian basement to the east (Hartley & Williamson, 1995). The principal ore minerals are sphalerite, with minor chalcopyrite, and traces of galena; pyrite with associated magnetite and

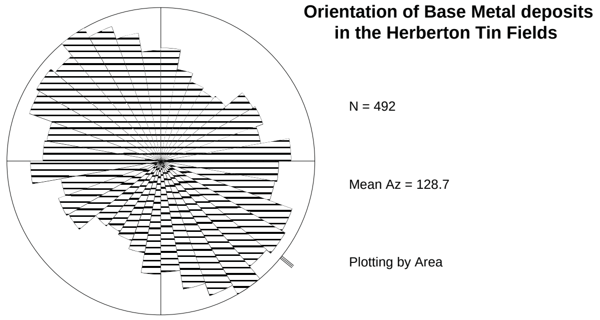


Figure 40. Orientation of Base Metal mineralisation in the Herberton Mineral Field.

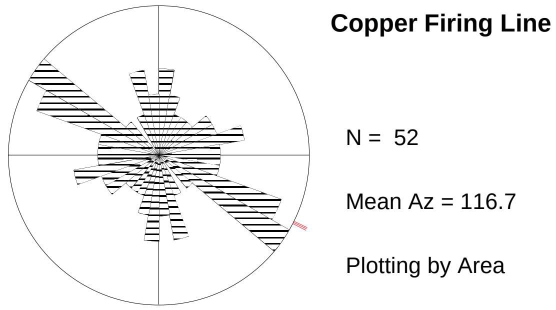


Figure 41. Vein orientation in the Copper Firing Line area.

pyrrhotite are commonly present in major proportions (Hartley & Williamson, 1995).

The **United North Australian (UNA)** Group includes the Easter Monday, Baal Gammon, Big Gossan, Crucible, Crucible Adit, Ironclad, North Australian, Shaughraun, Wyatts, Easter Sunday, Good Friday, Grand Secret, and Quartette mines. The deposit consists of irregular pods and lenses of semimassive and massive sulphides (mainly pyrite and pyrrhotite) in and adjacent to a 15m thick greisenised porphyritic microgranite sill. The sill intruded meta-arenites of the Hodgkinson Formation. The old workings focussed mainly on fractures containing remobilised base metals.

In the late 1970s and early 1980s Newmont drilled 300 holes here to assess the deposit as a tin resource. The tin mineralisation comprises 30% stannite and 70% cassiterite, but is very fine grained (A.C. Walter, personal communication, 1990). Great Northern made three attempts to mine the orebody but each time the price of tin dropped. Furthermore, the abrasive character of the topaz-bearing ore resulted in excessive and rapid wear of machinery and smelters would not accept the arsenic-rich copper ore.

The **Baal Gammon** deposit has been described as a porphyry-hosted breccia and stockwork system containing copper, silver and tin mineralisation. The history of mineralisation as proposed by A.C. Walter (personal communication, 1990) of Great Northern Mining Corporation is as follows. The microgranite sill is thought to have been emplaced during the last phase of intrusion of granitoids of the O'Briens Creek Supersuite. Late-stage magmatic fluids brecciated and altered this sill to form quartz, sericite, and topaz, and introduced tin minerals. Subsequently, fluids associated with the Glen Gordon Volcanics (Silver Valley Caldera?) crackle-fractured the porphyry and introduced the base metal sulphides. They also remobilised the tin minerals.

Significant quantities of copper ore were also mined from the **Silver Valley area**. The area is divided into two parts by a major north-south fault with most mineralisation located east of this structure. The main base metal producers were Lanette (342t Cu, 2t Pb, 825kg Ag), Westward Ho (202t Cu, 52.8t Pb, 1363.13kg Ag), Agnes (21.9t Cu, 25.4t Pb, 495.48kg Ag) and Battery (200t Cu, 656.4kg Ag.). The largest mine in this area was the **Lancelot** which produced mainly tin (1 369t cassiterite concentrate) from a complex ore assemblage of cassiterite, arsenopyrite, native bismuth, chalcopyrite, galena, pyrite, sphalerite, stannite, wolframite and rare native copper, in a quartz–chlorite gangue.

Mineralisation in the Silver Valley area is mainly in steeply dipping, shear-controlled quartz, quartz–chlorite or greisen lodes rich in arsenopyrite and pyrite. There are a few calc-silicate (skarn?) deposits containing traces of silver but production was very minor.

Copper deposits north and west of Herberton, form a belt known as the **Copper Firing Line**. These deposits were cumulatively probably the largest producers of copper in the region. Blake (1972) estimated this area produced several thousand tonnes of copper between 1909–1943, when production ceased, because of the closure of the Chillagoe Smelters. These deposits are mainly narrow fracture-controlled quartz veins, containing minor silver (in the copper minerals) and tin mineralisation. Minor argillic alteration has been recorded in some of the mines in this area.

The mineralisation is developed along a 400–600m wide zone which straddles the

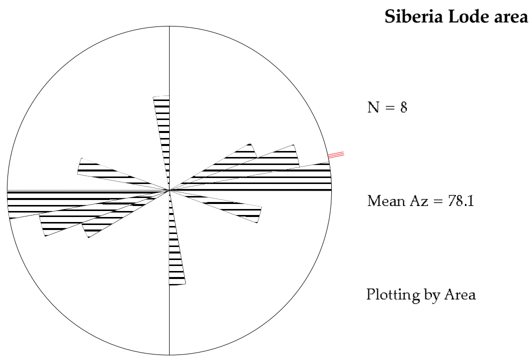


Figure 42. Orientation of reefs in the Siberia Lode Group.

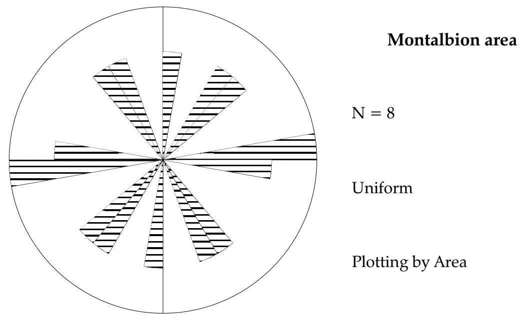


Figure 43. Orientation of mineralised veins in the Montalbion area.

faulted contact between the Saint Patrick Hill Granite and the Hodgkinson Formation (Firing-line Fault of Clarke, 1995). The tin mines are concentrated in the granite, the copper mines in the nearby contact with metasedimentary rocks, reflecting a marked mineral zonation. Galena is present in both host rocks. The copper mineralisation is confined to narrow, discontinuous, steeply dipping , east striking, siliceous gash veins and pipes. The veins/pipes are enclosed by an inner margin of silicification giving way to sericitisation (yellowy greenish–grey) and then argillic alteration (Clarke, 1995). Most mines only exploited the supergene ore from shallow workings.

The **Siberia Lode** (A1 Lode), 6km east of Emuford, was mined for copper and silver. The lode consists of several subparallel, east-trending, siliceous, brecciated veins hosted by metasedimentary rocks of the Hodgkinson Formation. These veins are continuous for at least 2km and sporadic outcrops occur over a distance of 5km. The main mines along this structure were the Magpie, Mount Emma, Mount Gossan Extended, Mount Gossan West, Mount Volk (Little Wonder), New Mount Gossan Tunnel, Rainbow, and St. Ledger. The first lease was pegged in this area in 1900, the main productive years being from 1909–1916.

Kelly (1976) proposed that the Siberia Lode is associated with a major fault, which is in turn related to a greisen fracture zone farther south. Secondary copper ore in the upper part of the lode grades into complex ore containing sulphides of copper, iron, arsenic, lead, and zinc below the water table. Ore grades in the secondary enriched zone were in the order of 23% Cu, and 180–210ppm Ag, whereas the primary ores contained ~5–6% Cu, and 150–270ppm Ag. Many rich parcels of ore, containing from 25–52% copper, were sent to the Chillagoe Smelters prior to 1914. This ore was extracted from the supergene enrichment zone slightly above the water table. None of the workings extended far below this zone of enrichment.

The **Montalbion lodes** were discovered in 1885 and by 1895, 49 258kg of silver had been recovered from 39 799t of ore (Skertchley, 1897). The deposits are in massive arenite of the Hodgkinson Formation (Donchak & Bultitude, 1994). The main mines are the Albion, Rio Tinto, Lady Jane Nos. 1 and 2 and Barossa Nos. 1 and 2.

The silver mineralisation is in narrow, steeply dipping, lenticular, and pipe shaped quartz veins within shear/breccia zones (see Figure 43). The principal ore minerals are argentiferous galena, argentiferous tetrahedrite (freibergite), cerussite, and anglesite. Berge & others (1899) recorded the presence of cinnabar and several unusual zinc minerals (such as calamine, goslarite and willemite). Small quantities of cobalt ore have also been reported from the Lady Jane mine, and stibnite from the West Albion mine. Selenium specimens were collected from the Albion mine and displayed at the Melbourne Exhibition in 1888. Traces of indium have also been detected in some of the ore (Dash & others, 1991). Most of the ore was derived from the zone of secondary enrichment which extended to depths of 15–20m. Gold values are also anomalous in the area but to date have proved subeconomic.

Mineralisation is associated with E–W and N–S trending shears, possibly related to a nearby large silicified fault zone trending 100–140°. The deposit was interpreted by Woodward (1976) to have formed in an epithermal environment, hydrothermal solutions being derived from nearby granites of the O'Briens Creek Supersuite.

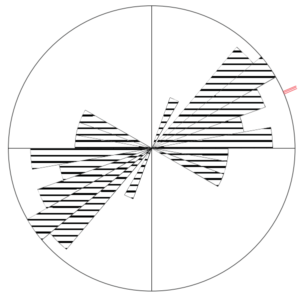


Figure 44. Orientation of mineralised reefs in the East and West Orient Camps.

The **Orient Camp East** and **West groups** of workings are located 9km north of Irvinebank in the Featherbed Volcanic Group (Bluewater Rhyolite). The silver–lead ores of this area were discovered in 1886. Production ceased in about 1924. The area probably produced less silver and lead than the mines at Montalbion (Blake, 1972).

Mineralisation is developed in well developed and persistent fissures which cut massive rhyolitic ignimbrite (see Figure 44). These narrow fracture or shear-controlled veins contain argentiferous galena, cerussite, and anglesite, sphalerite, pyrite, marmatite, cassiterite (minor), and stannite (minor). In the late 1980s, Great Northern Mining Corporation detected subeconomic concentrations of indium in the sulphides from these deposits, sphalerite probably being the main carrier. The ore shoots mined are characterised by high Ag and Pb grades down to water table. Below the water table there is 'clean' galena ore associated with sphalerite, marmatite and pyrite.

The Orient Camp mineralisation exhibits many salient features of epithermal deposits including (Cook, 1987):

- major and subsidiary branching veins, and possible stockworks,
- hosted by a major felsic volcanic complex, with high-level felsic intrusives nearby,
- vein minerals include sulphosalts, arsenic, precious metals, and the typical epithermal indicator elements Hg, Te, Sb, As, and Ba, and
- alteration styles include advanced argillic (at East Orient), plus widespread sericitic, propylitic, and ferruginous alteration.

Typical assay results for hand picked ore from the Orient East workings were 1439–1837g/t Ag, trace gold, 40–45% Pb, 10–19% Zn. Extensive exploration by Great Northern indicated there are four main, as well as two minor, mineralised vein systems in a north-east-trending shear zone. Individual veins have a strike length of up to 900m, and an average width of 0.6m. Dips range from 40° to almost vertical, but are most commonly between 45°–60° south (Osborne & Murdock, 1981). Pre- and post-mineralisation faulting has occurred.

King Vol

The **King Vol** orebody is hosted by the Chillagoe Formation. The deposit crops out as a ridge of manganiferous and limonitic chert/siliceous breccia (Culpeper & others, 1990).

Recent drilling by Aztec Mining, in a joint venture with Perilya Mines NL, delineated two parallel zones of anomalous zinc mineralisation associated with skarn rocks. An Inferred Resource of 350 000t of 25% Zn, 1% Cu and 25g/t Ag has been identified (Perilya Mines, 1993).

Mount Molloy

The **Mount Molloy** copper mineralisation has been interpreted as a Besshi–Kieslager type of volcanogenic massive sulphide deposit (Gregory, 1980). Mineralisation is hosted by rocks of the Hodgkinson Formation, near the faulted western boundary of the Molloy beds. Records of the mining indicate the deepest shaft was 143m with ore zones 4m thick and assaying in excess of 20% Cu.

The deposit comprises two main lenses of stratiform mineralisation, reported to be intruded by a body of porphyry and underlain by a narrow stockwork zone of quartz–sericite–pyrite, which is interpreted to be a feeder zone. A third, minor lens has been intersected during drilling. The presence of a stockwork zone suggests that the deposit formed proximally with regard to the source of the ore fluids. One ore lens is dominantly chalcopyrite and pyrite in a siliceous gangue, and the other is interlayered sphalerite, chalcopyrite and pyrite in a gangue of quartz, phyllosilicates, and carbonates. The latter lens shows repetitive zonation of copper and zinc.

Some chert and/or cherty silicification is associated with the mineralisation and its strike extension. Sill-like intrusive bodies of dolerite are confined to the hanging wall sequence but porphyry dykes cut the footwall sequence. A dolerite sill and numerous thinner microsyenite sills were also intersected in Departmental diamond drilling (GSQ Mossman 1), 1km to the north-east of the mine (Cranfield, 1990).

Grade estimates are 1–3% copper for the chalcopyrite–pyrite lens and 3% copper, 10% zinc, 10–30ppm Ag and ~200ppm lead for the copper–zinc orebody. The sulphide lenses crop out as massive to banded gossan. The upper 20–30m of the orebody is oxidised, and supergene enrichment is present to ~90m.

The orebodies are hosted by carbonaceous and pyritic shale. Stratigraphically below this is pyritic, altered, greenish basic volcanic breccia which hosts the stockwork 'feeder' zone.

Axis Mining NL has an agreement to maintain its 75% interest in the mining leases over the Mount Molloy deposit by the minimum expenditure of $200 000 over 2 years. A number of investigations have been completed over this deposit with the most recent being Noranda Australia (1984) who drilled 5 reverse circulation holes, and Cyprus Gold Australia (1989) who drilled another 5 reverse circulation holes. These holes did not test the down plunge extensions. Results of up to 2.6% Cu, 5.8% Zn and 55g/t Ag were recorded. Available data indicates the probable existence of a small shallow remnant, oxidised ore block of over 50,000t @ 1% Cu. This and the mine waters could justify a small electro-winning plant. The underground *in situ* remnant resource has yet to be defined (Axis Mining Ltd, Prospectus).

Copper mineralisation also occurs 1.9km east-south-east of the Mount Molloy Copper mine. At this occurrence a north-north-west trending vertical shear zone defined by clast-in-matrix rock (tectonic melange), within sedimentary rocks of the Molloy beds contains the mineralisation which displays a banded (?anastomosing) texture.

Considering the proximity to the Mount Molloy Copper mine and the absence of any nearby exposed igneous intrusions, it is more likely that this occurrence is either a very small volcanogenic massive sulphide lens which has been subsequently sheared or shear-hosted, remobilised mineralisation from a buried volcanogenic massive sulphide lens.

Nightflower Deposit

This deposit was originally mined for silver and lead but gold, antimony and zinc minerals are also present. The mineralisation is hosted by the late Carboniferous Nightflower Dacite of the Featherbed Volcanic Group and is located on the prominent north-north-west trending Nightflower Fault. Stockworks (ranging from <1cm–~30m wide) of sulphide-bearing veins grading outward into thinner and less mineralised quartz-pyrite veinlets have developed marginal to the lode. Accompanying this gradation is an outward reduction in base metal content (Laing, 1990).

The **Nightflower** mineralisation consists of pyrite, arsenopyrite, argentiferous galena, argentite, sphalerite, chalcopyrite, boulangerite, stibnite, cerussite, pyromorphite, and pyrargyrite (Laing, 1990). Stibnite is restricted to the main fissure and is almost entirely absent from the stockwork veins. It appears to have been deposited relatively late, possibly from a discrete fluid phase.

Laing (1990) considered the Nightflower lode to occupy a fissure which acted as a volcanic vent (which generated an adjacent breccia) and a conduit for fluids carrying base metals. The mineralising fluids may have been generated during the magmatism associated with the eruption of the nearby Featherbed Volcanic Group.

O.K.

The **O.K. group** of mines consists of four economically significant copper deposits (with minor associated gold and silver mineralisation) hosted by the OK Member of the Hodgkinson Formation. The lodes comprise several lenses of massive sulphide ore underlain by zones of stockwork ore in a sequence of altered basic volcanic rocks. The primary massive sulphide ore consists mainly of pyrite, chalcopyrite and sphalerite, together with minor tetrahedrite, tennantite and quartz-carbonate gangue. The ore bodies range from tabular to lenticular and are essentially concordant with the enclosing host rocks. About 80 000t of ore were mined between 1890–1918 for a yield of ~7 800t Cu, 100kg Ag, and 12kg Au (Register of Australian Mining 1995/96, page 206).

Fawckner (1975, 1978) described the deposits in detail and noted two types of alteration in the stockwork ores: a lower chloritic zone which grades upwards into a silicified zone. He described the O.K. deposit as a cupreous pyrite, volcanogenic massive sulphide deposit and postulated it formed at the site of incipient rifting in an extensional basin. Murray (1990) subsequently described the deposit as a Besshie–Kieslager type of volcanic-hosted massive sulphide.

The deposit is currently being investigated by Axis Mining NL. Of interest is the presence of high gold values in the gossan at North O.K. (up to 16g/t). Structural deformation is extensive with mining at the O.K. copper mine principally located in thicker ore zones on the axes of folds. Previous company drilling returned up to 24.4m @ 2.0% Cu (Minmet 7/11/97).

Wambanu Group

These workings are located on the south-west rim of the Herbert River Gorge where Dells and Flaggy Creeks join the Herbert River. The mines were first worked in 1909 and were reopened several times, between 1913–1914, 1935–1937 and in 1942. This area is now part of the Lumholtz National Park.

The Wambanu copper–silver–lead deposits are located in the upper part of a mafic granite (tonalite?:part of the undivided Ingham Batholith), adjacent to intrusive contacts with flat-lying to moderately dipping felsic volcanic rocks of the Glen Gordon Volcanics. The apical parts of the granite have been pervasively chloritised and partly sericitised, the base metal mineralisation being concentrated in shear zones developed within this alteration halo. These shear zones trend west-north-westerly within the north-easterly trending 'corridor' of mineralisation. The main mine (**Wambanu**) and nearby mines in the south are essentially copper orebodies, whereas the smaller workings spread out to the north and north-north-east are dominated by lead–silver mineralisation; the distribution of mineralisation implies some form of mineral zonation (possibly distance from mineralising fluid source).

Inspection of ore material from the Wambanu mine indicated the paragenesis was probably:

1. fracturing and introduction of sulphides (with very little quartz),
2. chloritisation,
3. brecciation of sulphides and chloritic gangue, and
4. precipitation of unmineralised quartz infill.

Morwood & Dash (1996) noted that similar deposits may exist in other areas where the roof zone of the granites are concealed by volcanic rocks.

Selected Minor Occurrences

The **Emerald Hill** workings located 5km south-east of Petford were the largest copper workings in the Petford area. The deposit is hosted in a shear zone which cuts Hodgkinson Formation rocks ~100m from the contact with the Petford Granite. The lode is reported to be 0.4–0.45m wide and to have an average copper content of 20% (ARDM, 1942). The shear zone contains blebs and veins of quartz up to 0.15m wide. Disseminated chalcopyrite is associated with the quartz.

The **Sweet William** copper mine is located ~5km north-west of Mount Molloy in the early Permian Mount Carbine Granite. The lode comprises north trending quartz veins which infill fractures in the marginal zone of the granite. The main workings appear to be those on the southern-most of the two main veins. Brecciation is evident in the veins as fragments of host rock cemented with infill quartz, wolframite and minor sulphides. Sericite is the main alteration mineral in the enclosing granite, but there is also some evidence of an albitic alteration halo. The northern most vein contains visible wolframite and molybdenite together with chalcopyrite and arsenopyrite. The wolframite and molybdenite were only found in clean white vein quartz, whereas copper minerals are in both the quartz and greisenised granite host rock. Minor concentrations (between 0.1%–1.0%) of tin have also been detected in both veins.

Aspiring Nos. 1 and 2 is a mineral prospect located 11km north-east of Chillagoe. This prospect was explored by Noranda Australia who defined an Inferred Resource of 50Mt @ 0.1%Cu, 200ppm Mo, and traces of Au and Ag. The host rocks are hornblende–biotite granodiorite (Almaden Granite) and rhyolite (Featherbed Volcanic Group). Mineralisation occurs on the contact of the granodiorite with the rhyolite. The mineralisation is concentrated in a SW striking fracture system where the degree of alteration in the host rocks is proportional to the fracture frequency. Ore minerals occur as fracture fillings, sparse disseminations and in quartz veinlets.

Porphyry Hill, a copper mine 11.2km west-south-west of Dimbulah, is considered to be a small porphyry copper deposit (Horton, 1982). The deposit is formed at the contact between rocks of the Featherbed Volcanic Group and an intrusive pod of late Carboniferous granite and microgranodiorite (Solanum Granodiorite). Complex sulphide mineralisation occurs mainly in veinlets or as disseminations in sheared and altered rocks of the contact zone. Secondary copper mineralisation is scattered over an area of 1.8km^2, soil geochemistry indicating a smaller, arcuate copper-anomalous area.

Current Base Metal Prospects and Main Known Resources

Baal Gammon

The Baal Gammon deposit has been described as a porphyry hosted breccia and stockwork deposit containing copper, silver and tin mineralisation (Register of Australian Mining 1994/95, page 216). Early in 1995 the owner Great Northern Mining Corporation NL entered an option agreement to sell its interests to Allegiance Mining NL.

Great Northern Mining Corp NL have been exploring this region extensively and have retained an independent geological consulting group to conduct further investigations. A joint agreement with Allegiance Mining NL and Queensland Polymetallic Resources Pty Ltd was entered into in December 1996 with Allegiance Mining NL required to spend $0.15m to gain an interest in 4 sub-blocks within EPM 10446. Exploration is to commence early in 1998.

King Vol (Walsh River Prospect)

Perilya Mines NL conducted a drilling campaign in 1993 to define resources at this old mine site. An undiluted Inferred Resource of 350 000t @ 25% Zn, 1% Cu and 25g/t Ag was calculated from the drilling results (Register of Australian Mining 1996/97, page 267). The company considers that potential exists for additional resources but development has been deferred pending an improvement in zinc prices.

Four prospects in the area were drilled by Perilya during 1996 with encouraging results. At the Ivors prospect, broad zones of base metal anomalism were intersected. Anomalous gold values were recorded over 109m in weakly silicified granites at the Morerag prospect. Field activities during 1997 have focussed on the nearby Beaverbrook prospect with the aim of generating drill targets within a large and complex porphyry related gold geochemical system.

Mount Garnet

This deposit lies adjacent to Mount Garnet township. The previous workings concentrated on the oxidised and supergene copper ores in the upper part of the deposit. The sulphide and zinc-rich parts of the deposit were ignored as the smelting techniques of the day were unable to treat these ores.

The deposit is in a near-vertical, calc-silicate–garnet skarn (with a strike length of 800m and a thickness of 50m). The mineralised zone occurs at the contact between Palaeozoic rocks of the Chillagoe Formation (arkose, sandstone and calc-silicates) and possible Precambrian basement to the east (siliceous mylonitic schists) (Hartley & Williamson, 1995).

The principal ore minerals are sphalerite, magnetite, and pyrrhotite with minor chalcopyrite, and traces of galena and pyrite (Hartley & Williamson, 1995). These minerals occur in a variety of skarn assemblages as fine disseminations, irregular patches and bands, or semimassive and massive ore. Selective replacement of fossils (mainly crinoids?) is common, the majority have cores of pyrrhotite and rims of sphalerite (Hartley & Williamson, 1995).

Perilya Mines NL have been exploring this historically significant base metal deposit which is currently owned by CRA Exploration Pty Ltd. The company is planning to establish a base metal operation centred on the Mount Garnet and King Vol deposits. Preliminary feasibility studies indicate the resources are potentially mineable by open pit.

Tartana

This prospect covers the historic mine workings of the same name north-west of Chillagoe. The property is currently owned by Dominion Metals Pty Ltd but Majestic

Resources NL has acquired an option to buy and are now actively appraising the prospect.

West Orient

This group of historic mines is held by Great Northern Mining Corporation NL. The company had been treating tin ores from these deposits in its Jumna plant until closure in December 1989. The deposit is currently optioned to Alliance Mining NL. Drilling conducted by Alliance during 1995 indicated potential existed for a large tonnage, low grade resource. The deposit currently contains proven/probable ore reserves of 182 000t @ 3.36% Pb, 213g/t Ag, and 9.36% Zn (MINMET, 7/11/1997).

COAL

Little River Coal Measures

Coal was first discovered along the **Little Kennedy River** in 1872 by Norman Taylor, the geologist accompanying Hann's expedition. The proximity of the coal to the Palmer Gold Field and the announcement of a projected rail link between Laura and Palmerville led to intensive prospecting in 1881.

Jack (1882) reported on the results of shaft sinking and described several outcrops along the river and its tributaries. The seams are in the Permian Little River Coal Measures and are up to 6m thick. However, they are steeply dipping, extensively deformed, faulted and slickensided. The coal is weathered in outcrop but reportedly improved in quality at depth, although it contains a high proportion of clay. Rands (1893) concluded that the coal is of inferior quality and that the steep dip of the seams would make them uneconomical to mine.

Mount Mulligan Coal Measures

Coal was first discovered at **Mount Mulligan** in 1907 but it was not until 1914 that production began. Operations commenced at the **State (Mount Mulligan) mine** north of Richards Creek, the privately owned **King Cole mine** (located south of Richards Creek) being opened in 1941.

Three coal seams were worked at the State mine, the No. 3 seam (0.6m thick) being the most extensively worked. The King Cole mine worked only one seam. One million tonnes of coal were mined from the Mount Mulligan area, the State mine being by far the larger producer. Peak production was in 1924 when 45 109t were extracted. The average annual production was ~20 000t (International Mining Corporation NL, 1982).

The State mine has the infamous record as being the site of Queensland's worst mining disaster when in 1921, an underground explosion caused the death of 76 miners — the entire underground shift. Mining continued until 1957 when the principal market for the coal was lost when the Tully hydro-electric scheme was completed. The King Cole mine had closed two years earlier (in 1955) as a result of a large rock fall.

The coal seams are in the late Permian Mount Mulligan Coal Measures. The sediments were deposited unconformably on the Hodgkinson Formation in a narrow, north-trending rift basin. The coal is a bituminous high-volatile, low-rank, high-ash thermal coal. The environment of formation is detailed in the geology section of this report.

Normanby Formation

The Permian Normanby Formation contains at least 30m of shaly coal in the **Little Oakey Creek** to **Deep Creek** area, ~30km south-west of Cooktown. Jack (1879a, b) reported that the coal-bearing sediments were exposed in an area 9.6km long and 2.4km wide. Some good quality coal was found between Oakey Creek and the Normanby Range, but only in seams <200mm thick. In general, the coal is of poor quality and has a high ash yield (Wells, 1989).

COBALT

The only cobalt occurrence recorded from the region is the **Cambourne** lode part of the Redcap group of mines, 12km north-west of Chillagoe. The mineralisation is related to metasomatic alteration of calcareous rocks (including metabasalts) in the Chillagoe Formation. The cobalt occurs as cobaltite and minor erythrite, associated with chalcopyrite and some chalcocite. Grades are low and the deposit is currently subeconomic.

DIMENSION STONE

Several small slate quarries or pits have been excavated in Hodgkinson Formation rocks between the St George and Palmer Rivers. They are worked intermittently due to poor access in the wet season. The stone is marketed in the Cairns area as random and crazy pavers, and for landscaping (Trezise, 1990).

Marble deposits in the **Chillagoe** district have been extensively quarried over the last decade for use as building stone. Marble deposits in this area are mostly massive and even-grained. The coarse to very coarse-grained, saccharoidal marbles are commonly the coloured varieties (cream, gold, pink, silver-blue, and blue), whereas the white marbles and pale to dark grey and black limestone are fine-grained. The stone has low compressive strength, inherent weakness along grain boundaries, and low abrasion resistance (Spry, 1986) which restrict its use to building interiors (*e.g.* as wall cladding).

The colour developed in the marble is the result of impurities within the calcite crystals. The white marble is pure calcite, pink marble is due to fine inclusions of iron oxides, blue and black marble have inclusions of organic material and fine fractures coated with natural oil. Some of the blue marble contains globules of oil inclusions in the calcite crystals whilst other blue marble releases small quantities of hydrogen sulphide (rotten egg gas) produced from fossil organic material in the limestone which was trapped during metasomatism.

Marble extraction began in 1984 from a site south-east of Chillagoe, followed by construction of stone processing plants in Cairns and Chillagoe. Between 1987–1989 2 680t of marble were quarried for processing into blocks, slabs, billets, and tiles for both domestic and overseas markets (Trezise, 1990). The high initial production rates have not been sustained. The annual production, for example, for 1991/92 was 600t of marble quarried from six sites (by several companies). Large reserves of marble remain in the Chillagoe area.

Small quantities of rhyodacitic to rhyolitic ignimbrite, are being intermittently obtained from several small quarries in the Featherbed Volcanic Group, north-east of Emuford. The stone is used as pavers, flagstones and in retaining walls. Small amounts of granite have also been extracted from sites west of Mount Garnet for use as facing stone. Several other granites in the region are considered prospective for this commodity.

FLUORITE

Most of the fluorite lodes in the region occur as prominent fissure veins cutting Palaeozoic granitoids, or to a lesser extent, rocks of the Hodgkinson Formation. The fluorite is generally massive and crystalline, and ranges from white to purple to green. Quartz-fluorite veins typically display multiple stages of brecciation and silica precipitation. Fluorite also occurs as a gangue mineral in many greisen veins in the Herberton–Mount Garnet area. Significant fluorite reserves have also been identified in some of the skarn deposits.

The main historical producer of fluorite in the study area were the **Perseverance** (9 272t CaF_2) and **Mistake** (~1140t CaF_2) mines. The largest fluorite deposit in the region is the **Gillian** prospect. A detailed review of this deposit can be found in the ‘Tin’ section of this report.

GEMSTONES

Sediments in streams draining the **Lakeland Downs** area contain ‘diamond indicator’ heavy minerals (zircon, picro-ilmenite, chrome diopside, orthopyroxene, brookite, phlogopite, olivine, pyrope garnet, corundum — including sapphire and ruby — and chrome spinel). Zircon, garnet and sapphire also occur in the weathering products of basaltic pyroclastic deposits at **Mount McLean**, **Hoskin’s Vent** and **Tom’s Hollow**, in the Lakeland Downs area. Zircon, garnet and rare sapphire occur in the drainage system at **Bull Hollow** (Domagala & others, 1993). Tom’s Hollow and Bull Hollow represent maars which have been largely infilled with lacustrine sediments. Microprobe analyses indicate the spinels and garnets in the pyroclastic deposits associated with these structures are kimberlitic and that the chrome diopside is probably kimberlitic. Bulk sampling so far has failed to recover any diamonds from these areas.

Topaz has been mined from several deposits in the Mount Garnet area, approximately 5km north-west of Innot Hot Springs. The main deposits are **Mount Gibson**, **Pattersons**, **Crystal**, **Yellow Jack**, **Jack** and **Happy Jack**. These deposits have formed at the margins of the O’Briens Creek Supersuite where it intrudes the Hodgkinson Formation metasedimentary rocks. The topaz occurs in greisen deposits often associated with tin or tungsten mineralisation. The largest of these topaz-greisen deposits occurs at Mount Gibson. The Mount Gibson deposit lies on the contact between a tongue of Mount Gibson Microgranite (O'Briens Creek supersuite) and Hodgkinson Formation metasedimentary rocks. Topaz crystals up to 100mm in length have developed in a siliceous greisen with numerous vugs of coarse-grained crystalline quartz. The topaz is commonly shattered, iron-stained and of poor quality. The topaz crystals at all the deposits are commonly not of gem quality being fractured, opaque, and iron-stained.

Stable isotope data indicates the quartz-topaz alteration is probably derived from interaction of magmatic derived fluids with wallrock (Clarke, 1990). This type of alteration is present in scattered localities throughout the Herberton Mineral Field but the topaz is generally very fine and gemologically irrelevant.

A small garnet deposit called the **Noble Garnet** has been worked SW of Mount Garnet. The dark green grossular garnet crystals are >10mm long but are of poor gem quality. They occur in thin lenses associated with quartz veins along a shear in Hodgkinson Formation metasedimentary rocks.

Sapphires have been recovered from time to time during alluvial tin mining operations in the Cooktown Tinfield and from **Campbell** and **Spear Creeks**, which are tributaries of the Palmer River.

Diamonds have been recovered from the East and West Normanby Rivers and Little Palmer River during alluvial gold mining operations. One 0.166 carat diamond, showing marks of vigorous and lengthy transport, has been extracted from tin-bearing deep leads near Herberton.

Diamonds have been obtained during alluvial gold mining of the alluvium of the Russell Deep leads, Little Beatrice River and headwaters of the Mulgrave River, these diamonds are small to very small (<1 carat), the largest observed was approximately 5 carats (A.D. Robertson, personal communication, 1994). Exploration to date has failed to find any diamonds or indications of kimberlitic material. The diamond potential of this region has not been fully tested by current models of diamond genesis as outlined by Barron & others (1994).

Northern Diamonds Pty Ltd have been exploring the Elizabeth Creek area near Mount Surprise for diamonds. This area has been extensively mined for alluvial tin and a number of diamonds have been recovered during these operations. Initial bulk sampling completed in 1993 recovered one 0.04 carat diamond.

GOLD

Clohesy River area

Several north-trending, gold-bearing quartz veins cut sedimentary rocks of the Hodgkinson Formation in the Clohesy River area. The main deposit is the **Waitemata** (Jannie Jan), which comprises one main quartz vein and numerous smaller veins which have not been fully explored. Accessory minerals in the veins are pyrite, chalcopyrite, malachite, arsenopyrite, covellite (in the Black Bear lease area) and bournonite (in the Waitemata mine).

The main vein at the Waitemata mine is a shear infilling. The vein pinches and swells and, at a depth of 13m in the most recent shaft it bifurcates. The gold occurs as coarse-grained specks and very coarse slugs, irregularly distributed throughout the vein (average production grade was 18.13g/t Au). Petrology of ore samples from the Waitemata mine revealed that the bournonite ($CuPbSbS_3$) occurs as fine streaks and clumps, and has a close spatial association with free gold.

Willmott & others (1988) noted that the Waitemata deposit may be granite-related as it is in the contact aureole of the Tinaroo Granite, 5km to the east. The deposits in this area also contain more copper than those in the Hodgkinson Gold Field to the north-west.

Hodgkinson Gold Field

This gold field included the mining centres of **Northcote**, **Minnie Moxham**, **Beaconsfield**, **Union**, **Thornborough**, and **Kingsborough**. Mines around the Kingsborough and Thornborough centres are referred to as the 'central Hodgkinson Gold Field', as this area was the original discovery site.

Mineralisation consists of gold–quartz and gold–stibnite–quartz veins hosted by the Hodgkinson Formation. The quartz veins range

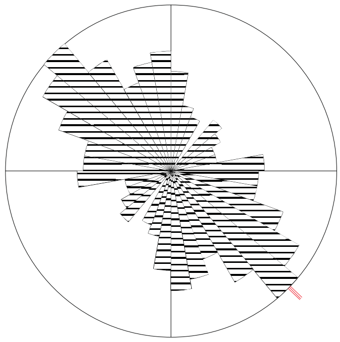


Figure 45. Trend of gold reefs in the Hodgkinson Gold Field.

from a few centimetres to a maximum of 3m in width and contain only minor amounts of sulphide minerals (Amos & de Keyser, 1964). A marked coincidence of mine occurrences with the dominant north-west trend of the major and minor faults in the region indicates a structural control on their distribution either parallel or trending at a low angle to these regional shear zones (see Figure 45). The presence of mafic volcanics in the **Union** mine area may have some influence on the presence of mineralisation in this area (Johnston & Hammond, 1984). Most gold lodes are steeply dipping and cut across the bedding and regional foliation. Kinks in the quartz veins are sites of ore enrichment.

The veins are a complex mixture of gouge and inclusion-rich quartz. The quartz is massive, milky-white and deformed, with abundant laminations, stylolites and clear quartz veinlets. The veins also show evidence of incremental quartz deposition. 'Ribbons' or laminations, dark grey country rock and associated sulphides within the quartz are commonly associated with higher gold grades. These laminations may be concentrated on one side of the quartz reef. Other gold-bearing vein types include massive (buck) quartz, complexly brecciated quartz, and fractured quartz. A footwall quartz-stringer zone is also present in many of the workings (Johnston & Hammond, 1984).

The laminations are thought to have formed from a crack-seal process as defined by Ramsay (1980). Native gold is commonly concentrated in this laminated quartz as specks/blebs along the laminations. Mining therefore tended to focus on the laminated quartz. Minor sulphides are associated with the gold; these include galena, arsenopyrite, pyrite, sphalerite, chalcopyrite and stibnite.

Poorly developed sericitic and argillic alteration zones form selvedges, a few centimetres wide, adjacent to the veins.

The gold–quartz and gold–stibnite–quartz veins are confined to discrete structural zones where they are localised in shears and secondary brittle reactivation zones along axial planes of folds. These discontinuities are associated with larger, commonly regionally significant shear and melange zones which show evidence of multiple deformation. The gold mineralisation in the Hodgkinson Gold Field, for example, is associated with the Retina, Monarch and Kingsborough Faults (central melange zone).

The source of the gold mineralisation in the Hodgkinson Province is uncertain. It may have been:-

- exhaled from submarine volcanic vents and concentrated within nearby mafic volcanics or chert of the Hodgkinson Formation and remobilised to the present sites,
- transported in hydrothermal solutions derived from plutons of Whypalla Supersuite,
- related to the emplacement of the Featherbed Volcanic Group and related high-level intrusives (rhyolites presumably associated with this activity crop out along the Retina and Kondaparinga Faults), or
- derived by the devolatilisation of the sediment pile during regional metamorphism and channelled to dilational sites in shear zones (Phillips & Powell, 1992).

A comprehensive study of this area was conducted by Peters (1987) and his interpretation of the mineralisation history is given below.

The mineralisation cycle commenced with vein growth, wall-rock reactions and assimilation, characterised by precipitation of large amounts of subhedral quartz crystals. This stage represents maximum fluid flow during mineralisation and maximum wall-rock interaction. Wall-rock inclusions and laminations may indicate that the growth of veins at this stage was by crack-seal processes. Sulphide precipitation was not common but disseminated, arsenopyrite and more minor pyrite, galena and gold were deposited in partially assimilated wall-rock inclusions and on vein margins. Late-stage interstitial quartz–carbonate–pyrite precipitation marked the end of this stage.

The second and main stage of mineralisation was accompanied by movement along shear zones. These movements resulted in cracking of existing brittle quartz veins and the introduction of shear gouge and fill. Fluids migrating along the brittle partings deposited galena, sphalerite, arsenopyrite, pyrite and gold. Gold occurs along stylolites as anhedral crystals up to ~3mm across. The fineness of the gold ranges from 720–740. Ore shoots were controlled by fault geometry and movement, together with lithology competence contrasts.

Late-stage mineralisation consisted of precipitation of quartz-carbonate veinlets in brittle fractures within quartz veins and wall rock. Chloritic alteration accompanied this stage which was barren of economic mineralisation.

Peters (1987) did not determine the timing of the formation of the stibnite–quartz veins present in the Hodgkinson Gold Field. However, work by Western Mining Corporation and Nittoc International Company Ltd established that the stibnite mineralisation postdated the main gold mineralisation (Dash & Cranfield, 1993). The antimony mineralisation is dealt with in more detail in the antimony section.

Recent studies of the structural, paragenetic, stable isotopic and fluid inclusion characteristics of the gold and gold–stibnite veins support a model involving a post-tectonic mineralising event for the formation of these ores. Some conclusions from these studies are as follows:

- A late Carboniferous mineralisation age has been obtained from K/Ar isotopic dating of alteration muscovite from gold–quartz veins in the Hodgkinson Gold Field (Morrison, 1988).
- Fluid inclusion studies by Peters (1987) indicate no evidence of boiling and suggest mesothermal temperatures of 285°–335°C. The inclusions have 7–10wt% NaCl, and $<1\%\ CO_2$.
- Golding & others (1990) indicated the stable isotope data for the Hodgkinson Province are compatible with deposition of most gold–quartz and antimony–gold–quartz veins "from homogeneous, deeply-sourced fluids generated during regional tectonism and channelled to dilation sites in shear zones".
- Many of the stibnite–gold–quartz veins are located on domain boundaries which truncate the gold mineralisation. The distribution, therefore, of the antimony–gold–quartz veins implies they postdate the main gold–quartz mineralising event, as postulated by de Keyser & Lucas (1968).

Phillips & Powell (1992) have proposed a metamorphic model for the formation of gold only deposits similar to the Hodgkinson Gold Field which accounts for all the above observations. Their model has the gold scavenged from the country rocks by low salinity, high temperature (>200°C) reducing fluids derived from devolatilisation during regional metamorphism. These fluids are enriched in sulphur (due to the presence of pyrite in the host rocks) and form ideal gold transporters in a Au–S complex. The deposition of the gold is considered to occur at temperatures of between 250°C–400°C and can be due to interaction with Fe-rich country rock, a drop in temperature, or lower oxygen activity. The distribution of the fluids is controlled by major shear zones.

This metamorphic model also accounts for the presence of gold enrichment around selvedges of host rock. The fluid interacts with the chlorite (Fe-silicate) present in the wall-rock causing the gold to precipitate. This wall-rock is subsequently incorporated in the vein by repeated fluid injection (the crack-seal process). The less common presence of disseminated gold within the vein quartz is due to decrease in fluid temperature.

Exploration by Western Mining Corporation Ltd (WMC) in 1985–1991 indicated the bounding fault (termed the "**Eastern Bounding Fault**" (E.B.F.)) on the eastern side of the central melange zone (Kingsborough Fault), contains a large, subeconomic gold resource with a grade in the order of 0.5g/t Au. This structure extends ~22km; detailed investigation by WMC delineated the Gate, Homeward Bound, Forget Me Not and South E.B.F. prospects.

Lode morphology consists of sericitised and silicified arenite fragments in a matrix of massive to crystalline quartz (Dugdale, 1989).

Mineralisation within these prospects occurs as fault-controlled vein systems, silicified arenite fragments in a matrix of massive to crystalline quartz, or disseminated within brecciated host rock and older quartz vein material.

The **Northcote area** contains measured gold reserves, in the order of 244 000t, containing 5.76g/t Au, within up to seven stibnite-quartz vein systems. These mainly comprise primary (sulphide) ore and were delineated by Western Mining Corporation Limited and Nittoc International Company Limited during and prior to mining the oxidised ore from this area in 1991 and 1992.

At **Beaconsfield**, gold mineralisation is in a similar setting to that of the central Hodgkinson Gold Field. The Beaconsfield group is separated from the Northcote area to the south by an east-trending photo-lineament interpreted by Peters (1987) to be an easterly extension of a major fault in the central Hodgkinson Gold Field. Total production from Beaconsfield is 300kg Au (Peters, 1987).

The **Belfast Hill (Disraeli) prospect** is located 18.4km NE of Dimbulah (to the south-east of the Northcote area) and contains a significant subeconomic resource of gold delineated by North Queensland Resources NL (70%) and Central Mining Corporation (30%). The prospect lies within a shear zone 6km in length which contains numerous historical workings. The mineralisation is developed in quartz stockworks and veins hosted by hydrothermally altered Hodgkinson Formation metasediments.

Gold was mined at the **Minnie Moxham** deposit from up to five quartz veins, hosted by shears in sedimentary rocks of the Hodgkinson Formation. Auriferous quartz veins were mostly on the margins of the shears and contained abundant black, slickensided mudstone layers. This type of ore was termed 'magpie rock' by early miners. This deposit differs from other gold deposits in the Northcote and central Hodgkinson Gold Field in that the shear is east-trending, not north-west-trending as at Northcote and the central Hodgkinson Gold Field. Slickensides within the quartz veins indicate repeated movement after quartz vein formation.

Minor amounts of fine-grained stibnite also occurred with the gold but there are no records of any antimony production. Saint-Smith (1917b) noted bladed, tabular barite in the upper part of the lode, as well as malachite staining. Small amounts of barite have been produced from the Minnie Moxham, together with 0.1t Cu.

A significant amount of exploration has been focused on the area east of the Retina Fault near the Mitchell River Antimony mines. Gold with associated antimony mineralisation occurs in a 1.5km wide 'fracture system' bounded by the Retina Fault to the west. The main discovery within this system is the **Tregoora** deposit (also known as the Black Knight–Rim Fire deposit) which occurs within a larger gold-anomalous zone called the Sleeping Giant.

Additional gold prospects at or near known antimony occurrences in this area have been outlined at the **Pillidge**, **Honey**, and **Lost Mine**. Strategic Minerals Corporation NL (1985) described the gold as occurring "in a pyrite–arsenopyrite mineralised phyllonite zone which typically contains quartz as veins, stringers and boudins (phyllonite is a rock which resembles a phyllite but is formed tectonically). Commonly, the phyllonitic material is gold-depleted at the surface.". The occurrence of the gold within broad zones of sheared country rock contrasts with the antimony mineralisation which is confined to the quartz-mineralised shears and associated structures.

In the Mitchell River area, a positive correlation between pyrite and arsenopyrite content and gold grade exists for the most part (Reisgys, 1986). Mineralogical examination indicates these sulphides are replaced by stibnite (Woodcock, 1958).

Near the north-eastern margin of the Featherbed Cauldron, the prominent **Maneater Peak** has been interpreted as the pervasively altered (sericite, silica) core of a hydrothermal breccia complex (Garrad, 1993). Some of the numerous quartz veins radiating from the peak have assayed up to 1.1g/t Au; the soil and rocks in the area are also characterised by anomalously high Pb, As, and Sn contents. Detailed mapping and sampling has to date failed to define an economic orebody.

Jeannie River prospects

Numerous chert ridges, some of possible exhalative origin, crop out in the Hodgkinson Formation between the Howick and Jeannie Rivers. The ridges comprise chert and silicified metasedimentary rocks. Quartz stockworks and iron and manganese-rich gossans are common. The cherts and stockwork zones are slightly anomalous in gold and some of the cherts are phosphatic. The main prospects in this area are the **Chert Ridge**, **Lagoon** and **Brown Peak**.

Visible gold is reported to occur in chert drill core obtained from the Chert Ridge prospect. Rock chip samples returned a maximum assay result of 1.52ppm Au. Petrological examination indicated some of the cherts are extensively silicified volcanic and sedimentary rocks which form large boudins in deformed metasedimentary rocks. Epidote and chlorite are common secondary minerals and magnetite is visible in hand specimen. Quartz veins, inclusions and limonite-stained fractures are common.

Jordan Creek Gold Field

Although this gold field was principally worked for alluvial/eluvial gold, several lode deposits have also been extensively mined. The alluvial/eluvial gold is derived from the weathering of numerous thin quartz veinlets in the deeply decomposed biotite granite (part of the Tully Granite Complex) of the area. The main workings were concentrated about **Henrietta** and **Jordan Creeks** (tributaries of the North Johnstone River).

Garnet, tourmaline, topaz, zircon and rare sapphire and ruby were also recovered from the alluvial deposits. The garnets are large and a deep red colour, whereas the sapphires and rubies are generally small (less than a carat).

Several small-scale lode mining operations attempted to work the larger quartz veins in the granite, and several batteries were erected around 1900. The **Wyreema** mine was the major workings in the gold field.

The gold occurs in splay veins, stockworks, and thin quartz stringers distributed throughout the decomposed granite which enabled successful sluicing operations. The reefs generally strike north-east and dip 70° to the north-west. They are commonly very crooked and cut by faults. Rounded aggregates of arsenopyrite and pyrite are present in massive white quartz of the reefs. The gold is associated with the pyrite and occurs in irregular shoots. Extensive alteration of the granite has occurred adjacent to some of the reefs producing auriferous zones up to ~3m wide. The historic underground workings appear to have concentrated on pyrite–arsenopyrite bearing quartz veins whereas the sluicing operations exploited the associated auriferous alteration zones.

The granite hosting the mineralisation in this region is a sphene-rich oxidised I-type (R.J. Bultitude, personal communication, 1994) which is a strong indicator for associated gold mineralisation (Blevin & Chappell, 1992).

The granite is overlain by basalt of the Atherton Basalt Province. Deep lead deposits have been located below these basalts but are uncommon and not extensive.

Kobi Creek and Hilda Creek

Both these creeks lie in the headwaters of the Daintree River. The headwaters of Kobi Creek contain the **Enterprise** mine which has shed small amounts of gold into the drainage system. Limited alluvial mining has occurred. Small nuggets of gold have also been recovered from Hilda Creek for which no reef source has been located.

The Enterprise gold mine consists of narrow gold-bearing quartz veins hosted by the Hodgkinson Formation. The lode was reputed to be very rich in gold and the average grade of ore mined was 78g/t. The deposit is a slate-belt type, the quartz veins being derived from regional metamorphism.

Mareeba Gold Field

The Mareeba Gold Field is located 7.2km ESE of Mareeba. Gold production from this area is comparatively small at 332kg. Most deposits form saddle reefs and are hosted by the Hodgkinson Formation. Almost all of the gold production came from the **Queen Constance** deposit (330.6kg gold) where auriferous quartz veins cut schistose metasedimentary rocks of the Hodgkinson Formation.

Mount Peter Provisional Gold Field

Three main gold-bearing quartz reef systems have been worked in this gold field since 1915, namely the **Talisman**, **Specimen Hill** and **Mount Peter**. The host rocks form part of the Hodgkinson Formation and consist of quartzite and pelitic schist (a small limestone lens is also located in the gold field). The reefs have irregular strikes and commonly anastomose (see Figure 46). The gold occurs in widely spaced narrow shoots (splay veins) in which it

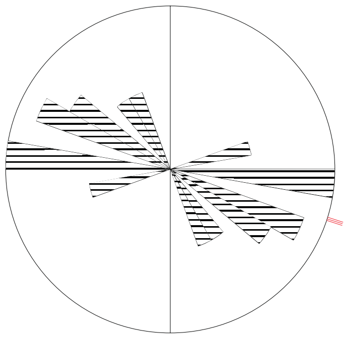


Figure 46. Reef trends in the Mount Peter Provisional Gold Field.

is mainly present as discrete visible specks of high fineness or associated with arsenopyrite (Denmead, 1947b). Apart from the Talisman, which maintained its size, the lodes were found to pinch out at depth. The veins are generally narrow and ribbon textured, with abundant host rock fragments forming the ribbons. The larger veins contain ribbon quartz, stylolites and clear quartz veinlets. These veins also show evidence of incremental quartz deposition. The ribbon texture may form on both margins of the vein or be confined to one side of a larger buck quartz vein. Other types of gold-bearing reef are buck quartz, complexly brecciated quartz, and fractured quartz.

Arsenopyrite commonly occurs along the ribbons where it commonly partly replaces the host rock fragments. Denmead (1947b) also noted the presence of pyrite and chalcopyrite in restricted narrow bands within quartz veins; galena is also present. The presence of sulphides often indicated higher gold grades.

The ribbon quartz is considered to have formed from a crack-seal process as defined by Ramsay (1980). Native gold is commonly associated with the ribbon quartz in which it occurs as specks/blebs along the ribbon surfaces; coarse grained gold also commonly occurs within the massive white quartz. The white, massive quartz generally had a low gold content and mining focused on the ribbon quartz.

The characteristics of the veins and the textures present are consistent with the slate-belt model of vein genesis as defined by Phillips & Powell (1992).

Mulgrave Gold Field

The Mulgrave Gold Field encompasses the **Goldsborough** (Lower Camp) and **Walter Hodgson** (Upper Camp) regions. The gold-bearing quartz reefs mined in this district are hosted by graphitic schists and meta-arenite of the Hodgkinson Formation. These reefs are both concordant with and cut the dominant foliation. The mineralised quartz veins are consistently associated with graphitic schist. In the Chance and Sheila mines (Goldsborough) the gold-bearing quartz vein occurs along the contact between the graphitic schist and meta-arenite.

The reefs in the region consist of ribbon quartz, commonly with associated massive white crystalline quartz. Host-rock selvedges within the ribbon quartz are composed of stylolitised graphitic schistose material which is commonly replaced by fine pyrite and arsenopyrite; galena has also been reported. The gold occurs as patches of mostly visible coarse grains associated with these selvedges within the ribbon quartz.

The quartz reefs:

- are commonly localised along the boundary between graphitic schist and meta-arenite,
- display ribbon textured quartz,
- are characterised by graphitic selvedges, and
- are characterised by rare infill textures in the quartz.

These features indicate the crack-seal model of ribbon/laminated vein formation (see Ramsay, 1980) appears to have operated. The lithological control on some of the reefs suggests the graphitic schist may have influenced auriferous reef formation. The presence of broad bands of massive crystalline quartz displaying infill textures is possibly due to increased hydrostatic pressures generating favourable sites for crystal growth. The veins appear to have formed from metamorphic devolatilisation of the country rock in a similar fashion to the auriferous deposits of the Hodgkinson and Palmer Gold Fields.

The **Kraft Creek** area (also called the **Bartle Frere Gold Field,** although it was never a gazetted gold field) is part of the Mulgrave Gold Field. It also contains gold-bearing quartz reefs hosted by the Hodgkinson Formation. These reefs range from several centimetres to >3m in width. The strike of the reefs parallels pervasive cleavage in the host rocks (see Figure 47). The rocks marginal to the veins

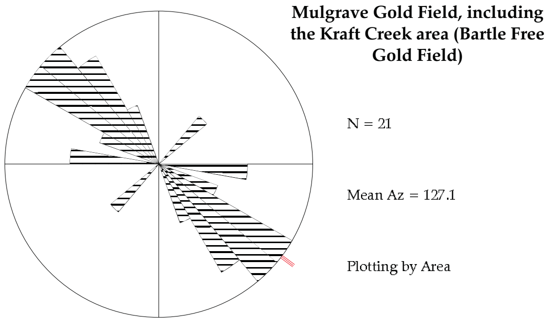


Figure 47. Reef trends in the Mulgrave Gold Field, including Kraft Creek area (Bartle Frere Gold Field).

commonly contain thin quartz stringers but no extensive stockworks have developed.

The gold occurs in association with sulphides and as discrete visible grains (often coarse grained). The sulphides which include pyrite, arsenopyrite, marcasite, galena and sphalerite form aggregates and disseminated grains within the coarsely crystalline quartz. Most lode mining operations concentrated on the sulphide ore. This was reported to contain the highest grades of between 31–186g/t Au. The majority of ore came from floaters of quartz (up to 1.5m across) in Kraft Creek and its steep banks. Most of these boulders could not be traced to a source; consequently their geological setting is not known. Field examination of the sulphide-rich quartz float yielded several samples containing disseminated visible gold associated with sulphide clots in massive crystalline quartz.

Inspection of the reef exposed in the **Krawil** workings and descriptions of the other deposits indicate the reefs consist of ribbon quartz — the ribbons containing abundant graphitic material. These reefs are similar to those in the Mount Peter, Towalla and Mulgrave areas. Most of the auriferous quartz boulders examined in Kraft Creek contained few graphitic ribbons and were commonly gossanous, contrasting with the quartz reef exposed in the Krawil workings. The quartz float may be from a discrete source, possibly related in some way to the nearby Bartle Frere Granite.

Palmer River Gold Field

Alluvial Deposits

The alluvial gold recovered was reportedly of a high fineness and occured in several forms. These include nuggetty, angular to rounded, bullet-like, wire, flat striated grains, wire and filigree attached to quartz, and very fine-grained flakes.

The **Palmer River** and its tributaries contain extensive deposits of auriferous alluvium. Three main types of Cainozoic alluvium/eluvium have been recognised as being associated with present-day drainage systems namely:

1. Recent wash occurring within flow channels and under active sand banks.

2. Older wash lying outside the active flow channels but adjacent to recent sand banks. This wash forms restricted deposits in the larger drainage systems such as the Palmer River.

3. High-level wash associated with old stream channels, situated some distance from the river, and forming terraces (in places 30–50m above present river level). These deposits are generally shallow but carry a higher gold content than recent river wash.

Lam & others (1991) listed the sources of the gold as:

- auriferous quartz veins and lodes (for example, lodes at Maytown and Groganville),

- stockworks of auriferous quartz veinlets (for example, White Horse, Kennedy, McGann, Sandy and Fine Gold Creeks),

- auriferous sulphide lodes (for example, antimony/quartz lodes near Saint George River),

- auriferous sedimentary units (for example, quartzite/chert beds at Mount Madden and Mount Bennett),

- *in situ* precipitation of gold nuggets, and

- concentration of gold from reworking of basal horizons of the Gilbert River Formation.

A significant feature of this gold field is that alluvial gold is found in the basal horizons of the Gilbert River Formation. These Late Jurassic–Early Cretaceous sediments overlie the Hodgkinson Formation to the north of the main centre of mining and Jack (1888) noted that the basal units were likely to contain deep

Table 8. Total Production from recent alluvial mining operations in the Palmer Gold Field.

Production Period	Gold Production
1986/87	82.08kg (2639oz) Au 15.7661kg (5069oz) Au Fine Gold Creek–McGanns Creek
1987/88	106.154kg (3413oz) Au 338.307kg (10877oz) Au Fine Gold Creek–McGanns Creek
1988/89	163.290kg (5250oz) Au 228.700kg (7353oz) Au Fine Gold Creek–McGanns Creek
1989/90	210.256kg (6760oz) Au
June 1990–Dec 1990	88.830kg (2856oz) Au
1991/92	39.314kg (1264oz) Au

lead gold occurrences which have been worked in scattered locations, for example Chinky Gully. Wilson (1987) suggests the origin of most of this gold is clearly detrital but some may be deposited from solutions.

The stretch of the Palmer River upstream from its junction with the Mitchell River to near Palmerville has been mined and prospected in the past, with little success. Upstream of Strathleven Homestead, 105.8kg of gold were produced at an average grade of 108mg/m^3. The gold is flaky and very fine-grained. Grades are erratic and volumes are generally insufficient for large-scale operations. The palaeochannel deposits are the most prospective. Testing at Lukinville, located near the junction of 12 Mile Creek with the Palmer River, indicated average grades of 167mg/m^3.

The Palmer River drainage upstream from near Palmerville was mined extensively in the early days of the Palmer Gold Field and reworked within the last decade. Small-scale mining is currently being carried out in the Palmer, North Palmer, South Palmer, and Little Palmer Rivers areas, particularly along small gullies draining the old lode workings.

The tributary creeks are generally narrow and winding. Gold occurs in stream bed alluvium and in patches of buried gravel on gentle slopes above the streams. Highest grades occur in the creek beds.

Recent alluvial mining activities have concentrated on mining alluvium from creeks draining Mount Madden, Jessops Creek, McLeod Creek, McGanns Creek, Fine Gold Creek, Sandy Creek, Pinetree Creek and Limestone Creek (Table 8). Mining ceased in 1992.

Exploration has indicated several areas with significant reserves, for example, 139 000m^3 at 0.41g/m^3 in Spear Creek, 254 000m^3 at 0.20g/m^3 in Blackfellow Creek, 1 400 000m^3 at 0.26g/m^3 along the Palmer River, 850 000m^3 at 0.8g/m^3 in the upper reaches of Doughboy Creek, and 70 000m^3 at 0.26g/m^3 in the Little Palmer River.

Madden Resources Pty Ltd were working the alluvial gold resources in the Mount Madden area in the late 1980s. A combined measured-indicated geological resource of 1.5 million lm^3 grading ~0.4g/t Au remains in the unworked leases held along Sandy Creek (Register of Australian Mining 1993/94, page 133).

In 1987, 1380m^3 of bulk samples from **Kennedy Creek**, near Laura, were treated for a gold recovery of 0.012–0.093g/m^3; minor platinum and cassiterite occur with the gold. The alluvium was considered to be uneconomic for bulk mining. Bulk samples of alluvium from the Mossman River returned 0.25–0.4g/m^3 gold. The concentrates were high in platinum (385.5–840.5ppm) and palladium (2.2–6.1ppm). The Indicated Resource was calculated as 232 000m^3 at a grade of 0.19g/m^3 Au with a cutoff of 0.1g/m^3.

The **Mitchell River** drains several gold mining centres including the Hodgkinson Gold Field and the Groganville area. Alluvium within the Mitchell River system has been worked in several locations, principally downstream from Groganville. Very little alluvial gold was associated with the Hodgkinson Gold Field.

The **Saint George River**, has been extensively mined for alluvial gold near its junction with the Mitchell River. In June 1987 Seamet Ltd calculated a probable reserves of 372 000 lcm @ 0.26g/t Au (Register of Australian Mining 1988/89, page 161). These resources were mined for a short period under tribute but the operations were on care and maintenance in early 1991.

Reef Deposits

The **Maytown** area contains the greatest concentration of Au-bearing quartz veins in the Palmer Gold Field. Approximately 160 lodes occur within an 11km by 2km north-north-west trending belt extending from the Palmer River (south of the abandoned township of Maytown) north to the Conglomerate Range.

The main features of the veins are:

- they occur in groups within a 2km-wide, north-north-west-trending zone,
- within each group of workings, the veins are subparallel,
- the reefs commonly strike 100° and dip 70–90° south (see Figure 41),
- pinching and swelling occurs along strike and tabular boudinage features occur down dip,
- reefs are brecciated on the margins and slickensided down dip,
- branching or bifurcation occurs in some of the major veins and closely spaced subparallel veinlets, spur veins and bends are common,
- they commonly are truncated by doleritic dykes,
- gold is disseminated throughout the veins, but is concentrated along contacts with host rock laminae, in small ore shoots, and in pinches along the lodes,
- gold fineness is upward of 920–940,
- associated sulphide minerals (everywhere very minor) include pyrite, arsenopyrite, marcasite, galena, sphalerite, pyrrhotite and stibnite.

The host rocks in the Maytown area are metasedimentary rocks of the Hodgkinson Formation which comprise a sequence of meta-arenite, phyllite, phyllitic mudstone and metasiltstone intruded by basic dykes. The meta-arenite contains weathered pyrite cubes up to ~10mm across.

Medium-grained doleritic dykes, up to 1m wide and often traceable for more than 1km along strike, are common in the area. They are subparallel to the regional north-north-west trend and commonly truncate the mineralised quartz veins. Up to 5% pyrite and arsenopyrite occur in the dykes, which invariably contain xenoliths of vein quartz.

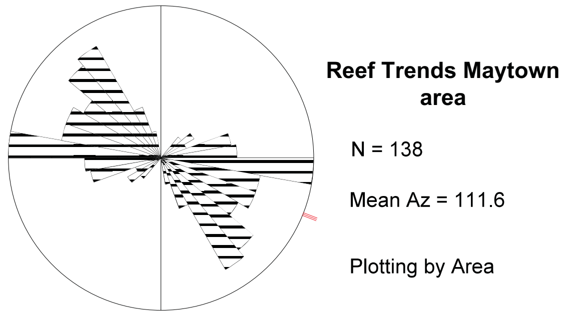


Figure 48. Strike direction of reefs in the Maytown area.

Mineralised quartz veins are commonly tens of metres in strike length and in depth. They form groups in which individual veins are arranged in an *en echelon* fashion, with a strike of between 100°–150° with a steep dip to the south (see Figure 48). The veins range from <10mm–0.3m in width and are fault/shear controlled. They comprise white drusy quartz with localised comb, vugh and ribbon textures, and contain gold, minor sulphide minerals and inclusions of host rock. Many of the veins were extremely rich, averaging 30–60 g/t gold; the mineralisation persisted below the water table.

The gold is unevenly distributed and is generally concentrated in pinches and in shoots associated with dilation zones in the veins. It occurs as discrete grains and as grains associated with pyrite and arsenopyrite. The gold is deep in colour and of a high fineness.

The sulphide assemblage in reef material examined from mullock dumps varied from mine to mine but generally contained pyrite, marcasite and arsenopyrite. Less commonly pyrrhotite, sphalerite, galena, stibnite and ?chalcopyrite was observed.

Host rock laminae, ranging from <1mm to centimetres in width, commonly define a crude banding in the veins. They are concentrated along vein margins. Laminae margins are commonly limonite-stained by oxidised sulphides.

Some of the veins physical attributes, such as tabular boudinage down-dip features, imply they have undergone intense ductile deformation as a result of faulting or folding and metamorphism.

The mineralisation is considered to be of the slate-belt style, mineralising fluids being generated by devolatilisation of the sediment pile during regional metamorphism. These

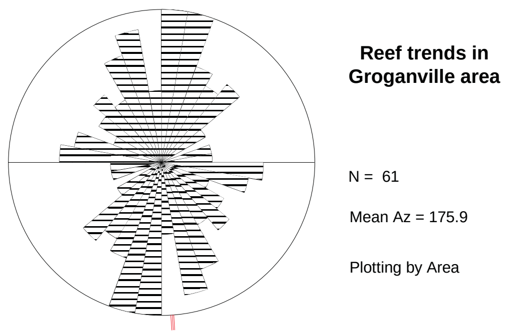


Figure 49. Reef trends in the Groganville area.

fluids scavenged precious metals from the host rocks. They were then focused into regional structures where precipitation of the gold and associated minerals was induced by pressure release at dilational sites or reaction with reductant lithologies. Davis & others (1996) however considered that the higher metamorphic grade of the Maytown area suggests the presence of a subsurface granite intrusion may be related to the gold mineralisation.

Approximately 49 reefs have been mined within a 11km long by 1.5km wide north-south corridor which lies along Limestone Creek extending from Hidden Valley in the north, through the **Groganville** township to the Four Mile area in the south. The major mines in the area are the Anglo Saxon and Good Hope located at Groganville. Intense faulting has occurred within the mine areas.

Mineralisation in the area comprises gold-bearing quartz lodes along east-north-east, east-south-east and north-trending shear/fault zones in a rhythmically interbedded sequence of arenite–siltstone–shale with minor lenses of basalt and conglomerate which have undergone low grade metamorphism (see Figure 49).

At **Hidden Valley**, mineralisation is associated with a zone of south-south-east-trending quartz lodes in feldspathic arenite and phyllite. The lodes comprise several distinct veins up to 1m wide and stockworks of veinlets. The stockworks are 0.2–0.4m wide containing white and vuggy quartz, hosting calcite, limonite and minor sulphides. The distribution of these veins and stockworks coincides with alluvial gold concentrations in the drainage systems.

Fault zones ranging from 1–5m wide can be traced along strike for >500m. Quartz lodes and brecciated arenite and siltstone occur along the fault zones. Gold mineralisation is patchy but is commonly concentrated in quartz lodes at fault intersections and in areas where faulting has been most intense. The two largest mines, the **Anglo Saxon** and **Good Hope** were sunk on intersections of east-north-east and east-south-east trending faults.

The quartz veins mined in the Anglo Saxon ranged from 1–3m in width and were deposited within a prominent north-east-trending fault zone. Fractures are commonly limonite- and scorodite-stained from oxidised pyrite and arsenopyrite in the veins. The veins comprise cherty or granular quartz, crosscutting quartz veinlets, carbonaceous laminae, pyrite and arsenopyrite. Jack (1889) reported that some quartz veins averaging 60g/t gold were generally <0.5m wide. Gold was patchily distributed throughout the veins, but was generally concentrated in ‘pockets’ and was associated with veinlets of black quartz and carbonaceous(?) shale laminae. The mineralisation persisted below the water table, the Anglo Saxon being worked to a depth of ~150m.

The **Mount Madden, Mount Buchanan** and **Mount Jessop** mines are situated on the margins of the Mount Madden dome. There are 9 main deposits within this ~5km^2 region.

Jack (1896) reported that the east-trending Mount Madden lodes occur in a unit of siliceous schist which strikes east and dips to the north at a low angle. The lodes consist of very friable and ferruginous quartz with very finely divided gold. Assays of lode outcrops averaged >30g/t gold.

The Mount Buchanan workings are on a south-east-trending lode and the Mount Jessop workings are on an east-trending lode which dips to the south. The geology, rock types and mineralisation are very similar to those at the Mount Madden mine.

Gold mineralisation occurs in chert/quartzite beds interlayered with metabasalt lava flows (Larramore Metabasalt Member). The chert/quartzite beds comprise massive to thickly bedded, weakly banded, cryptocrystalline to saccharoidal quartz/silica, and vuggy siliceous rocks with pyrite and rare sericite. The beds form resistant ridges which can be traced continuously from Mount Madden to Mount Buchannan. The chert/quartzite beds, with interbeds of shale grading into quartz-sericite schist, are up to 30m thick. Both the chert/quartzite beds and volcanic flows are cut by sulphide-bearing quartz veins as fracture infillings. Up to 5% pyrite, arsenopyrite and scorodite occur as disseminations in the chert and in the silica veinlets. Some of the mineralised chert/quartzite assayed >1g/t gold.

In 1979, R.B. Mining Pty Ltd and Newmont Holdings Ltd (AP 2181M) investigated the potential of the lode gold occurrences of the Mount Madden Group. They interpreted the chert/quartzite beds to be chemically precipitated exhalites related to submarine volcanism. However, in 1985, Western Mining Corporation Ltd (AP 2181M) reappraised these chert/quartzite beds as possible zones of intense surficial silicification of carbonaceous phyllite and quartz-sericite units. Higher gold contents are associated with fold noses and faults, and native gold (as grains generally <0.05mm in diameter), occurs in quartz–mica–goethite/pyrite composite grains.

Cambrian Resources NL located extensive stratabound gossans in the **Mammoth Bend area** of the Palmer River. Detailed rock chip sampling of gossanous banded cherts indicated that highly anomalous gold is associated with anomalous arsenic (up to 2.74ppm Au and 549ppm As). Results of 1.24ppm and 0.96g/t Au were obtained for chip samples adjacent to the intersection of sulphidic volcanics and a Tertiary basalt dyke. Drilling results indicated that the gold content of the primary zone of the mineralised cherts is uniformly subeconomic.

Russell Extended Gold Field (Towalla)

The mineralisation in the Towalla area is identical to that in the Mount Peter and Mulgrave Gold Fields, the gold being localised in extensively stylolitised and ribbon-textured quartz. Pyrite and arsenopyrite are associated with both the graphitic selvedges and the ribbons.

Russell River Gold Field

This gold field is located at the head of the Russell River, in dense rainforest. The majority of deposits in this area are deep leads. The auriferous alluvium occurs in Tertiary valleys and is overlain by up to 60m (average 15m) of basalt. A possible northern extension of these deposits occurs in the Gadgarra area (~15km to the north) where there are several smaller deep leads. The alluvium appears to occur at different elevations, suggesting a complex system of channels and terraces below the basalt.

The grade of the alluvium varies significantly with an average of 4.67g Au and 1.78kg Sn per cubic metre (Hughes, 1971). The gold is probably derived from weathering of thin, auriferous quartz veins in the underlying Devonian Hodgkinson Formation. The presence of gold-bearing reefs in the Towalla area, south of the Russell Extended Gold Field, supports this theory.

The Tertiary drainage was from west to east, implying the most likely source of the cassiterite in the alluvium was erosion of granites in the Malanda–Peeramon area.

Starke No. 1 Gold Field

The Starke No. 1 Gold Field, also called **Cocoa Creek**, contains north-north-west trending Au–Sb–quartz veins hosted by the Hodgkinson Formation. The gold is associated with both the quartz and stibnite. The mineralisation is relatively high level (certainly higher than that at Maytown and the West Normanby) but does not exhibit any significant epithermal characteristics. The alluvial gold deposits in this area are derived from these reefs. However, the deposits are small and only limited production has occurred.

Starke No. 2 Gold Field

This gold field is located in the headwaters of the Starke River north-west of Cape Flattery. Most of the mining activity was in the area north of the abandoned **Munburra** township. Approximately 117.5kg of gold has been won from shallow alluvial and eluvial deposits at Munburra and in the headwaters of Diggings Creek. Recent attempts to rework the alluvials have met with little success. Several smaller alluvial deposits containing nuggetty gold were also worked to the south-east of Munburra.

Gold–quartz veins occur within steeply dipping, north-trending metasedimentary rocks of the Hodgkinson Formation. The host rocks are mainly coarse- to medium-grained arenite or greywacke and carbonaceous slaty mudstone, with interspersed lenses of chert and melange.

Mineralisation occurs in quartz veins and stockworks spatially associated with porphyritic microgranite ('felsite') dykes and with some east to north-east-trending structural control. Almost all historical production came from discrete, steeply dipping, lenticular quartz veins which contain gold, pyrite, arsenopyrite and minor chalcopyrite. Minor stibnite is also present in some veins. Total sulphide content is <5%. The veins range from several centimetres to 3m in width (generally 200–250 mm) and strike north-east and south-east across bedding trends. The veins comprise euhedral buck quartz with ribbons and angular inclusions of pyritic host rock, which impart a brecciated texture to the veins. Reefs are commonly branched. Comb and fibre textures have been noted in the thinner veins. Distribution of mineralised zones was patchy; ore shoots were generally pipe-like and pitched steeply west. Historical grades were very rich at the surface (up to 300g/t) but decreased notably with depth. The gold was commonly fairly coarse and yellow. Silver content ranged up to 8g/t.

Quartz veinlet stockworking is generally confined to the more competent rock types such as arenite, silicified slate, chert and microgranite and contains low-grade, disseminated gold. The stockworking is best developed in the microgranite dykes, but may extend for several metres from fissure veins and dykes. Individual veinlets are 1–20mm thick and comprise medium to coarse-grained quartz with minor sulphides (dominantly pyrite). Minor sericitic alteration is associated with the stockworks.

Gold also occurs in a 50m wide mylonitic shear zone which contains quartz and chert lenticles in an anastomosing, dark grey, carbonaceous, slaty matrix. Pyrite is common along slickensided surfaces, as discrete grains in quartz lenticles and veins, and as coatings on microfractures. Extensive exploration in the Munburra area has failed to delineate any economic deposits.

West Normanby Gold Field

The lodes in the West Normanby Gold Field lie within a north-north-west-trending shear zone which follows the West Normanby River (see Figure 50). They comprise discrete, thin, gold-bearing quartz veins. They are fissure infillings which tend to be irregular in thickness both along strike and down dip. The veins follow joints and shears, forming a zig zag pattern. Minor spur veins follow the host rock schistosity and joints for short distances.

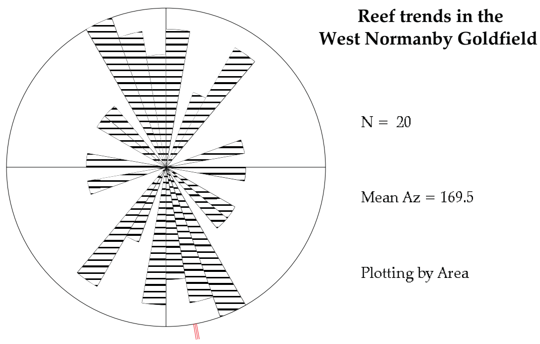


Figure 50. Reef trends in the West Normanby Gold Field.

Some of the main mines in the West Normanby Gold Field were the **Monte Christo**, **Star of Normanby**, **Isabelle**, **The Maddens**, **Wasp Gully**, **Good Luck** (Taylor Reef), **The Brothers**, and **Zig-zag**. The average lode grade is estimated to be in the range 30–60g/t Au. The mineralised veins averaged 0.3m in width and ranged from <0.1m–>1m. They consist of white drusy quartz with localised comb, vugh, and ribbon textures. The gold was irregularly distributed and commonly concentrated in pinches and shoots associated with dilational zones. The gold is a dark yellow, upwards of 940 fineness, and occurs as discrete grains and as grains intermixed with pyrite and arsenopyrite.

This area is one of the few locations where lode gold mining is currently being carried out (at the Maddens mine).

Queensland Metals Corporation NL discovered several auriferous, gossany, quartz-veined chert lenses in the central part of the gold field. The largest mineralised zone is a breccia stockwork at Mount Eykin. Gossanous samples assayed up to 1500ppm As and 2.56ppm Au. Drilling results did not delineate any economic mineralisation.

The river bed between The Brothers and Maddens Flat mines has deeply eroded meanders where loose sandy alluvium at the surface grade down into coarse bouldery wash. The average depth of the wash is 0.8m over an average river width of ~35m. Traces of cassiterite and gold have been found throughout the basal alluvium. The gold is coarse-grained and flaky, most grains being >0.5mm across.

The West Normanby River has been investigated for its alluvial gold potential. Recent investigations by Bulk Tests Pty Ltd have defined a small resource within the alluvium of the West Normanby River, this project has however been abandoned. The tributaries of this river also contain isolated pockets of alluvial gold, particularly Dead Dog Creek. The gold is the product of weathering of the reef gold deposits in the West Normanby Gold Field.

The **Ginger Pig** prospect near Digger Creek was also discovered by Queensland Metals Corporation NL. Anomalous gold mineralisation was found in two narrow zones in magnetite–garnet–amphibole–sulphide bearing chert lenses. The sulphides (up to 5% by volume) consist mainly of pyrrhotite (partly altered to pyrite), minor chalcopyrite and traces of galena and arsenopyrite. Gold in concentrations of up to 0.4g/t was detected in some of the drill samples. Rimfire Pacific Mining NL are currently exploring this deposit and the nearby Sporing Creek anomaly. Rimfire considers the Ginger Pig deposit to be a north-west trending garnet–amphibolite–magnetite skarn with anomalous gold values (Register of Australian Mining 1997/98, page 187).

Other minor deposits

The **Kamerunga** area is located above the Cairns–Kuranda railway line, 11km west-north-west of Cairns Post Office. The deposits have been referred to as the **Queenslander**, **Australian** and **Kaiser Bill**. The main lode is a fissure vein up to 2.7m wide (the average width is 1.0m) and at least 107m long. The vein consists of massive white quartz with a few chlorite inclusions and a little iron staining. Pyrite is the only accessory sulphide mineral recorded. The vein pinches and swells and both the hanging wall and footwall are sheared.

Gold–quartz vein mineralisation at **Six Mile Creek**, 9km west-south-west of Cooktown, occurs in a north-north-east trending belt of acid to intermediate volcanics and intercalated silty to sandy sediments of the Normanby Formation. Mineralisation comprises gold–stibnite–quartz–limonite vein stockworks and breccia in shear zones. Significant mineralisation occurs in a zone ~2.2km long by 60m wide. Intense silicification and sericitisation are associated with the mineralised veins; textures indicate an epithermal origin (Truelove, 1986). The Six Mile workings produced 2.7kg of gold with an average grade of 24.2g/t from the Goodluck, Thunderbolt, Mundic King and Mundic King No. 2 mines (Culpeper & others, 1994). Antimony mineralisation also occurs in the area but is generally not associated with gold.

Several gold–mercury geochemical anomalies have been delineated along a southern extension of a regional shear zone which includes the Six Mile mineralisation. There is some evidence for the presence of a subsurface granitic intrusion in the area, the anomalous gold–mercury representing the upper part of an epithermal system.

Oilmin NL drilled an 8km long chert lens in the Campbell Creek area. Mineralised zones up to 10m thick and assaying up to 0.6ppm Au were intersected; one sample assayed 5.05ppm Au.

At the **Taipan Prospect**, detailed bulk stream sediment sampling (cyanide leach) defined a 1.5km by 600m gold anomalous area comprising pyritic–hematitic chert, spilite and fine-grained carbonaceous sediments of the Hodgkinson Formation. Rock chip samples assayed up to 0.64ppm Au and 838ppm As. The geological environment may be suitable for the formation of carbonate-hosted gold deposits (Denaro & Ewers, 1995).

Anomalous gold occurs in a siliceous magnetite–garnet–amphibole–sulphide unit at the **Sporing Creek Prospect**. Sulphides are minor (<5%) and comprise mainly pyrrhotite, minor chalcopyrite, and traces of galena and arsenopyrite. The unit is cut by quartz–calcite veinlets.

At the **Dingo Shear Prospect**, anomalous gold mineralisation is associated with pyritic and oxidised, silicified, brecciated, quartz-veined arenite, shale and schist. Drilling intersections ranged from 2m containing 1.06g/t Au to 36m containing 0.3g/t Au.

The **Robin Hood** deposit, located 19km south-east of Mount Molloy, is a fracture-controlled quartz vein with rare arsenopyrite and minor sericite alteration adjacent to the vein. Rare arsenopyrite also occurs in the quartz vein. The mine dumps contain lumps of coarse-grained, white buck quartz with numerous stylolitic seams. The presence of numerous spider veinlets of comb quartz within the milky-white quartz distinguishes this quartz vein from barren quartz veins in the area (Price, 1990).

At the **Freedom** (also called Randall's, Joss House or Joss) mine, 10km south-west of Mount Molloy, a gold-bearing, milky-white quartz vein, containing arsenopyrite and pyrite, cuts a grey laminated chert of the Hodgkinson Formation. Gold occurs as very fine-grained sprays along fracture surfaces in the quartz vein. Approximately 18kg Au and 3kg Ag were produced from 250t of ore from 1937–1942.

The **Mitchell Prospect** is 200m east of the Fairchance limestone quarry, 12km SE of Mount Molloy. It was investigated in 1988 by Noble Resources NL who collected 150 rock chip samples from the area. Assay results ranged from 0–1.17ppm Au. The most persistent gold anomalism is associated with ironstone lenses and quartz veins close to the contact of an arenite melange with sheared, dolomitic breccia. The host rocks (part of the Hodgkinson Formation) are interpreted to be related to an isolated submarine volcanic centre, developed on a north-west-trending zone of crustal weakness. Fringing limestone reefs (Fairchance limestone quarry) were thought to have developed on a topographic high (seamount). There is a possibility that the ironstone lenses may represent the products of volcanic exhalations located along the fracture.

The **Big Hill Grid** is hosted by rocks of the Hodgkinson Formation. Exploration delineated a stratigraphic succession ranging from basic volcanic rocks (spilite) at the base, passing upwards through massive and laminated chert into siltstone/mudstone. Rare, small, manganese-rich gossans up to 1.5m thick are sandwiched between the massive and thinly bedded chert. Quartz veining in the massive chert is moderately to well developed. The veins contain limonite pseudomorphs after siderite and, less commonly, euhedral pyrite. The gossany lenses were mostly located towards the stratigraphic top of the chert horizon. The highest gold values occur in chert samples (up to 1.4ppm Au, 109ppm As, 365ppm Cu).

Breccia pipes and associated intrusives of the Price Dam Igneous Complex define a geochemical and geophysical anomaly in the **Bowler Creek** area, 38km north-west of Chillagoe. Disseminated pyrite/pyrrhotite grains (up to ~2%) occurs in the less oxidised granite outcrops. Traces of scorodite (as fracture filling) and cassiterite have been reported in the breccias (Duncan-Kemp, 1983), some sulphides occur in quartz-carbonate veinlets and along joints. According to Duncan-Kemp the mineralisation is generally associated with tourmaline in the matrix of the breccias or after mafic minerals in the granitic rocks.

The **Fluorspar group** of workings are situated ~17km south-east of Chillagoe. The main mines were the Australian Flag, Blue Ensign, Federal Flag, New Zealand Flag, and The Hiker. Total production from this area is ~140kg Au, and 0.5kg Ag. These figures are inaccurate as the early mining technique was to gouge out and hand dolly the rich ore pockets. More than 9 000t of fluorite was also mined from the Perseverance mine in this area (see Fluorite section). The mineralisation is hosted by the Almaden Granodiorite, Retchford Granite or Hiker Granodiorite close to their contact with the Featherbed Volcanic Group (Jamtin Rhyolite). These host rocks contain numerous shallow dipping thin greisenised veins which appear to be joint fillings (Dash & others, 1988). Later stage fractures filled with calcite, quartz, and clay minerals have intersected these greisenised veins and formed rich shoots of gold associated with kaolin and fluorite. Mapping by Weil (1980) has linked the structure hosting the gold mineralisation at the Federal Flag mine with that of the Perseverance mine.

Current Gold Mines, Prospects and Main Known Resources

Atric (Bellevue East) Prospect

This prospect has been investigated by several companies. Their combined efforts have defined a 6km long zone containing 12 gold prospects within a regional shear zone termed the Bellevue East Shear. This north-west trending shear zone is thought to represent a major thrust fault (south-west over north-east). The main prospect within the shear zone is the Atric prospect where anomalous gold mineralisation has been delineated over a strike length of 300m.

The gold mineralisation is intimately associated with very fine grained arsenopyrite and pyrite hosted by metasedimentary rocks of the Hodgkinson Formation (Birch, 1998). Gold anomalous zones appear to correspond to anomalous antimony values (commonly up to 30ppm). The current drilling data indicate the gold is concentrated in shoots with lower grade envelopes (Register of Australian Mining 1995/96, page 139). The mineralisation plunges shallowly to the south-east within a dilational jog in the Bellevue East Shear. Birch (1998) considers the deposit was formed from remobilisation of gold and sulphides present in the metasedimentary rocks, possibly associated with mafic volcanism or hot spring activity, to favourable structural sites or lithologies.

Pan Australian Resources NL conducted metallurgical evaluation of the deposit which indicated the mineralisation was refractory in nature through an arsenopyrite association which precludes conventional leaching processes to extract the gold. Further metallurgical studies are planned. Currently an Inferred Resource of 860 000t @ 2.22g/t Au has been calculated (Minmet, 7/11/1997).

Hurricane and Cardia

The Hurricane prospect is located 30km from Mount Carbine in the headwaters of Hurricane Creek (7865 405925) with the Cardia tenement adjoining. The prospect is owned by Minotaur Gold NL with Gateway Mining Ltd earning 65%. A RC drilling program on the Hurricane Main Lode, the Hurricane–Poseidon area and Raven prospect was completed by Gateway Mining. The results suggested at least two vein sets extending over 140m are present and open to the north and south. Further drilling is planned for 1995. The current Total Resource figure for the Hurricane main lode is 97 000t which includes a Measured Resource of 68 000t, Indicated Resource of 25 000t and Inferred Resource of 4 000t; at September 1995 a total Inferred Resource of 400 000t @ 1g/t was reported (Register of Australian Mining 1996/97, page 165). These figures have been recalculated and a total Inferred Resource of 230 000t @ 0.9g/t Au obtained for the Hurricane North, Main and Poseidon deposits to a depth of 30m (Minmet, 7/11/1997).

Exploration is focused on demonstrating the existence of a modest heap leach resource of at least 500 000t. The adjoining Reedy (formerly Cardia) tenement is being explored for extensions of the quartz vein systems identified in the Hurricane area. The Reedy prospect is located on the intersection of three major fault systems, the Kondaparinga, Hurricane and Fiery Creeks Faults. The northern part of the prospect is intruded by the Cannibal Creek Granite. Gold mineralisation in the area is hosted by quartz within mylonite shear zones.

Jessop Creek

This prospect lies on Jessop Creek, a tributary of Cradle Creek, in the Palmer Gold Field. The prospect contains a total area of ~115ha of auriferous alluvium and alluvial terraces held within ML 3054. The prospect is owned by Cambrian Resources NL who are in the advanced planning stages for extraction and processing of this resource using mobile screens and excavators with concentration at a central facility.

Maddens Mine

The Maddens Mine is located within the historic West Normanby Gold Field (part of the Palmer Gold Field 80km south-west of Cooktown. Gold-bearing veins in this part of the gold field are hosted by the Taylors Fault, a major regional structure. Veins have been emplaced throughout the history of this fault and commonly fill dilational jogs. Graphitic laminations have developed within these veins. Davis & others (1996) believe they are the product of dissolution of tabular country rock slabs which were tectonically sliced and incorporated into the veins. They also noted that the gold was concentrated in zones of relatively coarse-grained quartz adjacent to shear planes; the shearing produced numerous microfractures which allowed fluid access and consequent gold precipitation. The gold may have been introduced with the quartz and subsequently redistributed within the reef during deformation (Davis & others, 1996).

Recent production from this mine was 23.462kg (1994/95), 3.335kg (1995/96) and 8.48kg (1996/97) of gold bullion.

Davis & others (1996) proposed that the gold-bearing quartz veins in the West Normanby were emplaced in structures related to the D4 (our hD_7) deformation (early-late Permian) in the Hodgkinson Province. They also considered the close spatial association between Whypalla Supersuite granites and gold mineralisation implied the granites were an integral part of the major gold mineralising event in the Hodgkinson Province during the Permian, particularly in the West Normanby Gold Field.

Mount Cameron

The Mount Cameron prospect (discovered by Juldex Pty Ltd) is located north of the Herbert River Gorge. It consists of hydrothermally altered porphyritic rhyolite/microgranite and breccias which form a subvolcanic centre. An oval-shaped diatreme measuring 600m long by 350m wide has intruded both the Glen Gordon Volcanics and Carboniferous granites of the undivided Ingham Batholith. A zone of porphyry-style, hydrothermal alteration 2km by 3km has been delineated around Mount Cameron. Quartz stockworks in intrusive rhyolite/microgranite and silicified Glen Gordon Volcanics contain the gold mineralisation. A polymetallic quartz-sulphide vein system appears to be located around the margins of the subvolcanic centre (Marton, 1993). Base metal and gold mineralisation have been located in hydrothermal breccias. During June of 1993 a diamond drill hole was completed which failed to intersect any significant mineralisation. Tenements are still held over this area but the current status of the prospect is uncertain.

Mitchell River area

Centamin Ltd assessed the prospects in the vicinity of the Sleeping Giant/Tregoora prospect which was extensively explored during the 1980s. Centamin concentrated exploration on the Lost Mine prospect, located farther to the south-east. A mineralised zone 3km long was identified with a parallel zone 700m further to the east (Register of Australian Mining 1996/97, page 167).

Noal Adams, in a joint venture with Solomon Mines, has constructed a plant employing cyanide extraction methods with ore obtained from the Tregoora (renamed to the Big A), Retina and Black Knight deposits. The project will mine the oxidised portion of the ore body and satellite deposits. The antimony rich ore is concentrated using flotation methods and is being stockpiled.

Mount Mulligan–Mount McGann Prospect

Cutters Ridge Resources NL has signed a farm-in agreement with Odin Australia Pty Ltd to explore this region (EPM 9518). A total of seven drill holes (282m of diamond drilling and 1 051m of reverse circulation drilling) to depths of 369m tested four of the main prospects. Quartz breccia veining was intersected in all holes with variable associated sericitic alteration, pyrite, arsenopyrite and other sulphides. At the homeward bound prospect a large altered breccia zone was drilled. Results include 2m @ 3.56g/t Au from 26m, 4m @ 2.12g/t Au from 34m and 2m @ 3.83g/t Au from 130m (Minmet 7/11/97).

Northcote

This prospect encompasses several deposits (Ethel, Emily recently reworked) in the vicinity of the old Northcote township of the Hodgkinson Gold Field. The main mineralised trends in the prospect are related to north-west trending shear/fault zones which host quartz veins displaying mesothermal affinities but grade into veins of more epithermal character (Register of Australian Mining 1997/98, page 193). Beneath the oxide zone gold mineralisation is associated with stibnite, arsenopyrite, and pyrite with minor chalcopyrite, pyrrhotite, and galena in places. Stibnite mineralisation often occurs in later overprinting veins. Three principal lode types have been identified, laminated quartz, quartz breccia and fault breccia lodes and shears (Register of Australian Mining 1997/98, page 193). The oxide resource of these deposits was worked by Nittoc International Company Ltd.

Red Dome–Mungana Deposits

The Red Dome mine at Mungana, north of Chillagoe, was the largest and most recently operated gold mine in the region (owned by Niugini Mining Ltd). The area was originally worked for copper around the turn of the century, when it formed part of the rich Mungana group of copper deposits. Re-evaluation of the site in the early 1980s established significant gold reserves, estimated at the time at 13.8Mt of ore at 2.0g/t gold, 4.6g/t silver, 0.46% copper, and 1.0% zinc (Torrey & others, 1986). Mining of oxidised ore began in mid-1986 with the ore extracted from open pit operations. Mining ceased from the open pit in mid-1996 after 10 years of continuous operation. The feasibility of underground access to deeper reserves was evaluated and found to be uneconomic. The total production to June 1997 from the open pit is 15 860.9kg Au, 83 373kg Ag, 29 319.7t Cu (Minmet 7/11/1997).

Niugini Mining Ltd have also delineated a resource 2.6km north-west of Red Dome pit called the Mungana deposit. Metallurgical studies indicate the resource, amenable to open pit extraction, is only marginally economic due

Table 9. Annual production for Red Dome (source:- The Australian General Mining Year Book 6th Edition for years 1989–91 and Minmet 6/11/1998 for years 1992–98).

Year	Gold (kg)	Silver (kg)	Copper (tonnes)
1989	2 438.475	2 332.725	508
1990	2 177.210.	3 110.300	1524
1991	2 799.270.	8 397.810	4 064
1992	3 250.450	14 678.034	5 677.408
1993	1 484.173	9 499.789	4 386.072
1994	1 347.071	10 258.267	5 809.488
1995	3 465.496	19 588.545	4 995.672
1996	2 672.899	17 157.006	4 216.4
1997	1 541.9	10 916.81	3 767.328
1998	1539.754	9 916.009	1 111.504
Total	22 716.698	105 855.295	36 059.872

to complex metallurgy which detracts from the marketability of the gold/copper and lead/zinc concentrates which would be produced from the open pit resource (Niugini Mining Ltd, Annual Report, 1995, page 23).

The Mungana Deep prospect is located below the resource, amenable to open pit extraction, at the Mungana deposit. It was resolved by Niugini Mining Ltd to write off the capitalised cost of the exploration at the Mungana prospects on the basis that there is not a reasonable expectation that the expenditure will be recovered through development or sale of the properties.

The Griffiths Hill deposit is situated 200m south east of the current Red Dome open pit and adjacent to the old Griffiths open cut. This deposit has been explored in conjunction with the Red Dome deposit and more recently a drilling program has commenced to delineate the resource. The mineralisation is similar to that at Red Dome, but with more extensive supergene development. The western end of this deposit is characterised by oxidised gold and copper mineralisation, which is similar in nature to the ores at Red Dome. The eastern end of the Griffiths Hill deposit consists of high-grade oxide copper mineralisation (cuprite, native copper, malachite, and azurite), which contains only trace amounts of gold.

The Girofla prospect was discovered in late 1995 below the old mine workings at Girofla (located midway between the Red Dome and Mungana deposits). Initial drilling interested 23m (true thickness) of 0.4% Cu, 8.3% Pb, 4.5% Zn, and 125g/t Ag from a depth of 432m. Follow up drilling during 1996 failed to repeat this initial intersection (Niugini Mining Ltd, Report for the Quarter Ended 30 June 1996). The nearby historic Lady Jane, Hookworm, and Harpers mines are also considered prospective.

Harpers prospect located in the Calcifer area south-east of Chillagoe was tested by Niugini Mining Ltd. Drilling has indicated low grade gold mineralisation plus sporadic base metal concentrations occur in this large, geologically complex prospect.

The Mungana group of deposits is hosted by the Siluro–Devonian Chillagoe Formation. The formation reflects a complex thrust repetition structural history related to the Palmerville Fault. These thrust faults are likely to have controlled emplacement of the mineralising intrusives and related hydrothermal systems. For example, the Mungana group of deposits appear to lie along a belt of relatively closely spaced thrusts (Fordham, 1994). Fordham believes that similar deposits can be expected along faults and fault intersections throughout the Chillagoe Formation, not just at its faulted margins.

Barr (1995) described Red Dome as a Cu–Au skarn deposit and the Mungana prospect as a Cu–Au-base metal deposit. The Mungana deposit is thought to represent a higher-level manifestation of the Red Dome porphyry Au–Cu skarn system with a late hydrothermal brecciation and high sulphidation overprint. The mineral paragenesis is generally thought to be related to the emplacement of high level late Carboniferous fractionated I-type felsic intrusives into carbonate host rocks of the Chillagoe Formation. Three stages of intrusion are postulated by Barr (1995) and Nethery & Barr (1996). The oldest resulted in potassic alteration and development of early prograde skarn alteration assemblages (low Au–Cu phase). This intrusion has been correlated with the I-type O'Briens Creek Supersuite (~315–320Ma). A higher level oxidised intrusive emplaced along the margins of the first intrusion resulted in the formation of late prograde and/or early retrograde skarn alteration assemblages (moderate Au, high Cu–Zn–As phase). This event is correlated with fractionated members of the I-type Almaden and Ootann Supersuites (~306Ma). This second intrusive event is considered to have produced the pre-brecciation skarn and related alteration and mineralisation at the Mungana deposit. The third and last intrusive episode is thought to have produced explosive gas-generated brecciation at the Mungana and Red Dome deposits followed by a high sulphidation event (maximum Au phase). This final episode has been correlated with localised high level A-type plugs of the Lags Supersuite (~290Ma). The dates used by Barr (1995) have been obtained from often highly altered material and therefore contain a large degree of uncertainty. The intrusive suite associations are therefore best fit correlations. The intrusive units in the Red Dome area were considered by Mackenzie (1987) to probably have affinities with the Featherbed Volcanic Group. The mineralisation is considered by the authors however to be most probably related to the intrusion of the I-type granite (Almaden and Ootann Supersuite) rather than the A-type granites as suggested by Barr (1995) or the Featherbed Volcanic Group.

Gold at Red Dome occurs mainly as gold–silver tellurides forming inclusions within bornite, chalcocite, and sphalerite. Copper, lead, zinc, and silver minerals are also present in the ore assemblage, with copper production enhancing the profitability of the mining operation.

Nethery & others (1994) postulated that after the final intrusive phase a retrograde subvolcanic system developed as breccia pipes and veins comprising quartz + chlorite + pyrite + arsenopyrite + sphalerite + galena + minor chalcopyrite + tetrahedrite + chalcocite. Boiling occured in the upper levels of the breccia pipes developed in this phase creating hydrothermal eruption centres (diatremes). An advanced argillic alteration assemblage of jasperoidal silica + haematite + kaolinite (low Au) developed in the diatremes. This final stage was previously interpreted as karst collapse (Karjalainen & others, 1987) which does occur to a minor extent but is not relevant to mineralisation.

Triple Crown and Nymbool (Blacks Creek) Porphyry Prospects

The Triple Crown prospect is located 4km west-north-west of Mount Garnet and is currently being explored by Strike Mining. The prospect was discovered in 1983.

The mineralisation is hosted by the Chillagoe Formation which is intruded by the Hammonds Creek Granodiorite 1km south of the prospect. Gold mineralisation is associated with breccia zones in and around a late-stage, pod of microgranite (Gallo, 1995). The intrusion is located at the intersection of north-west trending lineaments with a north-east trending regional lineament. Quartz veins host the gold mineralisation. They also contain sericite, carbonate, chlorite, and a variety of sulphide minerals. The sulphides include pyrite, sphalerite, galena, chalcopyrite, arsenopyrite, and rarer species such as wittichenite (Cu_3BiS_3) and matildite ($AgBiS_2$). The gold is contained within pyrite and closely associated with sphalerite and galena. This deposit is considered uneconomic at current gold prices.

The nearby Nymbool (Blacks Creek) porphyry prospect consists of a mineralised feldspar porphyry hosted by a porphyritic granite which forms part of a large hydrothermal alteration system. Geological mapping and geochemistry have indicated that gold anomalism extends outside the currently drilled area. Zones of brecciation and north-south trending sheet veins were also identified. Geophysics suggests the presence of a large sulphide bearing body below and to the west of the drilled area. Further exploration is planned to test these targets.

A reinterpretation of previous exploration data generated a conservative open pit Indicated Resource of 1.175 Mt @ 0.79g/t Au and Inferred Resource of 180 000t @ 0.8g/t Au (oxide and transitional ore). A primary sulphide ore Indicated Resource of 560 000t @ 0.51g/t Au is also present.

HEAVY MINERALS

Cape Flattery

Generally, the transgressive dune systems of silica sand on the east coast of far north Queensland contain only minor proportions of heavy minerals. Heavy mineral content ranges from a trace to 0.75% at **Cape Flattery** (Cooper & Sawers, 1990). The main minerals present are ilmenite and zircon. This deposit is discussed in detail in the Silica Sand section of this report.

Coquette Point

Investigations of black sands at the mouth of the Johnstone River in an area called **Coquette Point**, were conducted during 1958. Sampling indicated the presence of fine tin with grades of up to 0.09kg/t. The grade was considered to be too low to support a dredging operation. The Russell River area was suggested as a more prospective target. Tantalum was also reported from this area by Dunstan (1905a), but subsequent investigations suggest that this may be due to a mistake during analysis.

Daintree River Mouth

The sand deposits north and south of the **Daintree River** mouth were considered to have potential for economic heavy mineral sands deposits. In 1970, Discovery (Alpha) Pty Ltd tested these deposits by drilling ten auger holes. Samples containing up to 2.6% of heavy minerals concentrate (consisting of ilmenite, zircon and tourmaline) was recovered from one of the drill holes. The deposit was not investigated further.

Kennedy River

Preliminary investigations by Metcalfe Holdings Pty Ltd in 1986 indicated a 30km long stretch of the river has potential for heavy mineral deposits. The alluvium averages 50m in width and 2.5m in thickness. Heavy mineral concentrates contain gold, monazite, xenotime and minor rutile and zircon. Monazite and xenotime comprise 57.8–84.4% of the heavy minerals and the monazite:xenotime ratio averages 16.2:1. Subsequent detailed follow-up investigations indicated the economic mineralisation is confined to the main watercourse with little or no reserves present in the terraces (Barron, 1990). The reserves delineated were considered insufficient to sustain a mining operation.

Ninian Bay

Minsands Exploration Pty Ltd investigated the heavy minerals potential of the coastal dunes at **Ninian Bay** in 1975 and 1976. Four bulk samples were prepared from drillhole samples. No significant mineralisation was detected and the company concluded that the area has no economic heavy mineral potential (Minsands Exploration Pty Ltd, 1976).

Currumbin Minerals Pty Ltd drilled hand auger holes to 8m depth in low beach ridges and dunes from Ninian Bay south to Saltwater Creek. Results were not encouraging for either cassiterite or heavy minerals. Heavy mineral contents were generally low (average 0.1%), with some irregularly distributed higher values (up to 0.61%). The heavy mineral concentrates consisted mainly of ilmenite, with minor rutile and zircon (Jack, 1990).

Palmer River

The Palmer River downstream of the Yambo Inlier has an anomalous radiometric response, which is mainly due to K-rich minerals. Jubilate Pty Ltd identified several areas with anomalous rare earth element mineralisation in 1987. Ilmenite, monazite, zircon and significant xenotime were identified in the concentrates. Preliminary concentrate samples assayed 0.3–2.45% cerium, 0.19–1.16% lanthanum, 0.0–0.32% thorium and 0.07–0.77% yttrium (Garside, 1988). Several localities with potential were delineated.

Princess Charlotte Bay

Holocene and Pleistocene beach ridges extend along the coastline from First Red Rocky Point south and around **Princess Charlotte Bay** to Bathurst Heads. Auger hole sampling across beaches and sand banks by Mid East Minerals NL generally yielded <0.1% heavy minerals (mainly ilmenite) and minor rutile and zircon (Zimmerman, 1969). Only at the mouth of the Nesbit River was the heavy mineral content >1% in any holes; here ilmenite formed 92% of the concentrates. Minor sampling of coastal sediments north of the Pascoe River by Consolidated Mining Industries Ltd yielded similar results (Hughes, 1972).

Astrik Resources NL collected four samples of shoreline sand bank deposits in the Cape Sidmouth area. Assay results were 2100ppm Ce, 1100ppm Y, 360ppm Nb, 0.37% Zr and 1.73% Ti (Pyper, 1989). There was some evidence that economic grades may occur in modern beach deposits.

A.O. Australia Pty Ltd investigated low beach ridges around Princess Charlotte Bay in 1975. Hand auger samples generally yielded only low heavy-mineral contents. Furthermore, although heavy-mineral contents of 3.1% were recorded in a few places, the minerals present were magnetite and ilmenite (A.O. Australia Pty Ltd, 1976; Shannon, 1976).

BHP Minerals Ltd drilled two holes in a beach ridge north-east of Lilyvale in 1992. A composite sample contained only 0.06% heavy minerals, comprising 60% zircon, 9% ilmenite, 8% leucoxene, 8% rutile and 15% other minerals (Darby, 1993).

Ramsay and Shepherd Bays

Ramsay and **Shepherd Bays** of Hinchinbrook Island and Rockingham Bay north of Cardwell have been investigated for their mineral sands potential. Results from grab sampling by Ocean Mining AG in Ramsay Bay were 3ppm Sn, 500ppm Zr, 2000ppm Ti and 100ppm V. In Shepherd Bay the results were 2ppm Sn, 50ppm Zr, 500ppm Ti and 3ppm V. The best results of spectrographic analyses of Jet Lift sampling in Ramsay Bay (2 samples) were 4ppm Sn, 500ppm Zr, 1500ppm Ti and 20ppm V; Rockingham Bay 4ppm Sn, 200ppm Zr, 1500ppm Ti and 20ppm V and in Shepherd Bay 3ppm Sn, 200ppm Zr, 1500ppm Ti and 15ppm V.

IRON

Iron has been mined mainly for use as a flux in the Chillagoe and Herberton areas. The largest of these deposits is **Mount Lucy** located 4km W of Almaden. This deposit produced 45 344t of flux ore for the Chillagoe Smelters. The total production from this mine represents approximately 58% of the recorded output of flux-ore mines in the Chillagoe district. The deposit forms a thin capping on a low hill called Mount Lucy. Granite crops out on all sides of this hill and drill holes have intersected granite at shallow depths. The magnetite–hematite rock which was the focus of mining is separated from the granite in many places by garnet–wollastonite skarn rock. Dunstan (1905b) attributed the ironstone to the surface weathering of garnet. An assay of Mount Lucy iron ore yielded the following results: FeO 6.81%, Fe_2O_3 90.30%, MnO 0.60%, Al_2O_3 1.22% and SiO_2 0.57% (Dunstan, 1906). All of the deposits worked for flux in the Chillagoe area are skarns.

Significant amounts of magnetite–hematite ores were also produced from numerous deposits within the **Copper Firing Line** group, near Herberton. These are in narrow fracture-controlled quartz veins.

A small ironstone occurrence in **Mourilyan Harbour** possibly represents banded iron style of mineralisation in low, greenschist grade rocks of the Barnard Metamorphics.

LIMESTONE

Chillagoe Formation

The Chillagoe Formation contains numerous lenses of variably recrystallised limestone and marble in two main areas. The northern outcrops form a north trending belt up to 6km wide extending between the Mitchell and Palmer Rivers. The southern group of lenses, a north-west-trending belt, crops out north and south of Chillagoe. The pale to dark grey massive limestone is interlayered with chert, and metabasalt. Krosch (1990) estimated that ~1 500Mt of limestone are in the northern belt. Parts of this limestone country may hold significance to the local aboriginal communities and should be considered in any future development.

The southern belt has been mined in the past for flux in the Chillagoe smelters. More recently lime has been produced for chemical and agricultural purposes, and marble has been mined as a building stone (see Dimension stone section).

Lime production also occurs at Ootann, 12km south of Almaden. This extensive deposit is located in a 5km^2 roof pendant of Chillagoe Formation surrounded by Carboniferous granites. Massive limestone is burnt for lime and coarsely crystalline marble is crushed for agricultural use. Total production from this deposit for 1995/96 was 4 301t of burnt lime and 1 117t of agricultural limestone.

Fairchance Quarry and Nearby Areas

Limestone has been extracted from the **Fairchance** quarry, near Yalkula 12km south-east of Mount Molloy, the White Gem quarry near the mouth of the Mowbray River and the **Mareeba Lime** deposit (test sampling only) 6.8km east-north-east of Mareeba. The largest deposit is at the Fairchance quarry which is currently operating. All three deposits are adjacent to prominent NW-trending lenses of chert and basic metavolcanic rocks. These limestone lenses are thought to have formed as bioherms on volcanic seamounts.

Melody Rocks Limestone Deposit

Queensland Metals Corporation Ltd currently holds a mineral development licence over the **Melody Rocks** limestone deposit near Kings Plains. The limestone forms large lenses in the Hodgkinson Formation. It crops out over ~2700m x ~700m area, with vertical exposures of up to 120m. Eight lenses are of potential economic interest and five are of major significance. The limestone is pale grey, fine-grained and homogeneous. The five major lenses comprise approximately 900 000t/vertical metre of limestone at 55% CaO, <1.0% SiO_2, <0.4% MgO, <0.2% Fe_2O_3 and <0.4% Al_2O_3. The company has carried out feasibility studies on setting up a cement clinker plant at Archer Point. The high quality of the limestone would allow it to be marketed, not only for cement manufacture, but also for the chemical and mineral processing industries, and agriculture.

MANGANESE

The numerous manganese deposits in the Hodgkinson Province appear to be of volcanogenic–sedimentary origin, mainly because they are commonly associated with ferruginous chert of exhalite origin. The manganese is thought to be sourced from submarine volcanogenic exhalations emanating from sea bed faults during basin formation (see Figure 51). Most of these stratiform deposits have zones of secondary manganese enrichment which was the focus of the historic mining activity. The deposits are all small and low grade. The largest of these deposits is **Mount Martin**. They are concentrated in the eastern part of the Hodgkinson Formation. The existence elsewhere in the Hodgkinson Province of Besshi-Kieslager volcanogenic massive sulphide deposits indicates that such exhalative processes did occur during basin formation. Some of the manganiferous cherts also contain anomalous concentrations of gold.

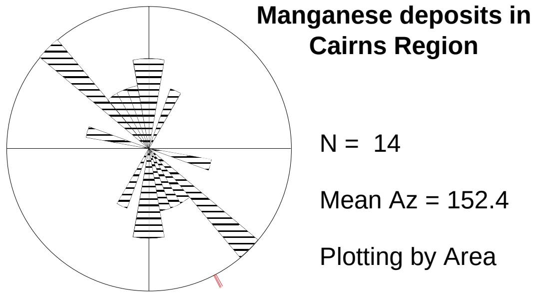


Figure 51. Orientation of all Manganese deposits within the study area.

MOLYBDENUM

Carbonate Creek

A porphyry molybdenum deposit (Horton, 1982), known as **Carbonate Creek**, is located 8km S of Dimbulah. Intrusions of porphyritic microgranite have been passively emplaced in this area, along a fault zone separating volcanic rocks of the Featherbed Volcanic Group from sedimentary rocks of the Hodgkinson Formation. Molybdenite and wolframite occur in flat-lying quartz veins, mainly hosted by the Hodgkinson Formation rocks.

Kirrama Range

Disseminated molybdenum mineralisation was found by Noranda Australia Ltd in the Kirrama Range (~26km west of Cardwell), as a result of a search for Climax-type mineralisation. The three main prospects are **Biok, Yamanie,** and **Yuccabine**; Yamanie was the most intensively investigated.

At the Yamanie and Yuccabine prospects, windows in the flat-lying to moderately dipping Glen Gordon Volcanics have exposed the roof zones of plutons of the Ingham Batholith. Disseminated and stringer mineralisation associated with mild chloritic alteration occurs in both rock units near intrusive contacts. Minor concentrations of copper ore were also detected at the Yamanie prospect.

At Biok, molybdenite, pyrite and trace chalcopyrite occur in quartz veinlets and along joint faces in an adamellite adjacent to the contact with a younger granodiorite. Similar mineralisation exists farther north-west at the Summit Hill prospect (also discovered by Noranda).

A simple sulphide mineralogy of pyrite–chalcopyrite–molybdenite is present in all these deposits (Horton, 1982). He also classified these deposits into the island-arc type of porphyry setting.

Wolfram Camp, Bamford Hill, Eight Mile, and Captain Morgan

Molybdenite occurs in association with tungsten mineralisation in this large north-south trending belt of endogreisen mineralisation. The deposits are related to granites of the Ootann Supersuite which have intruded the eastern margin of the Featherbed Volcanic Group. The deposits are discussed in more detail in the 'Tungsten' section of this report.

PERLITE

Commercial quantities of perlite were discovered in 1986 in the early Permian Nychum Volcanics, ~50km NW of Chillagoe. The deposit called the **Nychum** (or **Wrotham**) deposit is up to ~6.5km long, 3km wide and 30m thick and reasonably homogenous. The perlite has developed in a glassy, aphyric rhyolite lava flow. The deposit may contain as much as 700Mt of perlite (Jones, 1995). This deposit is unusual as most perlite has devitrified before it has reached the age of the Nychum deposits.

A pilot plant has been established in Mareeba to produce expanded perlite from bulk samples of the Nychum deposit. The product is brilliant white, similar to Chinese perlite product; 416t of perlite was extracted in 1995/96 for testing purposes.

PHOSPHATE

Starcke River and Barrow Point Areas

Phosphate minerals are associated with thinly bedded black chert and shale of the Hodgkinson Formation in the Starcke River, Barrow Point and Round Hill–Jeannie River areas, north of Cooktown. The rocks are intensely silicified and quartz veined; ferruginous gossans are well developed.

The cherts contain thin, white lenses rich in apatite. These may represent flattened phosphate pellets and balls which formed during deposition of the sequences. These lenses rarely constitute >25% of outcrops and it is unlikely that the deposits would contain >5% P_2O_5. Wavellite, strengite, variscite and gorceixite occur on joints and weathered surfaces and as veins. The deposits are considered uneconomic.

SILICA SAND

Archer Point

Extensive deposits of white quartzose dune sand occur at Archer Point, south of Cooktown. The sands occupy a 4km by 3km area and form a thin veneer on rocks of the Hodgkinson Formation. Martin (1980) concluded that the fineness of the sand and the large variation in some size fractions render it unsuitable for use in glass making. The average grade is 97.8% SiO_2, 0.7% Fe_2O_3, 0.2% Al_2O_3, and 0.21% loss on ignition, making the sand chemically inferior to that at Cape Flattery.

Cape Flattery–Cape Bedford Dunefield

The **Cape Flattery–Cape Bedford** dunefield (located 60km north of Cooktown) is ~55km long, up to 22km wide, and covers ~580km^2.

The dunefield developed on a low-lying coastal plain, 5–10m above sea-level. It formed because of an abundance of quartz sand derived from Palaeozoic granites and Mesozoic sandstones and exposure to strong south-easterly trade winds. Rising sea levels in Pleistocene interglacial periods resulted in erosion of frontal dunes, thereby creating a sand source by recycling the existing dunes (Cooper & Sawers, 1990). The Pleistocene dunes became enriched in silica by leaching of the calcareous sand component. The higher purity A2 horizon has then been formed into dunes and blowouts by the prevailing south-east winds which are more than 7km long and only 0.5km wide. The apical sand mound can be up to 90m above the surrounding sand plain.

The dunefield consists mainly of white, active, transgressive parabolic and elongate parabolic dunes, and older rounded degraded dunes stabilised by vegetation. The active dunes consist predominantly of quartz sand; the heavy mineral (mainly ilmenite) content ranges from a trace to about 0.75%. The optimum sources of white silica sand at the Cape Flattery Silica mine are the bare apical mounds of the active elongate parabolic dunes. The grain size

Table 10. Recent production figures for Cape Flattery.

Year	Total Production (Mt)
1988	1.17
1989	1.3
1990	1.5
1992	1.5
1993	1.8
1994	1.9
1995	2.1
1995-96	2.2
1996-97	1.97

distribution is particularly suitable for glass manufacture and foundry moulding. Cooper & Sawers (1990) reported export quality sand contained 99.82% SiO_2, 0.01% Fe_2O_3, 0.05% Al_2O_3, 0.02% TiO_2, <0.01% CaO, <0.01% MgO and 0.10% volatiles.

The **Cape Flattery Silica Mine** is owned and operated by Cape Flattery Silica Mines Pty Ltd. The region contains proven reserves of 200Mt under mining lease (Cooper, 1993). An estimated resource of 1 000Mt is present in the area. All production is exported for glass manufacturing, foundry purposes and the chemical industry (Table 10).

Mourilyan Silica Sand

The **Mourilyan** silica sand deposit, located south-east of Innisfail, extends 22km along the coastal plain. This deposit consists of an inner and outer beachridge-barrier complex. The inner barrier is of Pleistocene age and, in places, is covered by low, degraded, transgressive dunes. Part of the outer Holocene barrier is in the Inarlinga Defence Reserve. The transgressive dune system contains indicated reserves of 10 739 500t of >99% silica to 0.5m depth (Cooper, 1993).

Ninian Bay

Dunes along the western side of **Ninian Bay** represent a silica sand resource that would require beneficiation to produce a marketable product. The bulk of the sand averages 99.5% SiO_2, but iron and titanium impurities exceed standards for glass manufacturing. There is an estimated 24m maximum thickness of sand in the main dune area and 12m in the low dunes. The area is now in the Cape Melville National Park. An extensive area of older vegetated dunes to the south and south-west of Ninian Bay have not been investigated.

TIN

Several primary tin mineralisation styles are evident in the Cairns Region. They include quartz–chlorite lodes, sheeted quartz–tourmaline lodes and veins, greisen veins, greisen alteration zones, and argillic alteration zones. All are associated with late Palaeozoic S- and I-type granites.

Cannibal Creek Granite area

Alluvial deposits

At least 2 260t of alluvial cassiterite have been mined from both **Cannibal**, **Granite**, **Nine Mile**, **Tin** and **Fiery Creeks**. The primary source is narrow, quartz–greisen veins associated with the Cannibal Creek Granite.

Early production was mainly from rich deposits of shallow alluvium along Cannibal and Granite Creeks and their tributaries. Both waterworn and crystalline cassiterite, ranging from minute grains to slugs of up to 0.5kg were recovered. Cassiterite is also known to occur in Pinnacle and Gum Creeks.

Exploration by Northern Mining Syndicate in 1974 indicated that Tin Creek contained a resource of 383 000m^3 of stanniferous wash (with grades of 694g/m^3 cassiterite) and that Nine Mile Creek contained 76 500m^3 (683g/m^3 cassiterite).

Lode Deposits

The mineralisation at the **Cannibal Creek Tin mine** is associated with two steeply-dipping quartz lodes which strike at 110° in the north-western extremity of the Cannibal Creek Granite (see Figure 52). The main mineralisation at Cannibal Creek has a strike length of 400m and width of 60m. This zone contains pegmatitic quartz veins which contain minor cassiterite, scheelite, chalcopyrite, pyrite, and beryl. The cassiterite is irregularly distributed but generally occurs as coarse to very coarse-grained crystals on vein margins, particularly in muscovite-rich zones. The host rocks (Hodgkinson Formation) are silicified and greisenised adjacent to the veins. There is also a later phase of barren white quartz with a well-developed comb texture. Numerous subparallel mineralised veins ranging from

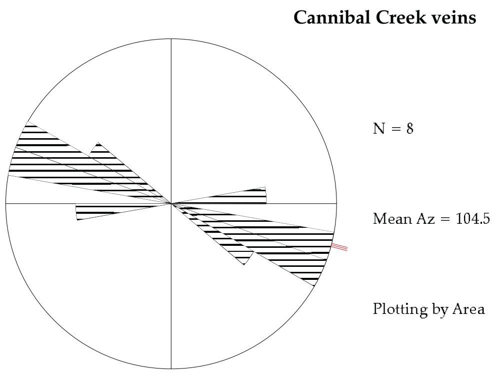


Figure 52. Tin vein orientations in the Cannibal Creek area.

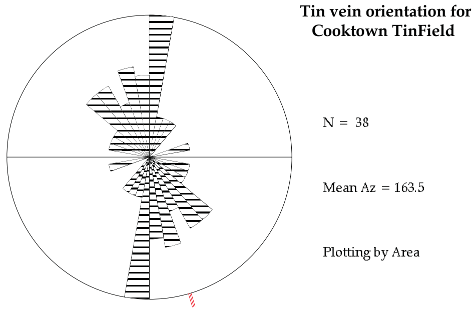


Figure 53. Orientation of tin veins in the Cooktown Tin Field.

0.5m–1.5m in thickness are present up to 30m from the main lodes.

These deposits are related to the nearby Cannibal Creek Granite which also hosts some cassiterite-bearing quartz–greisen veins.

At least 3.5t of cassiterite concentrate was produced from the small lode deposits in the area during 1880s. In 1969, Frost Enterprises Pty Ltd produced 34.1t of cassiterite from 37 515t of ore from a small opencut in the main zone of mineralisation.

Cardwell Area

Francis Creek is the main tin-bearing drainage system but **Shipmans, Tin,** and **Five Mile Creeks** have all been worked for alluvial tin. Tungsten-rich alluvium has also been reported from a small tributary of Shipmans Creek. Sluicing was the main method of mining, 18t of cassiterite concentrates being mined from Francis Creek during World War II (P. Dore, personal communication, 1994). However, official records show only 0.45t of cassiterite concentrates have been produced since 1939. The cassiterite recovered comprised black, grey, wood, and ruby varieties. Minor amounts of gold were also recovered.

The cassiterite is derived from greisen zones and stringers in the apical part of a granite pluton (undivided Ingham Batholith) near contacts with volcanic rocks of the Wallaman Falls Volcanics. None of the lode occurrences are economic.

Cooktown Tinfield

Alluvial deposits

The **Cooktown Tinfield** has been a major producer of alluvial cassiterite which has been recovered mainly from recent stream channel alluvium, eluvial and colluvial deposits, older alluvial terraces adjacent to the main streams, and perched terraces well above present stream levels. Cassiterite has also been obtained from older ferruginous gravels such as those at **Mount Poverty**, **Mount Hartley** and the **Big Tableland**, and in deep lead deposits below Tertiary basalt flows (*e.g.* in the Shiptons Flat–Bairds Gully area). Most deposits are too small or of subeconomic grade to support large-scale operations. Alluvial and colluvial deposits containing up to 1Mt of stanniferous wash offer potential for sluicing operations by individual miners and small syndicates (Denaro & Ewers, 1995). However, most of the prospective area is now within the Wet Tropical Rainforests Reserve. The Annan River for example, is known to contain subeconomic alluvial cassiterite deposits from its headwaters to the Helenvale area.

Alluvial cassiterite is also known to occur in the **Mount Misery**, **Mount Boolbun North** and **Mount Boolbun South** areas. The rugged topography and poor access has meant that there has been little mining activity or prospecting in these areas.

The main centres of production were **Rossville, Mount Poverty**, **Upper Romeo**, **Shiptons Flat**, **Grasstree**, **Big Tableland**, **Little Tableland**, **Mount Hartley**, **Mount Finlayson**, **Tabletop** and **Mount Amos**.

Lode Deposits

Several primary tin mineralisation styles are evident in the Cooktown Tinfield. These include sheeted quartz–tourmaline lodes and veins, greisen veins, greisen alteration zones, and argillic alteration zones. Historically, the most productive primary deposits were extensive greisen and argillic alteration zones on the margins of granite intrusions. However, quartz–tourmaline veins and lodes were also mined, notably at Mount Amos, Mount Leswell and the Big Tableland.

Tin greisen deposits in the Cooktown Tinfield are characterised by zones of vein-controlled greisenisation associated with the apical parts of fractionated S-type granites of the Cooktown Supersuite. Examples include the greisen systems at Mount Poverty and the Collingwood prospect. Zones of weathered greisen and associated argillic alteration were important sources of cassiterite in the early days of the field because they are amenable to hydraulic sluicing (for example, the Collingwood Face, Daly's Face, Home Rule). These deposits comprise greisenised and argillised granite containing disseminated cassiterite and stanniferous quartz–tourmaline veins and zones. The grade of mineralisation is erratic, but 0.9kg/m^3 was the average grade in early workings (Martin, 1979). The most prospective areas for hard rock greisen deposits are in the roof zones of granite cupolas which are capped by Hodgkinson Formation rocks.

All historical production has been from veins in S-type granites of the Cooktown Supersuite and adjacent country rocks. However, the development locally (*e.g.* in the Mount Hartley area) of sheeted vein systems in the overlying Hodgkinson Formation rocks also offers the potential for significant mineralisation. These deposits typically comprise quartz–tourmaline–cassiterite and tourmaline–cassiterite veins and pipes along or close to granite–country rock contacts.

Big and Little Tableland Groups

Mining commenced on the **Big Tableland** prior to 1890. The cassiterite occurs in alluvial, eluvial and lode deposits. Extensive abandoned sluicing and alluvial workings are scattered throughout the Big Tableland. The total recorded production from the Big Tableland is 413.2t of cassiterite concentrates. The largest lode deposit, the **Lions Den**, is also one of the largest in the Cooktown district. Lode mineralisation comprises siliceous tourmaline-bearing veins and pods in medium to fine-grained tourmaline granite (Collingwood Granite). The granite is silicified adjacent to the veins.

The Shell Company of Australia Ltd carried out geological mapping and stream sediment sampling in the Big Tableland area in search of lode tin deposits. It was concluded that the area represents the remains of a mineralised cupola and that most of the primary mineralisation has been eroded away. The Big Tableland appears to not have the same potential as the Collingwood and Mount Amos areas.

The **Little Tableland** is an elevated area at the heads of Four Mile and Poulsens Creeks, 4km north-west of Rossville (and west of the Big Tableland). It was also known as the 'Lower Tableland'. The country rock is a fine-grained microgranite (mapped as part of the Collingwood Granite). Mining involved sluicing of alluvium, colluvium and argillised granite. Several small cassiterite-bearing quartz–tourmaline veins are present in the marginal zone but none are sufficiently rich to warrant development.

China Camp

The China Camp group consists of three main mining areas, namely **Lode Hill**, **Roaring Meg** and **Pocket**. Alluvial, eluvial and lode deposits were worked. Cassiterite mineralisation is present in cassiterite-bearing tourmaline-rich quartz and quartz-feldspar veins which cut the marginal zone of the S-type Roaring Meg Granite. Extensive greisen zones containing irregularly disseminated fine-grained cassiterite are also present in this zone. In some places fine-grained cassiterite is also present in only slightly altered and unaltered granite.

Both coarse and fine-grained brown cassiterite were recovered from the alluvium, together with abundant quantities of black tourmaline and ilmenite. Occasionally blue sapphire and very fine-grained waterworn gold were also recovered. Some of the cassiterite was both waterworn and crystalline in form.

In the Lode Hill area disseminated cassiterite occurs in argillised microgranite, 'interlayered' with hard quartz-muscovite greisen zones. These 'layers' are cut by vertical quartz–tourmaline veins up to 1.5m wide, which contain minor cassiterite and arsenopyrite.

Martin (1979) reported the grade of the alluvial/eluvial deposits in the Bourgamba–Main Creek–Roaring Meg Creek area to be locally as high as 1.8–2.4kg/m^3 of cassiterite but that it was generally much lower.

Mount Amos Area

Mining in the Mount Amos area is concentrated along a 100m–250m wide zone of quartz–tourmaline–cassiterite mineralisation developed in granite close to its north-trending contact with the Hodgkinson Formation. Lodes within this zone comprise 1–2m wide veins and lenses of tourmaline–quartz rock. The adjacent granite is extensively silicified and greisenised. Mineralisation includes cassiterite, arsenopyrite, and pyrite, with minor wolframite, molybdenite, native copper, galena, and bismuth. The ore bodies are small, pipe-like shoots which have developed at the intersection of north and east trending greisenised shear zones within the north trending contact. The main concentrations of mineralisation are at the **Phoenician** and **Dreadnought** mines. Similar mineralisation also occurs at the Lions Den mine on the Big Tableland.

Large reserves of alluvial cassiterite occur in an abandoned stream channel extending west from **Waterfall Creek** to **Trevethan Creek**, in the Mount Amos area. Serem worked the area in 1979 and probably the early 1980s but only treated a small part of the resource.

Mount Hartley

The Mount Hartley group of workings is located ~12km south-east of Helenvale. Mining commenced at Mount Hartley prior to 1891. Deposit types present in this area include alluvial, colluvial, weathered greisen and argillic alteration zones, and quartz–tourmaline vein systems. A wolfram-bearing quartz vein was also worked. All of the hard rock deposits are in Hodgkinson Formation rocks close to contacts with granites of the Cooktown Supersuite.

In 1986, the Shell Company of Australia Ltd (Billiton) discovered a substantial granite and sediment-hosted vein system on the south-western flank of Mount Hartley. Mineralisation is developed in a sheeted siliceous vein system hosted by granite and metasedimentary rocks. Rock chip samples from ferruginous tourmaline–arsenopyrite–cassiterite–muscovite-quartz veins which cut tourmalinised metasedimentary rocks of the Hodgkinson Formation assayed up to 12.8% Sn. A large potential resource exists in this area but due to environmental constraints has not been fully tested.

The **Sand Hills** prospect located 2km south-west of Mount Hartley consists of a 300m long by 150m wide by 4.5m deep zone of eluvium and weathered greisenised granite. The cassiterite-bearing greisen was assessed by Dominion (ML 968) to contain an Indicated Resource of 14 963 loose cubic metres containing 0.74kg/m^3 cassiterite, and 28 416 loose cubic metres at 0.66kg/m^3.

Mount Poverty

All cassiterite from the Mount Poverty area has been mined from ferruginous palaeoplacer and recent alluvial deposits. Extensive areas of lateritic gravel remain unmined. The cassiterite appears to have been derived from greisen zones in granite close to the contact with the Hodgkinson Formation. The greisen zones comprise mainly quartz + muscovite + chlorite. Some of the chloritic greisen contains appreciable chalcopyrite as blebs and stringers.

Greisenised, chloritised and silicified granite occurs in the subsurface at **Mount Misery**, 4km south-east of Mount Poverty. The greisen zones are subvertical, sheet-like bodies, and concentrated in shear zones. Cassiterite, chalcopyrite, arsenopyrite, sphalerite, and pyrite occur in the greisen zones; tourmaline is an ubiquitous accessory mineral. The mineralisation style is probably similar to that at the Collingwood prospect, but the granite and associated mineralisation are at about 400m depth below the surface. Furthermore, the area is now included in the Wet Tropical Rainforests Reserve.

Rossville Area, Collingwood Tin Prospect

Mining commenced in the Rossville area in 1886, and was centred around hydraulic sluicing of alluvial terraces (up to 40m above present stream levels). The largest operation was the **Collingwood Face** where cassiterite occurred in deeply weathered and argillically altered, granite close to its contact with the Hodgkinson Formation.

Primary lode deposits (mainly cassiterite bearing quartz–tourmaline veins hosted by the Collingwood Granite and Hodgkinson Formation) were also worked throughout the area.

The **Collingwood Tin prospect** was discovered by the Shell Company of Australia Ltd in 1979. It is currently owned by Acacia Resources Ltd (50%) and North Ltd (50%). Investigations delineated a resource of 4.035Mt at 0.73% Sn (29 616t of contained tin). The prospect is a subsurface (50m below the ground surface), granite-hosted, mineralised greisen vein system associated with the roof zone of the Collingwood Granite. Underground drilling indicated probable reserves of 3 106 980t at 0.9% Sn (27 833t contained Sn) or 2 027 609t at 1% Sn (20 330t contained Sn) (Miezitis & McNaught, 1987). The most recently published resource figures are an Indicated Resource of 2.2Mt @ 1% tin and an Inferred Resource of 0.9Mt @ 0.6% tin (Register of Australian Mining 1996/97, page 301).

The prospect was discovered via a soil tin anomaly developed on the overlying Hodgkinson Formation. The mineralised zone extends over a strike length of 950m and has a vertical extent of 50–130m. Three types of endogranitic tin mineralisation have been recognised at Collingwood: steep siliceous sheeted veins, albitic veins, and flat-lying greisen (Jones & others, 1990). Most of the cassiterite is associated with *en echelon* zones of siliceous, sheeted quartz–tourmaline and greisen veins. Albitic veins within the siliceous vein system are generally small but some are up to 2m wide and have an irregular distribution. They cut the siliceous zone and contain the highest grade mineralisation. Flat-lying greisen zones are confined to small cupolas and irregularities in the granite/sediment contact.

Alteration minerals include secondary quartz, muscovite (sericite), green biotite and tourmaline. Associated minerals include chlorite, fluorite, apatite, cassiterite and sulphides (chalcopyrite, bornite, chalcocite, pyrite, arsenopyrite, stannite, sphalerite, and bismuthinite).

Oxygen and hydrogen isotope studies of granite and greisen from the prospect indicate similar fluids were responsible for both the pervasive alteration of the granite and the fracture-controlled tin mineralisation (Golding & others, 1990).

Herberton Mineral Field

The Herberton Mineral Field is one of the most intensely mineralised areas of the state. For the purposes of this report the Herberton Mineral Field is defined by the area between Almaden, Dimbulah, Mount Garnet, and Herberton. Pollard (1984) estimated the total production from the Herberton area to be >150 000t of cassiterite concentrate from combined alluvial and lode sources.

Tin mineralisation occurs in several highly mineralised centres, the main ones being **Herberton** (including the Herberton Hill area), **Irvinebank** (including areas west of the township), **Watsonville** (including the UNA Group), **Emuford**, **Koorboora**, **Stannary Hills**, **Brownville**, **Coolgarra**, **Silver Valley**, **Sunnymount** and **Ord**.

Most of the tin produced from the region since the 1930s has been obtained from alluvial and eluvial deposits using progressively more mechanised and sophisticated mining methods. This mining has been confined to the watercourses draining the mineralised granites of the O'Briens Creek Supersuite and the adjacent metasediments.

The cassiterite occurs, in a range of colours, but black to brown-red varieties predominate. Much of the cassiterite is magnetic (Blake, 1972). Studies by Greaves & others (1971) indicated that the presence of microscopic to submicroscopic inclusions of magnetite (average diameter 0.7μ), which probably exsolved from the host cassiterite, is responsible for this magnetism. The most important trace elements found in the cassiterite by Greaves & others (1971) are indium (which is concentrated in low-temperature cassiterite associated with sulphides) and niobium (which is concentrated in high-temperature cassiterite associated with greisens).

Stannite (Cu_2FeSnS_4) occurs in complex sulphide lodes in the Silver Valley area (Lancelot), Watsonville area (UNA Group, Stewarts T Claim), Copper Firing Line (W of Herberton, Isabel), Hales Siding area (Brass Bottle), Orient Camp West Group, Comeno mine (8.2km W of Irvinebank), and arsenic-rich tin lodes in the Stannary Hills area.

The average depth of the lode workings was <20m; only 27 mines have been recorded as being deeper than 100m. The largest single mine was the **Vulcan**, which yielded 13 916t of cassiterite concentrate (containing approximately 70% Sn). The main mines which have been in production since the 1960s are the **Jumna**, **Arbouin**, **UNA Baal Gammon**, **Tommy**

Burns, and **North Hope**. The North Hope was a recent discovery, north of the Jumna Mill.

The tin mineralisation in the mineral field is genetically related to the fractionated I-type granites of the O'Briens Creek Supersuite. It is commonly associated with late-stage, finer-grained phases and accompanying hydrothermal and metasomatic alteration (Clarke, 1990; Pollard, 1984). The mineralisation occurs mostly in veins, pipes and breccias in shear zones and fractures in nearby country rocks (mainly Hodgkinson Formation), or as veins, pipes and disseminated deposits within granites or at contacts with country rocks (Dash & others, 1991). Laboratory experiments and other studies by Heinrich (1990) indicated saline fluids of magmatic origin are involved in the formation of most tin ores which occur in veins, breccias and replacement bodies in aluminosilicate rocks. Studies by Black & others (1978) indicate the tin mineralisation is associated with several periods of granite intrusion.

The tin deposits in the Herberton district have been used as an example of Sn veins (Cornish-type lodes) by Cox & Singer (1992) in their deposit classification scheme.

Several alteration assemblages are associated with tin mineralisation in the Herberton Mineral Field; these are summarised below.

A) **Quartz–chlorite–cassiterite** assemblages account for the greatest number of mines and are most common in rocks of the Hodgkinson Formation. The largest single tin-producing mine of the Herberton Mineral Field — the Vulcan mine — is of this type. A significant number of tin occurrences in granites of the O'Briens Creek Supersuite are also chloritised. These are mainly in the Saint Patrick Hill Stock, Jumna Granite of the Watsonville area, and Emu Suite granite of the Emuford area. The cassiterite commonly occurs as fine crystals disseminated in medium-grained chlorite gangue developed along fractures, pipes and shears. Garnet occurs in this assemblage in several mines in the Bakerville, Mount Nolan, Watsonville and Copper Firing Line areas. Varying amounts of sericite, usually very fine grained, accompany the chlorite lodes. A small proportion of sulphide minerals (mainly pyrite) occur in the chlorite lodes in sedimentary rocks. Chloritic alteration of granite is generally extremely fine-grained and concentrated in quartz-filled shears forming a dark grey siliceous rock termed 'black rock' by the early miners. 'Black rock' was reported from mines on Saint Patrick Hill (east of Herberton) and in the Watsonville area. Cassiterite, sulphide minerals, fluorite, and sericite accompany the chlorite in the 'black rock'. Chloritisation of the shears postdates the main granite intrusion in each particular area. For example chloritic alteration associated with tin mineralisation at the Pot Luck mine, 1km south-west of Herberton, has yielded an age of 297Ma whereas granites in the area have been dated at 307Ma (Black & others, 1978). The chlorite style of alteration occurs in a significant number of mines in the Stannary Hills, Irvinebank, Bakerville, Herberton, Watsonville, Emuford and Hales Siding areas.

B) **Quartz–tourmaline** assemblages are almost entirely confined to the Hodgkinson Formation. Mineralisation generally occurs as stellate clusters of tourmaline, massive crystalline tourmaline or very fine bands of tourmaline, quartz and cassiterite (sometimes called 'streaky tin' by early miners) in fracture-controlled quartz veins or lenses. This type of tin mineralisation is prevalent in the Irvinebank and Bakerville areas.

C) **Greisen** assemblages are mainly restricted to granites of the O'Briens Creek Supersuite, most of the remainder being in metasedimentary rocks of the Hodgkinson Formation — generally very close to the granite contacts. The mineral assemblage consists primarily of quartz, sericite/muscovite, fluorite, topaz, cassiterite ± wolframite ± monazite ± minor sulphides. The cassiterite is mostly fine-grained. Ages obtained by Black & others (1978) for greisen alteration associated with tin mineralisation, including the Sparklet deposit, are essentially the same as the ages of the enclosing granites *i.e.* late Carboniferous–early Permian. The mineralisation commonly occurs as pipes, lenses or veins or as disseminated deposits. Some of the linear greisen zones can be traced for more than a kilometre. Some pipe, lensoidal and vein deposits in greisenised granite have a central core of quartz containing cassiterite (and also wolframite in some cases), surrounded by zones of intense greisenisation containing finer-grained cassiterite. Disseminated tin deposits are mainly confined to the Emuford area where greisen zones contain fine-grained disseminated cassiterite and myriads of tiny cassiterite-bearing quartz veinlets. The main greisen deposits occur in the Herberton Hill Group, the UNA Group, and the Stannary Hills Group.

D) Tin deposits associated with **albitisation** of granites have been recorded in the mineral field by Handley (1975), Johnston (1984), Pollard (1984), Witt (1985, 1987) and Charoy & Pollard (1989). This style of alteration is essentially "sodium metasomatism, accompanied by hydrothermal leaching of granitic quartz to form vuggy albite rocks..." these "...vughs created by quartz dissolution were filled by hydrothermal minerals, including albite, K feldspar, and/or muscovite and cassiterite" (Charoy & Pollard, 1989, page 1850). Later fractures (thought to have formed in response to fluid over-pressuring) were infilled with a similar assemblage of hydrothermal minerals and are thought to be formed at least partly contemporaneously with vugh infill (Charoy & Pollard, 1989). Charoy & Pollard also note that the zones of albitisation cut all textural varieties of Emu Suite granites in the Emuford area and are spatially related to late-stage medium and fine-grained granites. The albitisation generally occurs as narrow, irregular to linear alteration zones, with a central part consisting of up to 80% albite, surrounded by albitised granite and greisen zones (Charoy & Pollard, 1989). Witt (1987) proposed the following evolution of alteration styles related to cassiterite mineralisation in the northern Coolgarra Batholith: K-feldspar (perthite) ⇒ albitisation ⇒ greisenisation ⇒ late K-feldspar (nonperthitic). He concluded (page 447) that the "fracture-controlled felspathic rocks in the northern Coolgarra Batholith formed as a result of interaction between the host granite and its own magmatic fluids". This type of deposit model has been used successfully in exploration by Western Mining Corporation (Mount Tin, 8.2km SSE of Irvinebank, and O'Mara's Prospect at Emuford) and a BHP/Abrolhos joint venture (Black Diamond, Dove, Cigarette, Starlight and Sugar Bag at Emuford). Past production from these mines has been relatively small because they only contain minor amounts of high-grade ore. The highest production from this group of mines was 42t of cassiterite concentrate from the Dove mine.

E) Tin-bearing lodes in which **silicification** is the main alteration style are characterised by medium to coarse-grained cassiterite and minor associated sulphides in fracture-controlled quartz veins, pipes and lenses. The quartz is generally coarsely crystalline and vuggy in places. Many of these lodes have an overprint of mild sericitic, chloritic or tourmaline alteration, or grade out into such alteration. They may also grade into greisen-style alteration. A few of the large producers have been tentatively placed in this category, namely the Extenuate and Grass Humpy mines in the Herberton Hill Group, Stewarts T claim at Watsonville, and the Right Bower mine 9.2km WSW of Irvinebank.

F) **Sericitic** alteration is used in this report to describe those occurrences which are not greisenised but have varying amounts of sericite, locally accompanied by minor chlorite. Most occurrences are in rocks of the Hodgkinson Formation, in the Stannary Hills and Watsonville areas. They are characterised by the presence of very fine disseminated sericite in the enclosing wall rocks. The main producer was the Rosalee mine (8.8km W of Herberton) which yielded 23.1t of cassiterite.

G) **Hydrobiotite** alteration has been recorded in the Clyde mine, 0.9km W of Herberton, in addition to chloritic and sericitic alteration (A. Walter, personal communication, 1990). Hydrobiotite appears to develop in intermediate zones between zones of tourmaline and chlorite alteration. Hydrobiotite alteration is probably a variation of the more common chloritic alteration (Dash & others, 1991).

H) **Calc-silicate** type tin mineralisation occurs at the Magnum Bonum mine in the Silver Valley and Mount Garnet area. The lode, at the Magnum Bonum mine, is hosted by a shear zone which has intersected metabasalt (Hodgkinson Formation). The mineral assemblage is massive tin-rich garnet with magnetite, varying amounts of clinopyroxene and thinly layered fluorite 'wrigglite', and massive fluoro-vesuvianite with fluorite. These deposits are generally low grade. The largest is the Gillian (Pinnacle) prospect near Mount Garnet (see page 234).

Mineral Zonation

Local mineral zonation in the Herberton area has been noted by Blake & Smith (1970), Taylor & Steveson (1972), Taylor (1971), and Blake (1974). Mineral zonation is very complex on a regional scale in the Herberton Mineral Field because mineralisation has developed around several juxtaposed plutons, both exposed and at shallow depths in the subsurface. Another factor which contributed to the complexity of the zonation is that the area has been subjected to multiple-mineralising events (Black & others, 1978).

Typically, the elemental zonation away from a mineralising source is:

- tungsten, molybdenum, bismuth,
- tin,
- copper, and
- lead, silver.

Some deposits in the area display a reverse zonation where the upper zone is occupied primarily by cassiterite and base-metal sulphides occur below that level (*i.e.* closer to the mineralising source). This has been attributed to a secondary effect relating to oxidation of a stannite-base metal sulphide orebody above the water table. It is proposed that the stannite was oxidised to cassiterite and the base metals carried in solution downwards to the water table (Blake & Smith, 1970, 1971; Taylor, 1971). Black & others (1978) considered multiple-mineralising events could be an alternative explanation for this reverse zonation.

Greaves & others (1971), Greaves (1975), and Clarke (1995) suggest that the cassiterite pipe deposits in the Herberton area display a vertical zonation. Cassiterite from higher levels in the deposits is light brown, nonmagnetic, and contains relatively high indium contents (~500ppm), whereas cassiterite from middle level is dark coloured and magnetic (due to exsolved magnetite). Cassiterite grains from the lower levels is brown to reddish in colour (ruby tin), predominantly nonmagnetic, and contains high tantalum and niobium levels (up to 7000ppm).

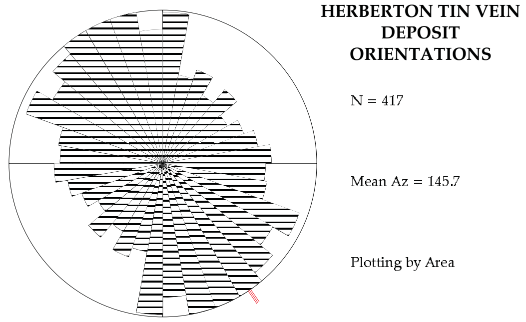


Figure 54. Tin vein orientations in the Herberton Mineral Field.

Mineralisation Controls

The vast majority of deposits in the Herbert Mineral Field are fracture-controlled, the main exceptions being the skarn, calc-silicate and some greisen deposits. Defining dominant structures which influenced mineralisation in the mineral field is difficult but the NNW structural trend which typifies much of the Hodgkinson province is significant in many areas, particularly at Stannary Hills, Emuford, Irvinebank, Silver Valley and the Copper Firing Line. There also appears to be a zone of more easterly-trending structures, which extends from the Orient Camp area, through Watsonville to the Herberton Hill group of mines.

Orebodies formed in dilational zones within larger shear zones commonly strike at an angle to the main shear zone (see Figure 54). Examples are the Ivanhoe, Kitchener and Black Rock zone at Stannary Hills. Although the majority of mineral deposits are in fracture-controlled veins, a central lensoidal or pipe-like body was the only area worked in many mines.

Most of these lenses and pipes formed in either:

- dilational zones where the fracture was refracted across rock units of differing competency, such as at the Jumna mine, or
- in zones of intersecting fractures where intense brecciation and increased permeability allowed higher influx of mineralising fluids, such as at the Dolly Grey mine.

In addition to the regional NNW structures associated with the Hodgkinson Province, other types of mineralised fractures include:

- those associated with caldera formation in the Featherbed Volcanic complex, the Glen Gordon Volcanics and Slaughteryard Creek Volcanics, and
- those developed during emplacement and cooling of the numerous granitoids in the region.

Alluvial deposits

The main alluvial deposits (Table 11) are located near Mount Garnet in Smiths, Nanyeta (Return), Battle and Nettle Creeks.

These drainage systems have been mined several times. The Emuford area was also a significant producer of alluvial cassiterite. Peak production was of the order of 600t of concentrate per year (Pollard, 1984).

The major deposits of alluvial cassiterite occur in lenses of sand and fine to coarse gravel within Cainozoic alluvium on the northern margin of the Mount Garnet Basin (Blake, 1972). This basin slopes gently to the south-east and is deeply alluviated. Cassiterite rich lenses are scattered throughout the alluvial sequence which is characterised by the development of cemented layers commonly termed 'false bottoms'. Basalt is also interbedded with the alluvium in the eastern part of the basin. The cassiterite becomes finer and less abundant to the south.

The alluvial cassiterite ranges from black to amber, brown, ruby and honey coloured. Some is also magnetic. The associated heavy minerals include topaz, monazite, zircon, ilmenite, and iron oxides. Isolated occurrences of spinel, garnet, corundum, barite, and beryl have also been recorded (Blake, 1972).

Deep lead deposits

The Herberton Deep Lead is the largest of these deposits. It extends from Herberton to the junction of the Millstream with the Wild River, a distance of ~37km. Other examples are the **Cassowary Creek** and **Bradlaugh Creek Deep Leads**, which were palaeotributaries of watercourses which form the Herberton Deep lead.

Table 11. Total production for the main alluvial tin deposits in the Herberton mineral field.

Drainage Name	Main Period of Production	Total Recorded Production
Smiths Creek	1953–69	10 671 tons cassiterite conc
Nanyeta (Return) Creek	1928–32 & 1939–52	6467 tons cassiterite conc
Battle Creek	1957–65	4170 tons cassiterite conc
Nettle Creek	1931–46 & 1965–69	3345 tons cassiterite conc
Upper Emu Creek, Emuford	1975–77, 1979–81	166t cst conc ~699 t P. Dash, personal communication

The extensive Herberton Deep Lead formed by the infilling of palaeochannels of the **Wild River** by basalt lava flows, probably of Pleistocene age. The thickness of basalt averages ~30m. The sequence consists of upper and lower basalt flows, separated by a layer of barren sand and gravel averaging 2m thick (maximum thickness ~6m). The upper basalt appears to have erupted from a vent at the head of Gibley Creek, ~10km south-east of Herberton (Cuttler, 1972). The alluvium at the base of the sequence is up to 6m thick but the tin-bearing wash is generally restricted to the basal 1–2m. The alluvium ranges from unconsolidated to cemented sand containing pebbles, cobbles and boulders of quartz, granite, and greisen. Small quantities of ilmenite, wolframite, topaz, gold, and rare diamond accompany the cassiterite (Cuttler, 1972; Berge & others, 1899).

More than 1 000 shafts and tunnels have been dug to intersect the deep lead in the Herberton–Basalt Creek area. High water flow in the stanniferous gravels was managed by tunnelling beneath the level of the wash. Production grades commonly ranged from 1–30kg/m^3 and locally were as high as 60–180kg/m^3.

More than 4000t of cassiterite concentrates are estimated to have been won from the deep lead deposits (Cuttler, 1972). Cuttler also considered there were more deep leads to be discovered.

Jeannie River, Saddle Hill, Radio Hill and Whitewater Creek Prospects

The Jeannie River prospect was discovered in 1979 as a result of a reconnaissance stream-sediment geochemical survey. The prospect is characterised by outcropping gossanous lodes in silicified sandstone. The mineralised zone is marked by stream sediments grading 0.14–1.1% Sn, a 1.2km by 300m soil anomaly with >250ppm Sn, and a significant, circular magnetic anomaly. The magnetic anomaly is caused by a concealed (beneath shallow alluvium) swarm of mineralised quartz veins containing abundant pyrrhotite, as well as some Sn, Cu, As, Pb and Zn mineralisation.

Complex cassiterite-base metal sulphide-bearing quartz veins and vein stockworks occur in four main zones — the Jeannie River, Saddle Hill, Radio Hill, and Whitewater Creek prospects but only the Jeannie River prospect has been tested at depth by diamond drilling. The mineralised veins cut metasedimentary rocks of the Hodgkinson Formation adjacent to an intrusion of biotite granite and associated porphyritic microgranite dykes and pods. The granite has been mapped as part of the early Permian Puckley Granite (Lucas, 1964; de Keyser & Lucas, 1968); it was not examined during recent survey.

Microgranite from one of the satellite dykes or pods has yielded a zircon fission track age of 234±34Ma (late Permian–late Triassic) (Denaro & Ewers, 1995). All of the deposits are within 6km of exposed Puckley granite. Mineralisation is probably related to a porphyritic phase on the margins of the main pluton. Ore minerals include cassiterite, pyrite, pyrrhotite, sphalerite, galena, chalcopyrite, arsenopyrite and scheelite, with rare tetrahedrite, stannite, bornite and sulphosalts. Gangue minerals include quartz, chlorite, calcite, muscovite, siderite, tourmaline and axinite. Wall rock alteration is common close to mineralised zones and comprises silicification, sericitisation and propylitic alteration (calcite, pyrite/pyrrhotite, epidote, chlorite). Minor tourmalinisation has also been noted (Denaro & others, 1992).

There are three main lode zones at the Jeannie River prospect — the **Leet Zone**, **Discovery Gossan**, and **Sheahan Zone**. The Leet Zone is the most important; drilling to 506m has delineated a mineralised zone with a strike length of 1300m, a width ranging from 0.8–5.5m, and grades of 0.70–3.87% Sn. The lodes trend south-east in highly sheared and boudinaged felspathic arenite, siltstone and shale.

Four main phases of vein formation have been recognised, namely (from oldest to youngest):

1. quartz + K-feldspar + cassiterite,
2. quartz + chlorite + sulphides + cassiterite,
3. quartz + adularia + prehnite + zeolite + alunite + fine acicular cassiterite, and
4. vuggy quartz + calcite + pyrite.

There is a metal zonation from an outer lead + zinc-rich zone, inwards to a zone enriched in copper + arsenic + tungsten. Tin occurs in both zones, but the best grades are in the outer zone. This zonation has been compressed and overprinted in major mineralised fractures with all the metals occurring together.

This is a significant vein tin deposit and represents a major discovery in a new tin province. Exploration ceased in 1986 because of the prevailing low tin prices.

Mount Lewis

Mount Lewis is located 11km NNW of Mount Molloy. Alluvial tin has been known from the Mount Lewis area since the turn of the century. Cassiterite occurs as euhedral grains disseminated within the S-type Mount Carbine Granite and also in numerous quartz and quartz–greisen veinlets which represent the late-stage fluids from the cooling magma. Minor wolframite is also commonly present. The cassiterite is a pale milky-brown colour, and difficult to recognise in hand specimens.

Most of the mineable resources present on the mountain top are in eluvial deposits but cassiterite and wolframite is shedding into many of the creeks draining the western side of the Mount Carbine tableland. Significant deposits include those in **Station**, **Leichhardt**, **Windmill**, and **Luster Creeks**. Significant reserves of alluvial cassiterite were delineated by Alluvial Gold Ltd and Ravenshoe Tin Dredging Ltd in the Station Creek (currently uneconomic) and Leichhardt Creek.

The Mount Lewis area is included in World Heritage listed Wet Tropical Rainforests Reserve.

Mount Spurgeon

Mount Spurgeon is located 18km west of Mossman. Mineralisation is concentrated in large to small tourmaline-rich quartz and quartz–feldspar veins hosted by the S-type Spurgeon Granite. The granite consists of an outer fine-grained porphyritic zone which grades into a central, more even-grained, medium grained zone.

Greisen zones developed in the granite also contain irregularly disseminated, fine-grained cassiterite. In some places fine-grained cassiterite is present in only slightly altered and unaltered granite.

Most of the tin was won by small-scale mining of alluvial and eluvial deposits. **Shannessy**, **Turner**, and **Sandy Creeks** have been the main tin producers on Mount Spurgeon. Outlying occurrences include Roots and Platypus Creeks which flow into the upper Mossman River.

In 1935, Zarda Alluvial Tin Ltd estimated that a tributary of the upper Mossman River had a potential resource of 250 000m^3 stanniferous alluvium. The wash is >3m deep in places, with an average cassiterite grade of 3.5kg/m^3.

Mount Windsor Tableland

Alluvial cassiterite was mined from the Mount Windsor Tableland area as early as 1890. It is derived from cassiterite-bearing quartz veins, greisen lodes, aplite and pegmatite dykes, and stanniferous granite. Large quantities of granitic alluvium have been sluiced along **Piccaninny Creek** and its tributaries. Mining has also been carried out along **Campbell Creek**, **Flaggy Creek**, and the headwaters of the **West Normanby River**.

The **Stephanie** mine is located on the south-western margin of the Windsor Tableland. Cassiterite occurs in two subparallel quartz veins in a coarse-grained porphyritic granite dyke. The dyke strikes northerly and extends for several kilometres into the metasedimentary rocks of the Hodgkinson Formation. It is probably related to granite of the Mount Windsor Batholith which crops out ~2km to the east.

The quartz veins mined are 0.3–4.0m wide, strike 120°, dip 80° south-west, and comprise massive white quartz with numerous vughs. Cassiterite occurs as aggregates up to 100mm long and 10mm wide and as disseminated grains. Minor arsenopyrite, scorodite, cassiterite, and traces of pyrite, chalcopyrite and malachite occur in zones along vein margins. Minor cassiterite is also present in potassically altered granite enclosing the veins.

Wangetti Area

Numerous small tin–tungsten–tantalum deposits are located in and adjacent to the Wangetti Granite, which is a small stock, comprising two zones (Willmott & others, 1988). The larger, outer zone comprises white, medium- to coarse-grained, even-grained, tourmaline–muscovite adamellite with zones of pegmatitic granite and greisen. Veinlets of milky quartz containing some sulphide grains occur in the greisens. The inner zone is highly porphyritic, grey, coarse-grained, muscovite–biotite adamellite, containing a few sulphide-bearing veinlets. The tin–tungsten–tantalum mineralisation appears to be related to the granite of the outer zone.

Two distinct vein systems were mapped by Kinnane (1982): tin–tantalum-bearing pegmatite veins at the eastern end and tin–tungsten-bearing quartz veins in the south-western part of the area. In addition there are zones of greisen-style mineralisation and locally developed eluvial deposits.

The tin–tantalum-bearing pegmatite veins are consistent in their strike but are of variable thickness. Mineralisation is erratic in distribution and ranges from coarse-grained, euhedral cassiterite, in the vein walls, to irregular aggregates and disseminations in the veins proper. The mineralisation consists mainly of black, tantalum-bearing cassiterite, with minor wolframite. The wallrock is generally extensively altered, and, in some places, contains disseminated cassiterite.

The tin–tungsten-bearing quartz veins contain far more erratic mineralisation, consisting of aggregates of fine-grained wolframite and cassiterite. Tantalite is also present but is scarcer than in the eastern veins.

Greisen-style mineralisation in the eastern area, along the Cook Highway, is widespread and is generally adjacent to pegmatite veins. Cassiterite and wolframite are disseminated, the higher grades present in more intensely altered zones. Mineralised scree containing some cassiterite and wolframite covers much of the eastern and south-western parts of the Wangetti area. Cassiterite is far more abundant than wolframite and ranges from very fine-grained to angular, pebble-sized fragments.

West Normanby River

In 1978 Westco Mining recognised three main types of cassiterite-bearing alluvium in the headwaters of the West Normanby River, namely:

1. recent alluvium comprising sandy wash with very minor cassiterite,

2. reworked, granite-derived sandy wash which is fairly clayey; the upper 0.5m contains the most cassiterite but is of very low grade; this alluvium is fairly extensive and attains thicknesses of 5m or more, and

3. older alluvium comprising granite-derived sandy wash, with granite boulders up to several metres in diameter, overlain by more recent sandy alluvium; the old granite wash is up to 4.5m thick; the cassiterite concentrated in the basal 0.5m.

The **Mountaineer** mine is located at the junction of Flaggy Creek and the West Normanby River ~1km from the granite contact. This deposit consists of narrow quartz–cassiterite veins hosted by the Hodgkinson Formation. The veins comprise quartz, cassiterite and muscovite, strike 090°, and dip 80° south. Tourmaline is noticeably absent.

It is likely that there are unexploited alluvial resources which would support small–scale mining operations should tin prices improve significantly.

Tinaroo Area

The tin–tungsten mineralisation of the Tinaroo area is restricted to the Emerald Creek Microgranite and adjacent marginal zones of the Tinaroo Granite. The microgranite has been intruded by the Tinaroo Granite, fluids from the latter producing numerous narrow quartz veins. Most mineralisation is associated with quartz, pegmatitic, and greisen veins. Mancktelow (1982) also noted the presence of scheelite in a 0.5–1km wide zone around the Tinaroo Granite associated with calc-silicate hornfels within the Hodgkinson Formation.

Cassiterite, wolframite, and scheelite occur in massive to crystalline milky quartz veins which also commonly host disseminated pyrite, chalcopyrite, arsenopyrite, and molybdenum. These veins are up to 1.2m thick and generally trend north-easterly. They cut both the Emerald Creek Microgranite and the Tinaroo Granite. The tin and tungsten bearing quartz veins are often overprinted and cut by quartz–tourmaline veins up to 5cm thick and characterised by open space infillings of coarse radiating tourmaline. Small blebs of molybdenite are commonly associated with both the tourmaline veins and coarse infill. The overprinting relationships indicate two discrete fluids were involved in the formation of the Sn–W–Mo mineralisation which characterises the Tinaroo area. Importantly the molybdenum mineralisation appears to have been related to a later boron-rich fluid. Supporting this hypothesis is the fact that the scheelite from the Tinaroo area yields a bright sky-blue fluorescence, indicating a low molybdenum content (Greenwood, 1943).

Mancktelow (1982) considered the tungsten mineralisation, within the contact aureole of Tinaroo Granite, to be derived from the Tinaroo Batholith and emplaced by broad scale infiltration metasomatism.

Watercourses draining the Tinaroo area have been extensively worked for cassiterite. The disposition of the tin workings suggests the cassiterite has been mainly derived from weathering of the Emerald Creek Microgranite (Willmott & others, 1988).

Small quantities of gold have also been found associated with the stanniferous alluvium. The gold is thought to have been derived from erosion of auriferous quartz veins in the granite or the reworking of Tertiary sediments in the area.

Selected Minor Occurrences

Minor cassiterite occurs in drainage systems on the eastern side of the Kelly Saint George Granite and on the south-western margin of the Desailly Granite.

The **Pandora** workings, 27.7km SSW of Hurricane Station, are located on the Pandora Fault, a west-north-west trending shear zone, truncated to the south-east by the Big Watson Granodiorite (Almaden Supersuite). The cassiterite is in a haematite–magnetite gossan developed in sedimentary rocks of the Hodgkinson Formation. Outcrop is poor and the rocks are extensively sheared. The source of the mineralisation was considered by de Keyser (1961) to be related to the nearby granite (his Elizabeth Creek Granite; now part of the Almaden Supersuite). Other possible sources are the magmas which produced the volcanic rocks (particularly the Early Permian A-types) of the nearby Featherbed Volcanic Group and associated intrusive rocks (Lags Supersuite). Some of these rocks are slightly to moderately fractionated.

The **Dover Castle** mines are located 5.5km north-west of Petford. This group was also called Lappa-Lappa or Peruvian Group of mines. The main deposits are Better Luck, Comstock, Dover Castle, Feldspar (Christmas Gift), Midas, Rocky Lode, and Silver King. Mineralisation is limited to narrow rich fissure veins which appear to be tension gash infills. The host rocks are late Carboniferous Muirson Rhyolite and Cotell ('Tennyson') Rhyolite of the Featherbed Volcanic group. Faults related to the Tennyson Ring Dyke traverse this area and are thought to have controlled mineralisation (Dash & others, 1988).

The Lags Microgranite (early Permian) intrudes directly north-north-west of the Midas Mine and appears to be emplaced along one of these faults, it is also slightly mineralised. Mineralisation is zoned across this group with tin at Dover Castle, Midas, and Feldspar mines, and silver-lead developed to the south and west. Within the Dover Castle mine the cassiterite is brown near the surface grading to black tin with depth. Both these zonation trends are related to fluid temperatures and suggest a mineralising fluid source from the east (Dash & others, 1988).

Large reserves of very-low grade alluvial cassiterite were delineated in the Mitchell River valley, around Skull Lagoons and the mouth of Plum Tree and Little Plum Tree Creeks (Dash & Cranfield, 1993). These resources are not likely to be economic in the foreseeable future. The cassiterite is derived from weathering of tourmaline–cassiterite–quartz veins in the Mount Alto Granite.

The **Ruddygore** mine near Chillagoe has been described as a weak porphyry tin mineral system (Dash & others, 1988) with copper grades showing an inverse relationship to tin grades. The tin production history and contained resources are unknown.

Subeconomic tin mineralisation is associated with some of the skarn deposits in the Chillagoe area such as Girofla, Harpers and Red Hill. Exploration of the Harpers deposit indicated that it contains about 0.1% tin (Dash & others, 1988).

Current Tin Mines, Prospects and Main Known Resources

The Cairns Region contains several significant tin deposits. The main impediment to the development of these deposits is the depressed state of the tin market.

Black Adder Flats

Black Adder Flats is on Garrawalt Creek, 43km west-north-west of Ingham, and downstream from areas which have been historically worked for alluvial cassiterite. Garrawalt Creek and its tributaries drain areas of mainly Carboniferous granite and rhyolite (Wallman Falls Volcanics) which form the Seaview Range. The source of the cassiterite is thought to be the contact zone between the granitic and volcanic rocks, 24km to the south, where greisenised fractures host cassiterite, wolframite, and molybdenite mineralisation. Adelaide Tin Exploration Ltd drilled dredging claims at Black Adder Flat between 1936–1938. Austral Malay Tin optioned the claims in 1938, after Adelaide Tin reported good results, but check drilling did not yield encouraging results.

Placer Prospecting Pty Ltd described the area as a shallow north-trending basin, 2.4km long x 0.8km wide, with a basement of reddish orthoclase granite. Alluvial cassiterite ranges from ruby red to white and is associated with significant amounts of iron oxides. Placer drilled 13 holes all of which bottomed in granite. The average grade of the wash (0.039kg Sn/m^3) was well below the economic requirements at the time. Alluvial deposits were delineated to a maximum depth of 12.8m by Placer; an average thickness of 7.6m of wash was estimated. At least two and possibly three alluvial terraces are represented.

Gillian (Nymbool, Pinnacle) Prospect MDL 38

The Gillian prospect (also called Nymbool or Pinnacle prospect) is reported in the Register of Australian Mining (1994/95, page 147) as containing a resource of 4Mt @ 11% fluorine with significant copper, tin and tungsten mineralisation.

Great interest has been shown in this prospect as a possible bulk low-grade tin deposit. The mineral assemblage is massive tin-rich garnet with magnetite and varying amounts of clinopyroxene, fluorite, and massive fluoro-vesuvianite. This mineralisation-style is unusual and has been termed a wrigglite skarn because of the thinly layered and contorted appearance of the mineralised rocks.

A financial evaluation prepared for Strike Mining NL indicated the prospect may be economic (Strike Mining NL activity report for quarter ending 30 June 1996). Reserve estimates and a drilling proposal were completed in 1996 which culminated in the calculation of an Indicated Resource of 1.3Mt grading 0.54%–0.69% tin and an Inferred Resource of 500 000t @ 0.54–0.69% tin (Register of Australian Mining 1997/98, page 385). Further exploration is planned for additional higher grade resources along the south-westerly strike of the mineralised zone.

Kings Plains Prospect

The Kings Plains prospect is a former channel of the Annan River and was first described by Best (1962). Investigations indicated that the ancestral Annan River is at least 50m deep in places. The alluvium is stanniferous, the best grades being concentrated at depths of >30.5m.

The Kings Plains deposit was assessed as a dredging proposition in 1975, but the grades were too low to be economic. Between 1977–1983, Triako Mines NL, in a joint venture with Serem (Australia) Pty Ltd and Buka Minerals NL, investigated the potential of the Kings Plains deposit for a dredging or gravel pumping operation. Percussion drilling indicated the presence of two stanniferous zones in the wash, separated by a layer with very low grades. The highest grade intersected was 10m of wash which yielded 267g/m^3 cassiterite. The alluvium deepens to the west, with an accompanying lowering in grade.

Leichhardt Creek Project

The Leichhardt Creek Project, a dredging operation located 12km ESE of Mount Carbine on a tributary of the Mitchell River, commenced production in October 1995. Operations are planned to produce 600t per annum of 40% cassiterite concentrate. The concentrates will be transported to a dressing plant at Mount Veteran, north of Mount Garnet, for upgrading to a 65–70% concentrate prior to smelting. Norminco Ltd is the major owner and operator of this project.

A series of machinery failures has affected production since commissioning. Production to June 1996 is 5.6t of 70% tin concentrate (Minerals Gazette, June 1996). Production rates have steadily increased, but by the end of September 1996, the mine had not reached break-even point. The main constraint to improved production is the presence of clay lenses in the alluvium. The project is currently abandoned with a feasibility study being completed in an attempt to raise funds to repay its debts.

Mount Veteran

The lease over this deposit, also called Mount Fraser, are currently held by Norminco Ltd. The company has recently recommissioned the large mining plant (originally commissioned in 1984) to treat concentrates from their Leichhardt Creek operations (see above). The mineralisation at Mount Veteran has been described by the former owners of the property as having potentially large reserves (Register of Australian Mining 1995/96, page 285), but no precise tonnage figures are available.

The mineralisation consists of a crushed zone of chloritic alteration developed in metasedimentary rocks of the Hodgkinson Formation (Bruvel & others, 1991). As of June 1996 exploration work was continuing. The feasibility of recommencing hard rock mining and processing of ore at the existing plant were also being assessed. Results have been encouraging but current reserves are below the target tonnages required to justify reopening the mill. The company is also considering other resources in the Mount Garnet area which could provide feed for the mill if reopened.

Smith's Creek

This area has been extensively mined for lode and alluvial tin. A group of companies is currently evaluating the lode tin potential. A detailed ground magnetic survey over the mineralised structures indicated the presence of small discrete pipe-like bodies of potentially stanniferous material. These results, along with surface geological mapping and diamond drill core logging, failed to indicate potential for significant mineralised bodies (Otter Exploration NL Annual Report 1996). The area is held under MDL 39.

Windermere

This deposit (also called Western Deposit) is located 18.5km WNW of Ravenshoe and was originally mined for smelter flux. The workings are located on a small hill in massive ironstone rich in magnetite. The mineralisation consists of massive hematite and crystalline magnetite associated with garnet which crops out over a width of up to 100m and a length of ~4km. The area has been previously explored by Otter Exploration NL but is currently being assessed by Strike Mining NL in a joint venture agreement. Strike Mining NL identified sporadic low-grade gold values and restricted tin mineralisation from exploration activities. An Inferred Resource of 650 000t grading 0.56% tin was calculated from this activity (Register of Australian Mining 1997/98, page 385).

The prospect was investigated for its potential as a low grade tin skarn deposit similar to the Gillian deposit. Connah(1954) estimated reserves at 70–80 000t with samples averaging 54.6% Fe and 6.1% Si and he also stated that this grade is from surface sampling which may be higher than the true average.

TUNGSTEN

Bamford Hill, Captain Morgan and Eight Mile

These three large endogreisen deposits fall into a broad approximately 25km long north-south trending zone from Wolfram Camp in the northern end and Bamford Hill in the south. This trend fringes the eastern margin of the Featherbed Volcanic Group.

At **Bamford Hill** ore was mined from sheeted veins and pipes which appear to be controlled by a shrinkage joint pattern. These were possibly the original conduits for late stage fluids in the granite cupola (Blevin, 1990). The recorded total production of >2 000t wolframite, 170t molybdenite and 20t bismuthinite concentrates is regarded as being far short of the true production. Studies by James Cook University staff and students indicate a very shallow emplacement (~500m) of the granite (Bamford Granite, Ootann Supersuite) into the Featherbed Volcanic Group. Exogreisens are restricted to four small areas very close to the contact with the Featherbed Volcanic Group. Alteration in these greisens is quartz, hercynite, and andalusite overprinted by quartz and muscovite.

Alteration within the granite (enogreisens) is quartz, sericite and albitisation giving the ore zone granite a grey appearance. Sheeted veins and pipes are both subparallel to the contact. Pipes display large open cavities with wolframite and molybdenite crystals gravity settling to the lower sides of vughs. The pipes are complex structures with cross sections <15m by 10m and up to 200m in length. The pipes commonly display zoning and branching. They are thought to have been formed by magmatic gas stoping (Levingston, 1955). Zoning inwards is as follows:-

- quartz, muscovite altered granite,
- highly silicic blue granite,
- white euhedral quartz, molybdenite, wolframite with molybdenite deposited during and after wolframite,
- native bismuth in vughs,
- galena, arsenopyrite, pyrite, chalcopyrite, fluorite, calcite, and
- clay in some vughs.

Pipes are best developed on the top of the granite margin where the dip increases sharply. The vast spaces required to make room for the pipes is possibly explained in Dash & others (1988) by:-

- initial intrusion, exogreisenisation, chilling margins,
- magma pressure relieved by movement of magma to another area,
- hydrothermal activity increasing with magma withdrawal, and
- repulse of magma, causing stoping of cracks, joints and deposition of ore.

This also explains the internal contacts in the granite which have been sericitised and the xenoliths of pegmatite with sericitised margins.

The **Eight Mile** deposit is a semiclosed system greisen (Dash & others, 1988). The granite has been argillically altered with the feldspars replaced by green clay minerals, locally termed ‘green spot granite’. Placer Austex drilled the deposit in 1979 and found that the cusp of mineralisation extended to 30m depth and that the present topography approximates the original granite/volcanic contact. This region has been extensively explored for 'blind' granite cusps.

The **Captain Morgan** deposit comprises two areas 200m apart. The main area on the northern end is a greisenised cap zone in granite 80m x 30m, with only minor quartz veining, and disseminated wolframite in greisenised granite. This main area is capped by a dacitic porphyry, part of the Featherbed Volcanic Group. The smaller area is 200m further south, where workings are on quartz veins which have equal concentrations of wolframite and molybdenite. This area has deeper shafts due to the vertical nature of the veins.

All three deposits have been extensively scraped for eluvial material in the late 1970s removing most historic mine workings.

Cooktown Tin Field

Only two occurrences of wolframite are known in the Cooktown Tinfield. A wolframite-bearing quartz–tourmaline lode at **Mount Hartley**, ~12km south-east of Helenvale, trends between 135°–160° and dips between 45°–82° to the south-west. It is up to 1.5m thick (average 0.3–0.6m) and occurs in fine to medium-grained porphyritic biotite to tourmaline granite, close to the contact with the Hodgkinson Formation. The wolframite is very coarse (to 50mm) and occurs in bands of blady crystals near the vein margins. Arsenopyrite, chalcopyrite, pyrite, chalcocite, and covellite also occur in the quartz. The host granite is silicified, greisenised, tourmalinised, and foliated. Holes drilled by Dominion Mining NL intersected zones up to 1.2m thick, assaying up to 0.12% W, 800ppm Cu, and 200ppm Bi (Kinnane, 1982).

At the **Clearwater** tungsten prospect, near Romeo Creek 11km south of Rossville, wolframite, scheelite, and cassiterite occur in sheeted quartz–tourmaline and quartz–feldspar veins which cut microgranite and granite. Silicification and greisenisation occur in the granite adjacent to the veins. The veins occur in two main zones which are up to 25m wide, strike 135°, and dip between 70°–80° to the north-east. The Shell Company of Australia Ltd (Billiton) carried out detailed exploration of the prospect. Rock chip samples assayed up to 0.76% Sn and 1.8% W. Drilling results indicated an Inferred Resource of 2Mt at 0.1% W to 50m depth (Truelove, 1982).

Cumble Cumble Deposit

The deposit is located in the headwaters of Spencer Creek 25.7km west-north-west of Mossman. It consists of minor tungsten mineralisation associated with a stockwork of quartz-muscovite veins near the margin of the Mount Carbine Granite. Disseminated blady wolframite grains (up to 20mm long and 5mm wide) occur throughout the quartz and as stringers along vein margins. Scattered mineralisation also occurs along the contact of the granite with the Hodgkinson Formation.

Davies Creek Prospect

This prospect contains scheelite-bearing calc-silicate rocks, 300m west of the Tinaroo Batholith (S-type granitoid), the western margin of which probably dips between 30°–50° to the west. This granite was intruded at 2.5Kbar (Rubenach, 1994) probably deeper than most mineralising systems in the region. Host rocks are phyllite, schist and possible mafic volcanic rocks currently mapped as part of the Hodgkinson Formation.

The mineralised zone in some areas appears to be a continuous bed, and in others, it is discontinuous and pod-like, within a particular stratigraphic interval. Scheelite in the deposit is 0.3mm average grain size and increases in abundance eastwards. Hollingsworth (1974) postulated a further increase in intensity of scheelite mineralisation towards the intrusive contact to the east. However he considered the mineralisation to be patchy, thin and low-grade.

Reappraisal of the prospect by Duval Mining (Australia) Pty Ltd in 1984, indicated the original host rock was probably a mafic volcanic rock. CRA Exploration Pty Ltd (Strickland, 1982) interpreted the calc-silicates to be near-horizontal and 0.3m–1.0m thick but not of sufficient grade and thickness to interest the company.

Dingo Mountain

Tungsten and molybdenum mineralisation at **Dingo Mountain**, 50km west-north-west of Cardwell, occurs as fine-grained disseminations in large areas of intensely sericitised and greisenised granite, where it intrudes overlying rhyodacitic rocks of the Glen Gordon Volcanics. Most abandoned workings are located along quartz-filled fractures in the greisen, where the mineralisation is coarser grained and was economic to mine at the time. The mineralisation appears to have been related to a later-stage phase rather than the main body of granite (Fletcher, 1971).

There are numerous anomalous concentrations of wolframite associated with small greisen zones between Dingo Mountain and Smoko Creek. Potential, although low, exists for the discovery of tungsten- and molybdenum-bearing endogreisens in apical portions of granite plutons which are concealed by cover rocks. Indicators of such mineralisation could include these small greisen zones and/or minor vein-style deposits which may be localised in fractures above such endogreisens.

Herberton Mineral Field

Tungsten occurs either in association with molybdenum, bismuth or tin, or as a sole commodity. Its distribution pattern approximates that of tin. In accordance with its high temperature of deposition, the majority of tungsten deposits occur within granitic host rocks.

The most common styles of deposit are the greisen vein and quartz vein lodes. Wolframite is the dominant tungsten mineral and occurs in:

- quartz veins, lenses and pipes, commonly with minor amounts of sericite,
- pegmatite veins, lenses and pipes,
- greisen veins and irregular zones (locally with cassiterite),
- central quartz cores within greisen zones,
- porphyry molybdenum deposits, and
- chloritic lodes (rare).

The wolframite is generally medium to coarse-grained in all but the greisenised granite type of deposit. It is accompanied by cassiterite in some of these deposits. Minor sulphides, particularly molybdenite, can accompany wolframite in all of these deposit types.

The quartz-lode type occurs both in granites of the O'Briens Creek Supersuite and in adjacent sedimentary rocks of the Hodgkinson

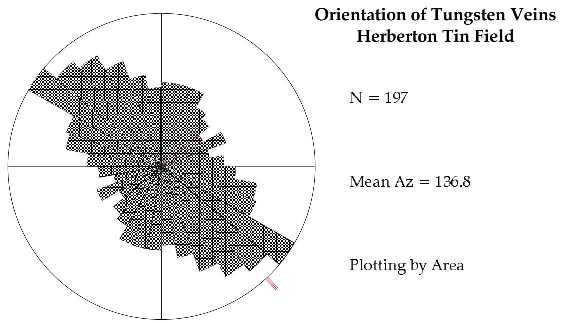


Figure 55. Orientation of tungsten vein deposits.

Formation. This type commonly has clean white quartz gangue with sparse sulphides, such as molybdenite, arsenopyrite, bismuthinite, and pyrite. Only minor sericitic wall rock alteration fringes the quartz veins.

The pegmatitic and greisen types predominate in granitic host rocks. Pollard (1984) noted that at several localities in the Emuford district, wolframite (molybdenite) mineralisation appears to be associated with relative late fine-grained granite and/or pegmatite. The greisen deposits commonly have central cores of quartz and fluorite with abundant large wolframite crystals. The cores are flanked by coarse mica-rich zones which grade into outer zones of barren quartz–mica greisen (Bruvel & others, 1991). Sulphide minerals, topaz, and tourmaline are common accessories; monazite has also been reported.

Tungsten-bearing chloritic lodes occur in metasedimentary rocks of the Hodgkinson Formation. An example is the chloritic lode at the Great Southern tin mine. The lode contains scattered crystals of coarse wolframite. Other minor chlorite lodes containing wolframite are present in the Stannary Hills and Watsonville areas.

The **Carbonate Creek Group**, 8km south of Dimbulah, is an example of a porphyry molybdenum/tungsten deposit (Horton, 1982). Wolframite and molybdenite occur in flat-lying quartz reefs, where pods of porphyritic microgranite have been passively emplaced along a fault zone between volcanic rocks of the Featherbed Volcanic Group and metasedimentary rocks of the Hodgkinson Formation. The deposits are mainly in the Hodgkinson Formation.

Koorboora

The **Koorboora** area is located 12km east of Almaden at the western extremity of the Herberton Mineral Field. Although mainly worked for tin this area has yielded significant tungsten production. Many of the lodes worked were ferruginous and chloritic, the massive tin and wolfram being confined to fault and fracture zones. The deposits in this area are very rich but of limited extent.

The main wolfram producing mine was the **Neville**. It was the richest wolfram-bearing deposit in the area and in 1909 was considered to be one of the greatest single wolfram mines in the world averaging 10–20% wolframite concentrates to 40m depth (Dash & others, 1988). Total production is considered to be 590t of wolframite concentrates from 9 100t of ore obtained between 1905–1919. Cassiterite content increased with depth down the spiralling pipe orebody which measured 25m long by 10m wide at 65m depth and averaged 1% wolframite and cassiterite. The sulphide content (pyrite, galena, sphalerite, and chalcopyrite) increased markedly below 65m depth.

Lode Hill

Scheelite mineralisation in the **Lode Hill** area, (south-east of the Mount Carbine deposit), developed where faults cut basic igneous dykes. The fluids, probably derived from the nearby Mount Carbine Granite, metasomatised the calcium-rich minerals in the basic dykes to form a suite of calc-silicate minerals and scheelite. Most of the lodes trend north-west, parallel to the granite contact, which is generally <250m away.

Prospecting by companies indicated the scheelite occurs in quartz veins and veinlets, feldsite dykes and chloritised zones in the basic igneous host rocks. Minor scheelite was also found in felsite dykes and quartz-tourmaline veins in sedimentary rocks. According to Pahminco Pty Ltd, the most significant fault in the area is the Mount Molloy Fault (Duck & Walker, 1983), previously termed the Lode Hill Fault. Mineralisation at Salt Bag, Lode Hill, Mountain King, and Rifle Range Hill prospects are inferred to be controlled by this fault. Alteration zones are up to 2m wide.

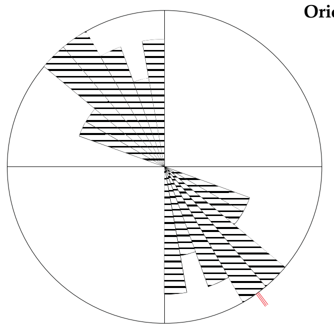


Figure 56. Tungsten vein orientations in the Mount Carbine area.

Mount Carbine

The **Mount Carbine** deposit consists of sheeted quartz-wolframite–scheelite veins in metasedimentary rocks of the Hodgkinson Formation. The Mount Carbine Granite, thought to be the source of the mineralising fluids, crops out 500m to the east. The granite is a member of the S-type Whypalla Supersuite (Champion, 1991; Bultitude & Champion, 1992). Holes drilled to depths of up to 500m beneath the pit have not intersected granite.

The deposit consists of several zones of quartz and quartz–feldspar veins in a 2.5km long north-trending belt. Two sets of sheeted vein systems have been identified, the main set trends north-west, parallel to the fault which truncates the ore zone to the south-west (see Figure 56).

Individual quartz veins have a lateral and vertical extent of up to ~29m, and range in width from 0.1–1.0m, (most are between 0.15–0.20m thick). The area of the open-cut mine is ~750m x 160m x 200m deep but mineralisation is known to extend for at least 100m below the bottom of the pit. Production stopped in September 1987 because of low tungsten prices.

The hydrothermal sheeted vein swarms are considered to be genetically related to the adjacent Mount Carbine Granite (Murray, 1990; McLean, 1980). In contrast, studies by Higgins & others (1987,) indicated the fluids were partly sourced from magmatic and partly from sedimentary rocks. De Roo (1988) interpreted the evolution of the mineralisation to be as follows:

- fracture dilation, marked by fibrous tourmaline infill and associated wall rock alteration,

- subsequent major dilation marked by emplacement of veins of fibrous quartz–K–feldspar–apatite–muscovite–biotite containing wolframite and probably some molybdenite and bismuth,

- secondary veins which cut and are marginal to the earlier veins; these contain fluorite, chlorite, albite, scheelite, cassiterite, pyrite, sphalerite, pyrrhotite, molybdenite, bismuth and carbonates; wolframite in the earlier veins shows some degree of replacement by scheelite and sulphides, and

- late brittle fractures, many of which are filled with post-ore granitic dykes.

Retrograde chlorite–sericite alteration accompanied the replacement stage of mineralisation and post-ore fracturing and faulting. In similar prospects nearby, Mount Carbine-type veins grade into greisen zones and granite dykes, supporting the theory of a granitic source for the hydrothermal fluids (de Roo, 1988).

Mount Perseverance

Mineralisation in the **Mount Perseverance** area (10km south-south-west of Mossman) is similar to that at Mount Carbine. The lode consists of several quartz veins with feldspar/mica-rich selvedges, within mudstone and fine-grained arenite of the Hodgkinson Formation. The Mount Carbine Granite crops out about 2.5km to the west. The quartz veins are randomly oriented and their dip ranges from near-horizontal to 70°. The thickness of the veins ranges from 10–60cm. The veins are cut by normal and reverse faults with minor displacement. Most of the faults have been interpreted by Levingston & Carruthers (1953) to pre-date the mineralisation. The quartz is hard and glassy with a bluish tint in places. The margins of the veins are defined by yellow muscovite/sericite-rich selvedges up to 7.5cm thick which also contain wolframite in places. Seams of this muscovite/sericite also branch out from vein margins into the country rocks. The presence of sericite was considered by the miners to be a good indicator of mineralisation.

Ore minerals include wolframite, scheelite, tungstite, pyrite, arsenopyrite, chalcopyrite, copper carbonates, and rarely, cassiterite. Production of 1.75t of cassiterite concentrates was recorded from alluvial workings in watercourses in the vicinity.

Pom Pom

The **Pom Pom** deposit, 7.4km west-north-west of Mount Molloy, comprises fault-controlled, quartz-greisen and pegmatite veins in arenite and mudstone of the Hodgkinson Formation. It is located only a few hundred metres west of the contact with the Mount Carbine Granite. In the south (the site of the main workings) the deposit is in a south-east-trending fracture up to 1.2m wide. The lode consists of a quartz core, surrounded by quartz-greisen. A pegmatite dyke occurs along at least one margin.

The main ore mineral is wolframite, accompanied by chalcopyrite, molybdenite, bornite, cassiterite, and pyrite. Wolframite mainly occurs in the quartz core and pegmatite dyke, whereas the chalcopyrite, bornite, and pyrite occur mainly in the quartz core and the quartz greisen. Chalcopyrite is also disseminated in the adjacent wall rocks. The molybdenite is fine-grained and occurs on the margins of the quartz core and quartz-greisen veins as well as in the adjacent wall rocks.

Taylor (1971) reported significant amounts of scheelite, as both discrete crystals and an alteration product of wolframite in the walls of the adit. He also observed granitic rocks (dykes?) in both the hanging wall and footwall of the adit.

Spring Creek–Mount Hurford Area

The main occurrences are in the **Spring Creek** area, located near Cannibal and Granite Creeks. The lodes consist of subparallel, vertically-dipping composite quartz-greisen veins striking ~110° in a 1km-long zone. These scheelite-bearing veins cut tourmalinised metasediments of the Hodgkinson Formation. Coarse-grained crystals and aggregates of scheelite occur on vein margins and within muscovite-rich parts of the veins. Scheelite also occurs in anastomosing veinlets in the alteration haloes of the lodes and as disseminations within the tourmalinised country rocks.

The vein systems are associated with a subsurface granite intrusion, possibly related to the Cannibal Creek Granite. They were discovered by Frost Enterprises Pty Ltd in 1968; 24.8t of scheelite concentrates were produced from 17 235t of ore at head grades of 0.15–0.34% WO_3.

Keddie's Workings, one of the largest lodes, is a mineralised zone comprising six, parallel, vertical, 0.2–0.5m wide muscovite–quartz veins. The lode was mined from an opencut measuring 150m long by 50m wide. The veins contain coarse quartz, muscovite, and scheelite, with minor cassiterite, chalcopyrite, pyrite, beryl, and selvedges of tourmalinised host rock. Several drillholes have intersected the Keddie lode to depths of 35m, but no zones of significant mineralisation were detected; granite was intersected at depths ranging from 43m–75m (McConnell, 1983; McConnell & Carver, 1984b).

Watershed Prospect

Mineralisation at the **Watershed** tungsten prospect is mainly in steep westerly dipping, stratabound lenses of calc-silicate rocks of the Hodgkinson Formation. The rocks are exposed in the hinge zone of a megafold. Scheelite occurs as fine to coarse-grained disseminations in the lenses, and also as coarse crystals in quartz–feldspar veins in the calc-silicate rocks and adjacent granite. The host rocks are calcareous arenites and conglomerates within predominantly arenite units of the Hodgkinson Formation. Within the calc-silicate rocks, the scheelite is accompanied by minor pyrite, pyrrhotite, arsenopyrite, fluorite, sphalerite, chalcopyrite, and molybdenite.
Scheelite-bearing veins are generally <10cm wide and contain coarse-grained scheelite, which is generally concentrated along vein margins but also occurs within muscovite-rich parts of the veins. Vein mineralisation comprises much of the higher grade mineralisation in the deposit. High-grade disseminated haloes occur adjacent to veins. This large low grade tungsten deposit is held by BHP Australia Coal Pty Ltd, as MDL 127, who have mothballed the project pending an improvement in the tungsten price.

From the deposit model characteristics outlined by Meinert (1993) the Watershed Grid deposit is best described as a reduced-type tungsten skarn.

Wolfram Camp

The **Wolfram Camp** molybdenum–tungsten–bismuth field is situated 50km west-south-west of Cairns. The main mines worked at Wolfram camp were the **Avoca**, **Enterprise**, **Larkin**, **Forget Me Not**, **Mulligan–McIntyre**, **Murphy and Geany**, **Pepper**, **Tully,** and **Victory**.

The Wolfram Camp deposit is located in the roof zone of a pluton of fractionated granite (James Creek Granite) which has intruded the Hodgkinson Formation and is overlain by the Featherbed Volcanic Group (Beapeo Rhyolite) to the north-west. The mineralisation is confined to greisen zones and the deposit consists of ~250 irregular branching pipes, plus minor mineralised flat joints and irregular segregations in a zone 3.2km long by 800m wide and 170m deep along the inclined northern contact of the granite (~50° to the north). These pipes are up to 6m in diameter, and are enriched where they intersect small joints and faults or barren quartz reefs. The pipes have been worked to approximately 200m depth.

The mineralised pipes are commonly elliptical in cross section with an asymmetric mineral zonation. This zonation in inclined pipes from the lower surface upwards is:

- narrow dark quartz rim (<5cm thick),
- coarse grained ore, radiating tabular wolframite crystals (up to 50cm long) with intergrown molybdenite (up to 20cm across), bismuth, bismuthinite, pyrite, marcasite, chalcopyrite, and arsenopyrite replacing along cracks and cleavages,
- crystalline quartz with common vughs (up to 3m x 5m wide) lined with quartz crystals (up to 1m thick and 3m long), and
- upper contact of pipe commonly has small vughs lined with arsenopyrite, fluorite, and calcite.

A 286Ma K–Ar age (recalculated according to Steiger & Jager, 1977) for mineralisation was obtained from muscovite extracted from an ore-bearing vein at Wolfram Camp (Richards & others, 1966). Herr & others (1967) calculated an age of 230±30Ma by the Re–Os method for molybdenite from Wolfram Camp.

The quality of the quartz crystals in the Enterprise mine was such that they were mined for use in radio sets. Samples of the ore from this mine were very spectacular, and specimens are held in museums throughout the western world.

A drilling program at the Wolfram Camp deposit was completed by Allegiance Mining NL during 1995 to outline an open pit tungsten–molybdenum resource based on extensions of the known ore bodies (Register of Australian Mining 1995/96, page 300). The company completed a bulk sampling program in June 1996 but have decided to relinquish interest in the area. Despite its extensive production history this deposits still contains an Inferred Resource of 2Mt @ 1.0% WO_3, 0.5% Mo and 0.1% Bi (MINMET 6/12/96).

Wolfram Hill

Wolfram Hill, located 18.2km west of Mareeba, is a contact metasomatic deposit at the greisenised contact between the Mareeba Granite and metasedimentary rocks of the Hodgkinson Formation. Some greisenised acid volcanic rocks also crop out in the area. The workings are in schist at the northern end of the hill and also in joints in the nearby granite. The main ore minerals are wolframite, chalcopyrite, arsenopyrite and molybdenite.

Selected Minor Occurrences

The **Whumbal Wolfram** (also called Spring Hills) deposit consists of several discontinuous quartz–wolframite–arsenopyrite filled shear zones in the margin of the Kelly St George Granite, 44km west-north-west of Mount Carbine. The shears are lenticular and dip 30°–50° to the north-east, parallelling the contact with the Hodgkinson Formation. Wolframite occurs as blady crystals up to 20mm by 10mm, and makes up 0.5–1% (by volume) of the lode. Greisen-style alteration is present mainly along the lode margins and, to a lesser extent, is represented by muscovite clusters in the quartz forming the lode.

The **Mount Elephant** deposit, 24km north-west of Mount Carbine, consists of scheelite in greisen and quartz veins in granodiorite and pegmatite of the Desailly Granite. The veins are subparallel, vertical, and strike between ~060–080°. The veins range from 50mm up to 250mm in thickness and contain coarse-grained scheelite crystals up to 50mm. The scheelite is concentrated along vein margins and comprises several percent of individual mineralised veins.

Numerous small-scale wolframite-bearing quartz veins occur in granite in the **Kirrama** area, where there are also scattered lenses or irregularly shaped pods of pegmatite. The veins and pegmatite zones are concentrated in granite adjacent to intrusive contacts with felsic volcanic rocks of the Glen Gordon Volcanics. The flat lying to only moderately dipping volcanic rocks are topographically higher than the nearby granite, implying the mineralised veins formed in the roof zones of the pluton. None has been of great economic importance but the lodes are believed to be the main sources of alluvial cassiterite and wolframite in adjacent areas.

Sparse wolframite occurs in quartz veins and quartz-greisen veinlets in tourmaline-rich granite of the Mount Carbine Tableland, on the western slopes of Mount Lewis 11.1km north-north-west of Mount Molloy. The wolframite is commonly associated with cassiterite.

Quartz–cassiterite–wolframite veins have been reported in the Howick Island Granite (Yates Supersuite) on **Howick Island**. Wolframite has also been mined from quartz vein stockworks in hornfelsed Hodgkinson Formation rocks on Noble Island. The veins contain up to 5% wolframite and arsenopyrite, as well as traces of scheelite.

Minor wolframite–quartz veins occur in granite in the headwaters of **Gordan** and **Piccaninny Creeks**, on the western side of the Mount Windsor Tableland.

URANIUM

There has been no mining of uranium minerals in the region but numerous prospects containing radioactive minerals have been identified by exploration companies. All these prospects are in rocks bordering the main outcrop areas of the Featherbed Volcanic Group. The main prospects are **Doolans Springs**, **Fishermans Waterhole**, **Graemes Anomaly** and **Pinchgut Pinnacle**.

Doolans Springs is located on Doolan Creek, a tributary of the Walsh River, and contains anomalous uranium mineralisation which has been concentrated by natural processes around several active and abandoned cold water springs. These springs are surrounded by travertine deposits characterised by anomalously high radioactivity. The springs are located on the faulted margin of the Featherbed Volcanic Group. Two sources for the uranium mineralisation have been proposed (McKay, 1983):

1. leaching by groundwater of a uraniferous unit within the volcanic sequence, or

2. leaching by ground water of a high-grade uranium-rich lode.

Fishermans Waterhole is located on the Walsh River, 13km NE of Chillagoe. The uranium is restricted to a small zone near the surface; no vein mineralisation was identified at depth in drill holes. Minor fluorite veinlets (to 2mm) are present in areas of high radioactivity. This deposit is considered to be of no economic significance because of the millimetre size of the fracture infillings which host the mineralisation.

Secondary uranium minerals occur as coatings and cavity linings in a narrow shear (mylonite?) zone in sericitised micro-leucoadamellite at the Pinchgut Pinnacle prospect 12.5km east of Chillagoe.

Uranium was reported from a tungsten mine on the bank of Pine Log Creek, 6.6km NE of Irvinebank. Torbernite and a uranium-bearing carbonate occur in a quartz-biotite-muscovite rich pegmatite lens in a greisen zone. This occurrence was reported in 1953, when there was an Australia-wide initiative to document all known uranium deposits (Australian Atomic Energy Symposium, 1958). Small flakes of U minerals also occur along joint planes in the Peacemaker tin workings, Herberton Mineral Field.

OTHER COMMODITIES

Concentrations of **gallium** (up to 16ppm) have been reported in quartz-stibnite veins of the Herberton Mineral Field (Dash & others, 1991).

Rutile occurs as a minor component in a few quartz lodes in the tin mining areas around Herberton. The most significant occurrence is in the Herberton Hill Group (7963 310764), 2.6km ESE of Herberton, on the bank of Bradlaugh Creek. At this occurrence, euhedral crystals of rutile up to 12mm long occur in a quartz pegmatite vein 150m long and 5m wide, in coarse granite.

Cadmium was detected by Great Northern Mining Corporation NL in the silver–lead–indium ores of the Orient Camp West group of mines.

A small **mica** mine is located in the headwaters of Bloodwood Creek, 6.4km E of Emuford. The mica is in the pegmatite core of a quartz greisen in the Bloodwood Granite. Books of mica are up to 12cm across. Ten tonnes of mica were reportedly produced from this mine in 1958 (Garrad, 1991).

Anomalous concentrations of **nickel** occur in lateritic soil profiles developed in a serpentinised, ultrabasic lens, 8km north-east of Julatten (RUMULA). This body is thought to have been tectonically emplaced.

A small amount of **kaolinite** has been mined from the summit area of Mount Lewis. The deposit is probably an eluvial/alluvial accumulation of clay from the decomposition of the Mount Carbine Granite.

Significant quantities of **bismuth** have been mined from Wolfram Camp and Bamford Hill (see tungsten section) with lesser amounts produced from complex sulphide ores or tungsten-bismuth ores mined in the Herberton Mineral Field (*e.g.* Vulcan, General Gordon). The mines of the Glen group, located 13km south-west of Irvinebank in the Herberton Mineral Field were the main producers of bismuth as a by-product. These mines worked flat-lying greisen lodes containing topaz, wolframite, arsenopyrite, bismuthinite, chalcopyrite, fluorite and quartz (Blake, 1972). The greisens formed along flat lying joints in the granite and are connected via vertical greisen pipes.

Indium has been detected in numerous workings and prospects in the Herberton Mineral Field. It was recorded as a significant trace element in cassiterite in the Herberton area (Greaves, 1964; Greaves & others, 1971) and occurs in subeconomic concentrations in the UNA tin–copper–silver mines, the Montalbion silver–lead mines and the Orient Camp silver–lead mines. All higher grade copper–tin–silver mineralisation in the UNA Group contains indium at levels of 40–60g/t (Dash & others, 1991). Indium is present in some of the Orient Camp West workings in concentrations of up to 120g/t, mainly in sphalerite, stannite, chalcopyrite, cassiterite or sulphosalts of Sn, Pb, Cu, or Sb. It also rarely occurs as discrete minerals such as indite ($F\ In\ S_4$), roquesite ($Cu\ In\ S_2$), sakuraiite ($[Cu,Ag]_2\ [In,Sn]\ [Zn,Fe]\ S_4$) and dzalindite ($In[OH]_3$).

Monazite was reported to occur in the Cave tungsten–tin mine, a pipe deposit in greisen, 1.6km NW of Emuford.

MINERAL RESOURCE ASSESSMENT

P.D. Garrad

Classification and Methodology

An assessment of mineral resource potential is concerned with the distribution of known mineralisation and the defining of areas which have a potential to host economic mineral resources. The mineral resource potential of the Cairns Region has been assessed using a qualitative assessment method adapted from those used by the United States Geological Survey and previously used by the Geological Survey of Queensland for the Cape York Peninsula Land Use Strategy (Denaro & Ewers, 1995). The presentation of the results detailed in this document is on a technical level which will requires some degree of technical knowledge by the user to completely understand.

A qualitative assessment of the mineral potential of a region combines knowledge of its geology, geophysics, geochemistry, and mineral deposits with current theories on mineral deposit genesis and the results of any exploration (Commonwealth Department of Primary Industries and Energy, 1993). In particular, the assessment draws on the regional characteristics of mineral deposit models and their setting in the regional geological framework to establish whether or not specific mineral deposits are likely to occur.

The mineral resource potential information in this report is given in terms of mineral deposit types (models) and their geological settings. Deposit types are based on the geological characteristics of known deposits within the study area. No attempt has been made to assess the potential for all the other mineral deposit types that may be present in the geological environment of the study area. However, as further mining and exploration are carried out, and as the geological factors controlling mineralisation in the area become better understood, the potential for other exploration models will be more readily evaluated.

A mineral deposit model is a description of the essential attributes or properties of a group or class of mineral deposits. The models used in this report are based primarily on the characteristics of known mineralisation in the study area, with supplementary deposit model data from Cox & Singer (1992) and other sources.

Various criteria can be used to assess the potential for a mineral resource. Recognition criteria are of three types:

1. **Diagnostic** criteria are those that are present in nearly all known deposits of a given type (for example, favourable host rock and known mineral occurrence).

2. **Permissive** criteria commonly, but not necessarily, suggest the presence of a given deposit type. Such criteria strengthen the possibility that a deposit of a specified type exists, but their absence does not rule out such a deposit.

3. The proven absence of a diagnostic criterion can in effect, be a negative criterion (for example, where a required type of host rock is known not to be present) (Gair, 1989).

The mineral resource potential of an area is an estimation or evaluation of the likelihood for the occurrence of mineral deposits. It **must** be remembered that resource assessments are dynamic rather than static. As more geoscientific and exploration data become available for an area, as new concepts on mineralisation controls and ore genesis evolve, as mining technology improves, and as commodity prices fluctuate, the resource potential of an area may be upgraded, extended or eroded. Care must be used if applying the results of this assessment to questions involving economics. The economic viability of the deposits that make up the models detailed in this document vary widely, from deposit to deposit and from model to model.

In this study, regions have been defined where geological, geochemical and/or geophysical criteria suggest a geological environment is favourable for the occurrence of a particular deposit type. These regions have been assigned a **favourable** mineral resource potential. Because of the size of the study area only generalised regions have been defined, more detailed assessment would require analysis of more specific regions and the use of a quantitative approach. The geological data necessary for quantitative analysis has been compiled in a form compatible for use in a Geographic Information System (GIS) and is available from the Department of Mines and Energy. A metallogenic study for the study area and adjoining regions has been completed by AMIRA as project 425. This information is currently confidential and has not been used in this report but may be obtained by approaching AMIRA.

Geological maps and maps showing the location and types of mineral deposits have been used to outline favourable areas and included as figures where possible in the relevant sections of this report. Geophysical data, where available, has also been used, as well as knowledge of the mining and exploration history of the study area.

Favourable geology is the most important overall condition to be satisfied in identifying an area as having mineral resource potential and encompasses all aspects of geological settings. Favourable geology is deduced from associations of mineralisation with specific rock types or other geological features such as faults.

The presence of known mineral occurrences, particularly small ones, does not automatically indicate mineral resource potential. However, mineral occurrences have a strong positive influence on the evaluation of resource potential because actual mineral occurrences support the possibility of still more (and bigger) occurrences. The absence of known mineral occurrences in parts of a rock formation that has occurrences elsewhere is not considered to be very significant because it may only reflect insufficient exploration. The assessment of these regions must be based on other considerations, such as geophysical anomalies in the formation, or mineralisation occurring in similar rocks elsewhere.

The degree of previous and current exploration activity may have two opposing influences. Firstly, because many types of ore deposits tend to occur in clusters, success in finding one deposit stimulates the search for other undiscovered deposits. A good example of this is the continuing search for economic gold-base metal deposits in the Mungana area. On the other hand (and more rarely), exploration activity may be so thorough that the probability of an undiscovered deposit is minimal. The latter scenario is not applicable to the study area.

BRECCIA-HOSTED DEPOSITS

Deposit Description

Mineralised breccias are typically localised near the intersection of intrusive ‘corridors’ with major structural or lithological contacts. Occurrences tend to occur in discrete corridors characterised by concentrations of subvolcanic intrusions and, in some cases, crustal scale faults.

Breccia bodies commonly have a pipe-like form with multiple brecciation and intrusive phases. Subvolcanic breccias have the form of an inverted cone centred above a porphyry plug or stock, a predominance of angular, clast-supported breccia with a tabular style typical of the pipe margin, an equant partly rounded style in the core, and, in some cases, a collapsed roof that partly preserves original host rock stratigraphy. There are numerous classification systems for breccias but most can be described as either intrusive, collapse, or crackle breccia (or combinations of the three).

In all breccia types, mineralisation is most commonly developed as:-

- structurally controlled post-breccia veins which may be restricted to one portion of the pipe,
- cavity fill, or
- replacement of the breccia matrix.

Diatreme breccias also host epithermal precious (± base) metal deposits. A diatreme is a breccia-filled volcanic vent which extends to the surface in the form of maar volcanoes (maars). They have a complex form, typically consisting of nested breccia bodies with an extrusive apron as well as internal pipe facies. The predominant breccia type is matrix-supported, with subrounded fragments, which locally exhibits crude layering, size grading, and other sedimentary structures. Mineralisation is localised within the diatreme or around its margins in ring faults and associated structures.

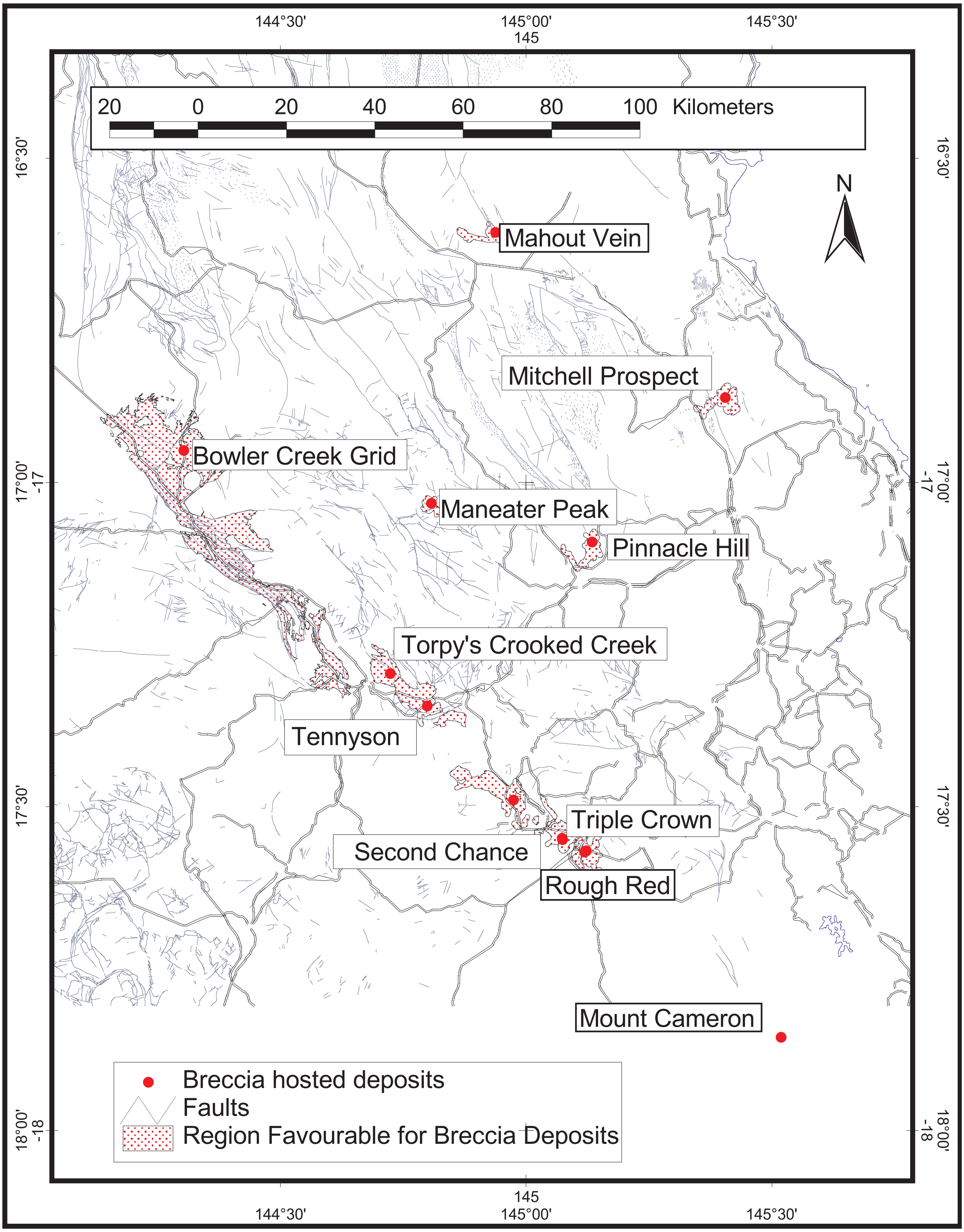


Figure 57. Distribution of known breccia hosted deposits and regions favourable for breccia hosted deposits.

For the purposes of this report any mineralisation developed within a breccia system has been group as breccia hosted (excluding fault breccia deposits).

Known Deposits

Maneater Peak, Mount Cameron, Torpy's Crooked Creek?, Triple Crown, Second Chance.

Age

Late Palaeozoic

Assessment criteria

- Intrusive corridors with subvolcanic rhyolitic to trachytic intrusions,
- presence of mineralised breccias or deposits related to high-level intrusives, and
- presence of regional or local scale fault structures and their intersections.

Areas of Potential

The south-western margins of the Featherbed Volcanic Group presents a favourable setting for this deposit style due to the presence of regional fault structures, high-level intrusives, and known, although limited, mineralisation.

The Chillagoe corridor of mineralisation may host breccia systems related to shallowly emplaced intrusive units. The Red Dome deposit has a significant breccia component to its ore assemblage. The presence of the Palmerville fault and known breccia deposits (some unmineralised) suggest this corridor is prospective for this style of mineralisation. The deflection of the Palmerville fault to the west in the vicinity of the Chillagoe township may have focused mineralising events in this area.

The presence of significant placer gold in the Russell River Deep Leads and proximity to known maars (Broomfield Swamp) may be coincidental but this region may be prospective for diatreme associated precious metal deposits.

CHERT-HOSTED GOLD DEPOSITS

Deposit Description

Gold-bearing chert/quartzite units have been found in a number of places in the Hodgkinson Formation. These deposits are commonly hosted by chert-sulphide beds spatially associated with mafic volcanic lithologies of the Hodgkinson Province. The cherts are considered to have formed from chemically precipitated exhalites related to submarine volcanism. The chert and volcanics contain sulphide-bearing silica veins as fracture fills associated with folding. Up to 5% pyrite and arsenopyrite is disseminated in the chert and volcanics.

The deposits are typically stratabound to stratiform. Sulphides are disseminated uniformly in the host units or irregularly distributed in structurally controlled quartz-sulphide veins. A strong correlation with folds or fracture systems related to folding has been recognised with mineralisation commonly thickened and structurally remobilised to fold hinges.

Minerals present include native gold, pyrite, arsenopyrite, pyrrhotite, magnetite, haematite, quartz, and carbonates. Up to 5% pyrite and arsenopyrite is disseminated in the chert and associated mafic volcanics. Overall gold grades are generally low (<6g/t Au) and occasionally anomalous in base metals but veins grading of the order of 30g/t were mined at Mount Buchanan and Mount Madden. The highest gold contents (up to 30g/t) are associated with quartz veins/stockworks in fold noses and faults. The chert beds tend to form resistant ridges within the Hodgkinson Province. These deposits typically develop an iron and manganese rich gossan.

Known Deposits

Mount Madden, Mount Buchanan, Mount Jessop, Jessops Hill, Mount Bennett, Mount Eykin, Mammoth Bend, Freedom, Chert Ridge, Taipan Prospect, Brown Peak, Wavellite Hill, Seaview Hill, Starcke No. 1 Gold Field, Ginger Pig Prospect, Sporing Creek Prospect, and Taipan Prospect.

Age

Siluro-Devonian

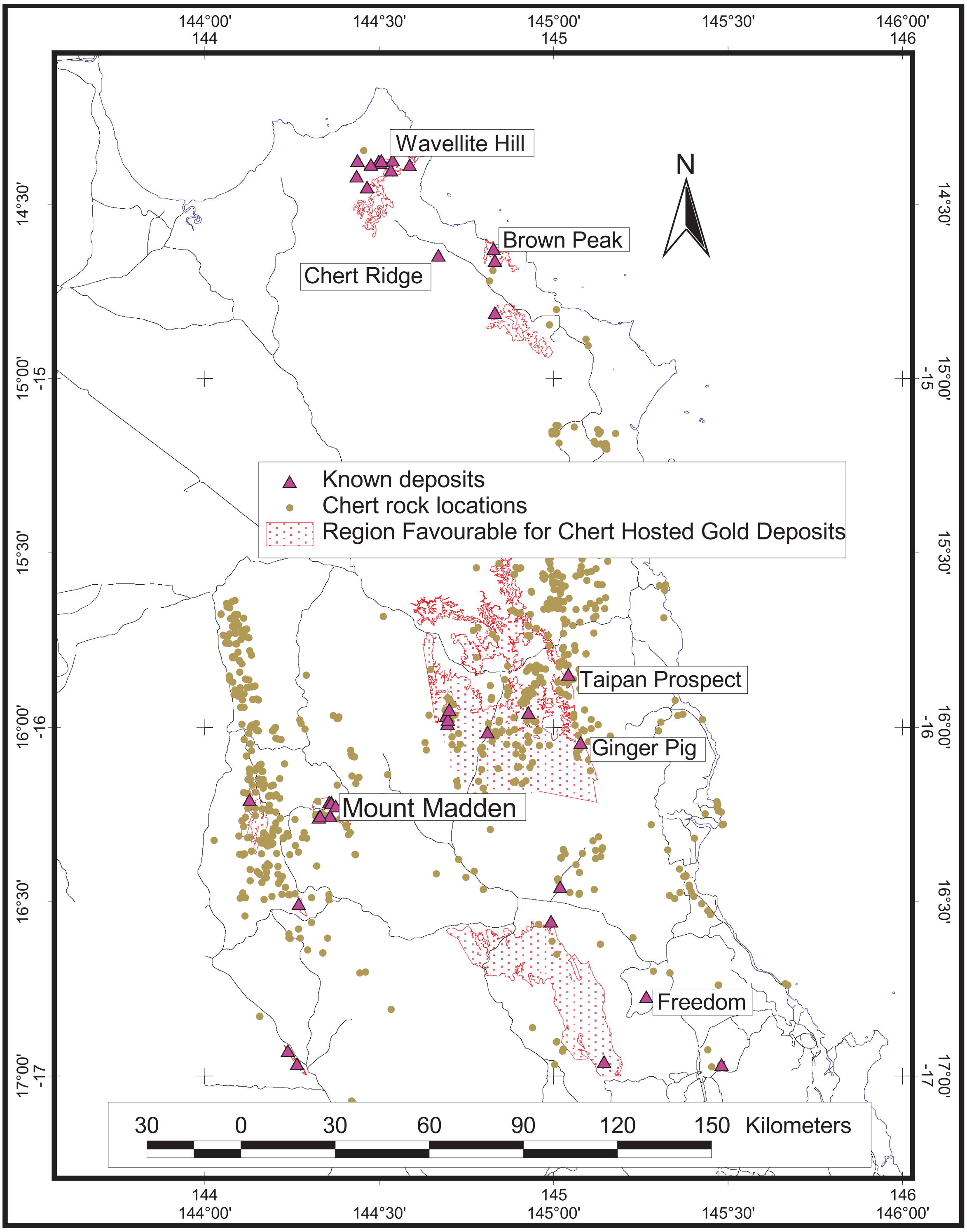


Figure 58. Distribution of known chert hosted gold deposits and and favourable regions for chert hosted gold deposits.

Assessment criteria

- Distribution of exhalative chert units in the Hodgkinson Formation, particularly those associated with or spatially close to mafic volcanics,
- distribution of known mineralisation, and
- spatial association with regional scale fold hinge zones.

Areas of Potential

The region along the Palmer River to the headwaters of Sandy Creek, encompassing the Mount Madden and Mount Bennett areas, contains interbedded chert and basic volcanics of the Hodgkinson Formation, adjacent to the contact with the Chillagoe Formation. Denaro & Ewers (1995) considered these cherts exhalative and defined this area as AuC3 and AuC1 on map 4. This area has a favourable resource potential for chert-hosted gold deposits.

Chert horizons are also present in the OK member south-west of Mount Madden. These cherts may be of an exhalative origin and therefore prospective for this deposit model.

A large area centred around the headwaters of the Laura River and West Normanby River drainage has a favourable resource potential. This extensive area comprises numerous north-north-west-trending chert ridges interbedded with arenite and argillite of the Hodgkinson Formation. Numerous gold prospects have been identified in the area defined by Denaro & Ewers (1995) as area AuC4 on map 4. These cherts are however commonly associated with mudstone and carbonaceous sedimentary rocks and are considered to be dominantly of a sedimentary origin in a distal setting within the Hodgkinson Basin. Their probable sedimentary origin down grades this areas potential.

In the Cocoa Creek area (also called Starke No. 1 Gold Field), widespread areas of haematitic brecciated chert assaying up to 4.74g/t Au have been located. The cherts are also anomalous in As, Sb, Se, and Ag. There is a permissive mineral resource potential for small chert-hosted gold deposits. Denaro & Ewers (1995) defined this area as AuC5 on map 4. This mineralisation may be more epithermal in character.

Gossanous, quartz-veined chert is common in the area enclosing the headwaters of the Starke River and hills to the south-east. In outcrop, the rocks comprise brecciated zones of quartz-veined chert fragments in a ferruginous pelitic matrix. Haematite staining is extensive. There is potential for small chert-hosted gold deposits in this region. Denaro & Ewers (1995) defined this area as AuC6 on map 4.

Numerous chert ridges, some of possible exhalative origin, crop out in the Hodgkinson Formation in the area south of Cape Bowen. Some of these ridges have been investigated as potential gold deposits (Chert Ridge prospect, Lagoon Prospect, and Brown's Peak). The ridges comprise chert and silicified metasedimentary rocks. Quartz stockwork veining and iron and manganese-rich gossans are common. The cherts and stockwork zones are slightly anomalous in gold and some of the cherts are phosphatic. There is potential for small chert-hosted gold deposits.

The area between Barrow Point and Bathurst Bay consists of shallow to moderately dipping, siliceous laminated sediments, pelitic sediments, and minor zones of stockworking and/or brecciation. Gold is generally more anomalous in the more altered lithologies. There is widespread evidence of sulphide mineralisation as fine to coarse-grained disseminations and as stratabound massive sulphide units up to a few metres thick. Creeks draining chert outcrops in the area carry traces of fine-grained alluvial gold.

Some of the siliceous sedimentary units are impregnated with carbon, and a discordant, carbon-rich, pipe-like zone with sulphides and quartz stockworks was intersected in one drillhole. Cambrian Resources applied an epithermal model to the prospects but Western Mining considered the prospects to be typical Hodgkinson Formation rocks with surface silicification. Denaro & Ewers (1995) defined this area as AuC7 on map 4 and classified it as having a permissive resource potential.

Abundant chert horizons in the Chillagoe Formation are commonly found in close spatial association with basaltic horizons. These scattered chert bodies have a limited potential to host gold mineralisation.

COAL

Within the study area, coal is known to occur in Carboniferous, Permian and Mesozoic sediments (Denaro & Shield, 1993).

Seams of coal up to 6m thick occur in the Permian Little River Coal Measures. It consists of thick bedded, medium to coarse, feldspathic and lithic sandstone, grey silty shale, with interbeds of dark impure limestone, fine sandstone, and thick, poor quality coal (Carr, 1975). They are steeply dipping and strongly deformed, faulted and slickensided. The coal is weathered in outcrop but reportedly improved at depth, although still containing a high proportion of clay. Rands (1893) concluded that the coal is of very inferior quality and that the steep dip of the seams would make them uneconomical to mine.

The Permian Normanby Formation (previously known as the Oaky Creek Coal Measures) contains at least 30m of shaly coal in outcrops along the West Normanby River. Jack (1879a,b) reported that the coal-bearing sediments extend over an area 9.6km long by 2.4km wide and up to 30m thick. Some good quality coal was found, but only in seams <75mm thick. In general, the coal is of poor quality and has a high ash yield (Carr, 1975; Wells, 1989).

The Little River Coal Measures and Normanby Formation were deposited in a number of grabens within a single larger basin which was affected by intermittent movements of the Palmerville Fault (Hawthorne, 1975) and Daintree Fault. This unstable depositional environment may account for the poor quality of these coals. Both the Little River Coal Measure and Normanby Formation appear to have little potential for economic development but still remain as a potential resource.

The Mount Mulligan Coal Measures are poorly exposed in a narrow strip below the Pepper Pot Sandstone cliffs (up to 300m high) which form the Mount Mulligan tableland. Four coal-bearing seams were recognised ranging from 0.4–2.1m in thickness and lensing out to the west and south. The coal is a high volatile, low rank, high ash coal within the bituminous range. The area has produced approximately 1Mt of coal which was mainly used for steam raising. Remaining reserves are unknown but according to Hawthorne (1975) are unlikely to warrant further mining.

The Bathurst Range deposit (MDL 253) is located near Bathurst Head at the northern extremity of the study area. This deposit contains an Indicated Resource of 45Mt of coking coal and is hosted by the Dalrymple Sandstone. This unit is a nonmarine, fluvial sedimentary sequence which ranges from 80–120m thick and consists of quartzose and quartzo-feldspathic sandstone, siltstone, mudstone, and coal. There is a significant resource of high quality coal in this area which is currently under evaluation. Further resources probably exist within the region.

ECOLITE SUBDUCTION (ES) - DIAMOND MODEL

Deposit Description

The classic deposit model for diamond exploration has been the kimberlite pipe and, more recently, the olivine bearing lamproite pipes discovered in Western Australia in 1977 (both are types of diatremes). These deposits are only found in Proterozoic terrains. The Cairns region contains few rocks of this age.

A second diamond model, the ES-diamond (eclogite-subduction) model, proposed by Barron & others (1994) to account for the scattered diamond occurrences found on the east coast of Australia, has the carbon source for diamond formation derived from subducting unconsolidated forearc sediments. Diamonds are formed during active (rapid) subduction of a slab of sediments which is up to a thousand degrees cooler than the surrounding mantle. The oceanic crust and anoxic sediments forming the slab transform according to the prograde facies trend of lawsonite blueschist-eclogite-coesite eclogite-diamond eclogite. The subducted slab is detached (by subduction displacement) and sampled much later by nephelinite or alkali basalt magmas which intersect the slab during their ascent to the surface where they form dykes and diatremes. Alternatively, the diamonds may be brought to the surface by tectonic excavation.

Diatreme breccias which may have sampled the detached slab have a complex form. Typically they consist of nested breccia bodies with an extrusive apron as well as internal pipe facies. The predominant breccia type is matrix-supported, with subrounded fragments, which locally exhibit crude layering, size grading, and other sedimentary structures.

Known Deposits

Scattered occurrences of diamonds have been reported from numerous areas within the Hodgkinson Province; Tom's Hollow, Mount McLean, Hoskin's Vent and Bull Hollow Prospects.

Age

Proterozoic to Cainozoic. Original ages equal the subduction event. Reset ages may be up to the age of diatreme emplacement or tectonic excavation.

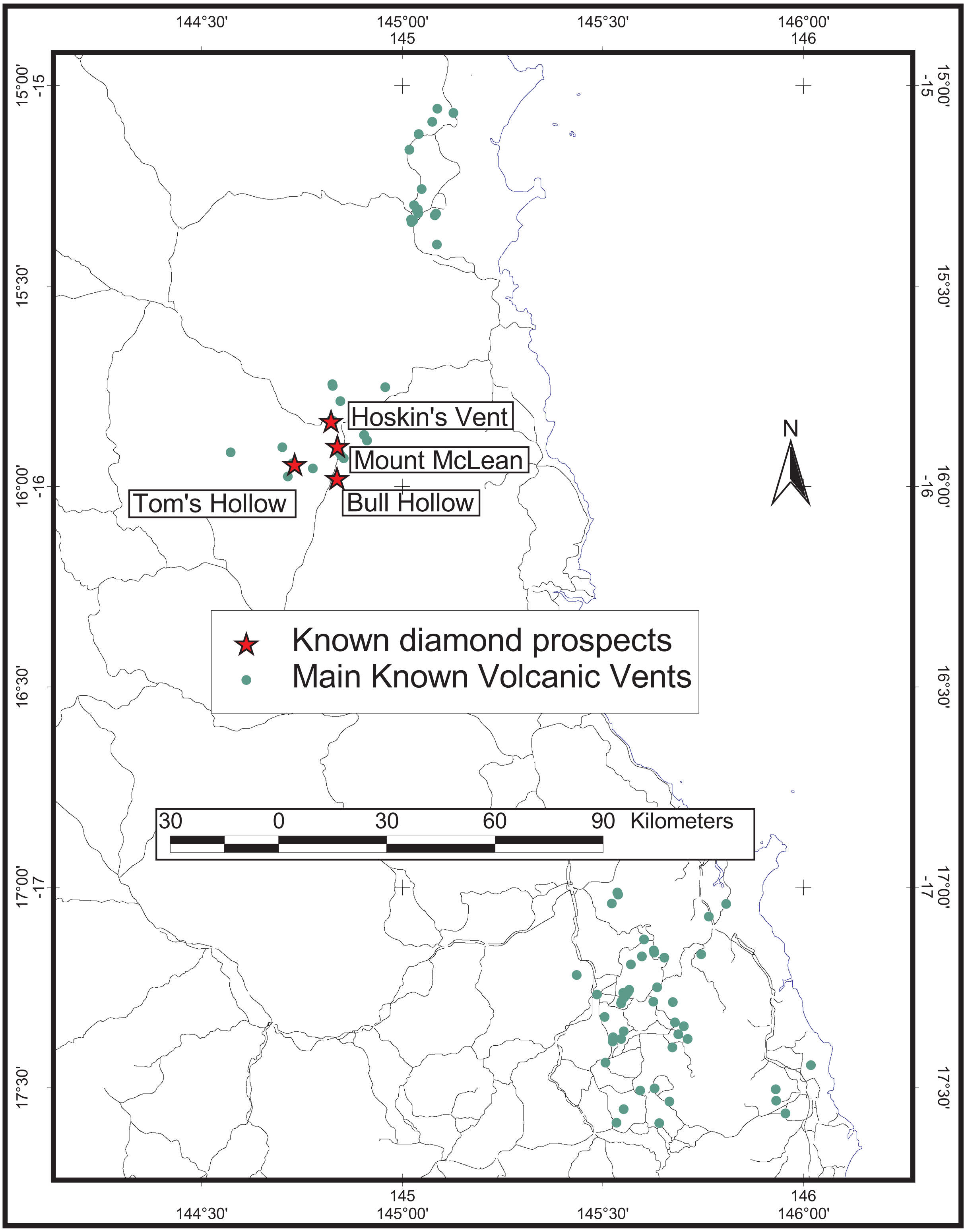


Figure 59. Distribution of known volcanic vents and diamond prospects.

Assessment criteria

- Presence of nephelinite or alkali basalt intrusions and diatremes,
- topographic depressions and craters,
- micro and macro diamonds in stream sediments and distribution of diamond finds, and
- may have associated corundum mineralisation.

Area of Potential

Rare diamonds have been recovered during alluvial mining in the East and West Normanby, Little Palmer and Laura Rivers. Sediments in streams draining the Lakeland Downs area are anomalous in 'diamond indicator' heavy minerals (zircon, picro-ilmenite, chrome diopside, orthopyroxene, brookite, phlogopite, olivine, pyrope garnet, corundum [including sapphire, and ruby] and chrome spinel). Exploration has centred on two maar structures (Tom's Hollow and Bull Hollow) which form topographic depressions in the McLean Basalt. These maars comprise bedded pyroclastics, agglomerate and alkaline (leucite) basalt and are infilled with lacustrine crater sediments. Microprobe analyses have indicated that the spinels and garnets are kimberlitic and that the chrome diopside is probably kimberlitic. Bulk sampling has failed to recover any diamonds from the area.

This region was classified by Denaro & Ewers (1995) as GsA1 (Map 4). There is a potential for discovery of deposits using ES-diamonds model.

Scattered diamond occurrences have been reported from alluvial mining of drainages from the Atherton Tableland. The presence of numerous maars in this region (Figure 59) may be coincidental but suggests that the area has a low potential for diamond deposits.

EPITHERMAL DEPOSITS

Deposit Description

The term epithermal gold deposits is used in this document to refer to all subtypes of this group, such as high sulphidation acid sulphate (quartz-alunite) deposits and low sulphidation adularia-sericite and alkalic (quartz-adularia) deposits.

Deposits described in this report as epithermal are those which have formed from hydrothermal process at high levels or at the surface of the crust; mineralisation taking place generally within 1 000m of the surface. Regional fracture systems, major normal faults, fractures related to doming, ring fracture zones, and joints are all favourable settings for epithermal mineralisation. These fracture systems hosting the epithermal system are commonly, but not necessarily, associated with large-scale volcanic collapse structures. An Island arc tectonic setting is also a fertile environment for this deposit model. Mineralisation commonly occurs in volcanic terranes with well differentiated, subaerial pyroclastic rocks and numerous, small subvolcanic intrusions.

The idealised epithermal system will be —

- related to faults generated during caldera formation
- display vein, stockwork, breccia, disseminated or replacement mineralisation styles
- have open space fill, crustiform, colliform bands, comb, breccia quartz textures
- gangue mineralogy will contain quartz (very fine grained/ chalcedonic/ opal), calcite, fluorite, pseudomorphs
- formed between 200–300°C (Lindgren (1933) suggests 50–200°C)
- involve a low salinity fluid
- common element association of Au, Ag, Hg, (As, Sb, Pb, Zn, Cu), Tr, Tl, U.

Veins are the most common ore host, although breccia zones, stockworks and fine-grained bedding replacement zones are present. Ore zones (ore shoots) bottom in either barren rock or pass downward into subeconomic zones containing base metal sulphides. Ore and associated minerals are deposited dominantly as open space filling with banded, crustiform, vuggy, drusy, colliform, and comb textures. Repeated cycles of mineral deposition are common. Gold and silver are the main economic minerals and occur along with anomalous concentrations of Hg, As, Sb, and, rarely, Tl, Se, and Te. The main ore minerals are native gold and silver, electrum, argentite and silver-bearing arsenic-antimony sulphosalts. Additional minerals which may be present include galena, sphalerite, chalcopyrite, enargite, cinnabar, stibnite, and tetrahedrite. Gangue minerals are mainly quartz and calcite, with lesser fluorite, barite, and pyrite; chlorite, haematite, dolomite, rhodonite, and rhodochrosite are less common. Silica occurs as quartz, opal, chalcedony, and cristobalite. Precious metals are generally associated with silicification.

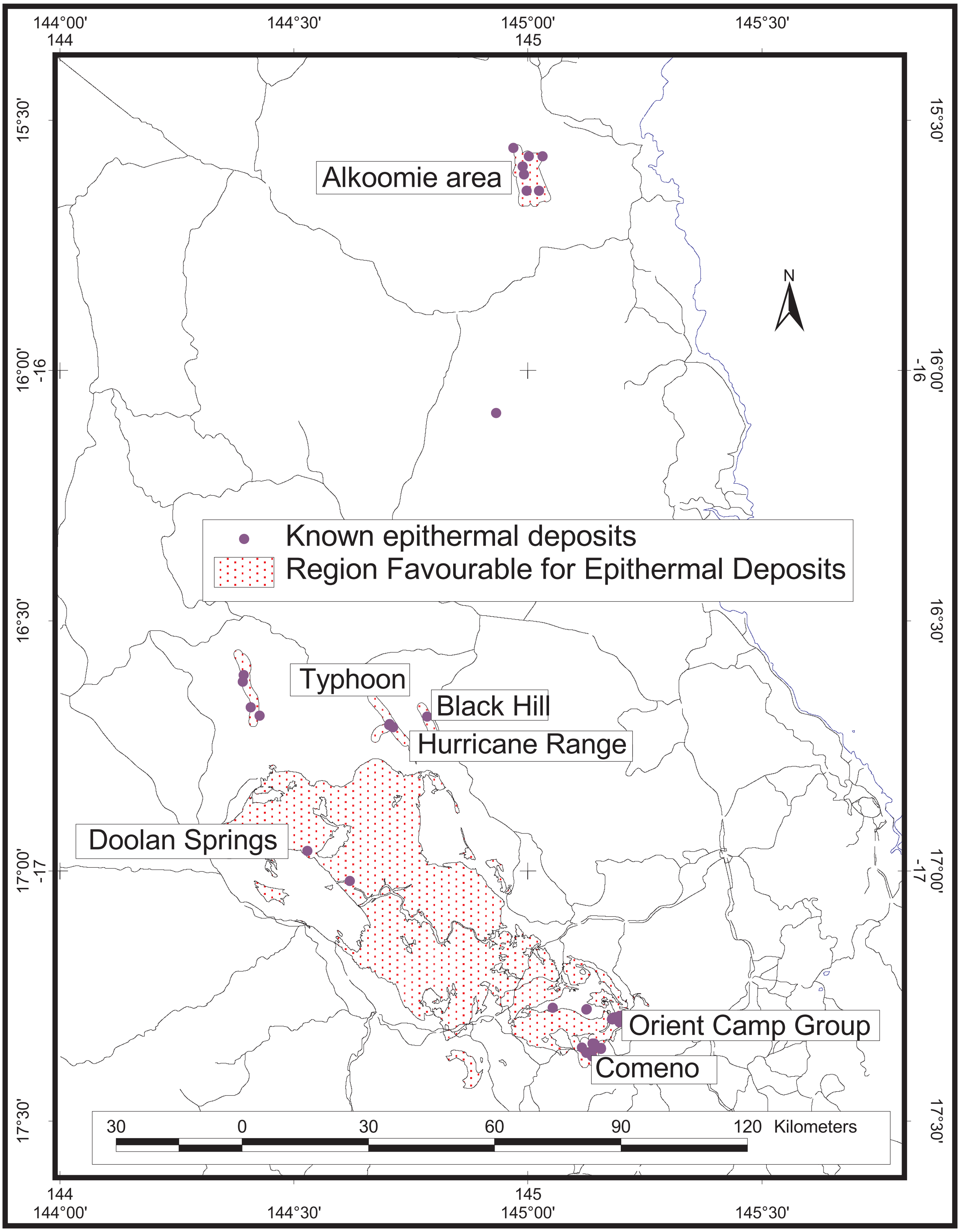


Figure 60. Distribution of known epithermal mineralisation and regions favourable for epithermal deposits.

The alteration assemblage typical of epithermal mineralisation is adularia, sericite, kaolinite, illite, smectite assemblage or a alunite, kaolinite, illite-smectite assemblage. Alteration zones include silicification, argillic, propylitic, and alunitic.

Epithermal deposits in north Queensland are of the low sulphidation quartz-adularia type, with banded chalcedonic and comb quartz exhibiting bladed pseudomorph textures, internal brecciation, and local concentrations of carbonate and sulphate minerals. Silicic, argillic, sericitic, and propylitic alteration are well developed, and advanced argillic alteration has been noted locally.

Known Deposits

Doolan Springs, Hurricane Range, Typhoon, Orient Camp East and West Groups, Black Hill, Comeno, East Leadingham?, Emily?, Watson's Tunnel, Weinert, Maneater Peak, and Six Mile Creek area.

Age

Can be any age. North Queensland examples are commonly hosted by Carboniferous to Permian volcanic and sedimentary terranes.

Assessment criteria

- Distribution of late Palaeozoic subvolcanic intrusions and associated volcanic/sedimentary sequences,
- appropriate structural control such as fracture systems, ring structures and faults, and
- known mineralisation and geochemical anomalies (*e.g.* Hg).

Areas of Potential

The Featherbed Volcanic Group as a whole appears poorly mineralised but the margins of this large caldera sequence do host some significant mineralisation systems such as the Orient Camp East and Orient Camp West group of mines (Figure 60). The whole of the caldera complex, but in particular the marginal ring structures, have a favourable mineral resource potential.

There is potential for small epithermal gold deposits in the Six Mile Creek area. Significant mineralisation occurs in a 2 200m long by 60m wide zone of quartz-limonite stockwork veining and brecciation in sheared and highly altered intermediate volcanics and sediments. The presence of a broad zone of mercury anomalism in this region suggests the presence of epithermal mineralisation which is possibly related to Permian granite intrusion. The recent paper of Davis, Lindsay & Hippertt (1996) suggests that granites have played a greater role in gold mineralisation within the West Normanby Gold Field, located approximately 50km to the south-west, and may be responsible for gold mineralisation in zones of high metamorphic grade Hodgkinson Formation sediments. The Six Mile Creek area may also be an expression of this spatial relationship.

HYDROTHERMAL DEPOSITS

Deposit Description

This classification is used to describe deposits formed from hydrothermal fluids of an uncertain origin which are structurally focused into vein deposits, commonly shear/fault zones. The veins display quartz textures which are not diagnostic of any formational environment. These deposits commonly fringe volcanic assemblages such as the Featherbed Volcanic unit but display no obvious features which would allow a more descriptive classification. They are typically hosted by metasedimentary rocks of the Hodgkinson Formation.

Narrow alteration haloes are commonly developed marginal to the veins consisting of predominantly silica-sericite but the larger deposits may also have developed chloritic alteration assemblages.

Base metal sulphides (the main focus of mining) and carbonate minerals are a common accessory within these veins. The veins are seldom persistent in strike length or depth.

Known Deposits

Tartana Hill area, Nightflower mine and surrounds, Torpy's Crooked Creek, Lappa junction area, Clohesy River Gold Mines Group, mines fringing the Nanyeta Volcanics, Siberia Lode (A1 lode), and Silver Valley.

Age

Palaeozoic

Assessment Criteria

- Proximity to regional or local structures,
- proximity to volcanic complexes and related structures,
- associated alluvial Au deposits, and
- distribution of historic workings.

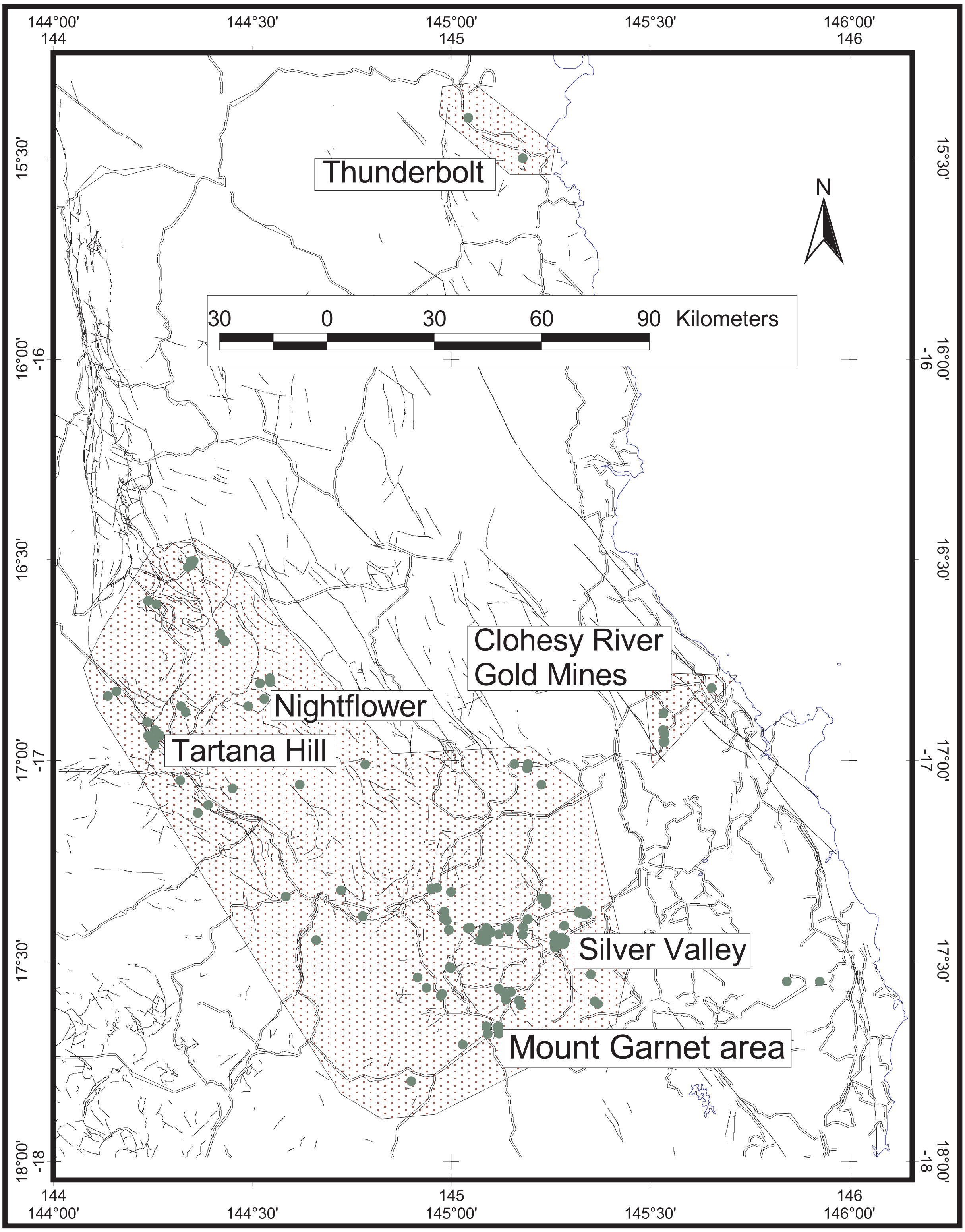


Figure 61. Distribution of known hydrothermal mineralisation (fluids from unknown source) and regions favourable for hydrothermal deposits.

Areas of Potential

The margins of the Featherbed Volcanic group and related structures have a favourable resource potential for this style of mineralisation.

The areas adjacent to the Palmerville fault south from Wrotham Park to Almaden has potential. This area is traversed by the Palmerville Fault and is also intruded by Permo-Carboniferous granites and the Featherbed Volcanic Complex which may have acted as fluid sources. The presence in this region of reactive lithologies (*e.g.* limestone) in the Chillagoe Formation has produced skarn styles of mineralisation from the emplacement of hydrothermal fluids.

The Clohesy River Gold Mines (Figure 61) have potential for small deposits of hydrothermal mineralisation to occur in the vicinity of the existing mines. The presence of Permo-Carboniferous intrusives, historic mining and fault/shear structures within the Hodgkinson Formation satisfy some of the assessment criteria.

Numerous small hydrothermal deposits are also present fringing the Nanyeta Volcanics in the Mount Garnet area. This area is considered to be a small cauldron subsidence structure (Branch, 1966) which when considered in conjunction with the presence of historic mineralisation identifies the area as having potential for further mineralisation.

The base metal deposits in the Silver Valley (Figure 61) are hosted by the Hodgkinson Formation within steeply dipping, shear/fault zones. These deposits may have been formed from fluids derived from the Glen Gordon Volcanics and channelled along related structures or represent the distal base-metal assemblage of fluids emanating from the O'Briens Creek Supersuite granites. This area has potential for further structurally controlled deposits.

The Siberia Lode (A1 lode) mineralisation is related to a large east-west trending fault (Kelly, 1976) which may be related to the formation of the Featherbed Cauldron. Fluids have been focused along this structure either from the volcanic sequence or later granite emplacement. This structure and similar faults in the area have potential for hydrothermal (base metal) deposits.

INTRUSIVE RELATED DEPOSITS

Intrusive related deposits includes all deposits derived from fluids emanating from granitic intrusives or fluids heated by these intrusions. Most mineralisation is either hosted within a granitic body or emplaced along or near its margins.

The relationship between Cu–Mo–Au with relatively oxidised granites and Sn with reduced granites has been known for some time. The majority of Sn mineralisation in the eastern Hodgkinson Province is associated with the strongly fractionated Cooktown Supersuite whilst the O'Briens Creek Supersuite is largely responsible for the extensive mineralisation in the Herberton area.

The work of Blevin & Chappell (1992) has identified that the degree of fractionation of a granite controls the likelihood of economic concentrations of ore elements in conjunction with its oxidation state. Anomalous concentrations of ore elements have previously been considered the result of the elemental concentration in the granites source rock. Crystal-melt fractionation drives granites to more felsic compositions, causing the build up of incompatible, and depletion of compatible elements (Blevin, 1994). Ore elements also respond to this process but are also a function of the magma mineralogy and oxidation state. Ore elements can commonly substitute for Fe and Ti in a variety of minerals or into sulphides so the behaviour of sulphur is another controlling factor (Blevin, 1994).

Knowledge of the granites oxidation and fractionation state along with sulphur activity and magma mineralogy can act as a guide to fertile granite suites but the formation of magmatic hydrothermal mineralisation requires the ore forming elements to be partitioned into a volatile phase and transported to a depositional site (Blevin, 1994). The volatile phase once formed is commonly focused in the apical regions of the magma chamber and is tapped via eruptive or structural activity to enable passage and precipitation of the contained ore elements.

Clarke (1995) observed that the Herberton Batholith contained separate granite phases broadly evolving from least fractionated through to highly silicic and fractionated granites enriched in incompatible elements. He concluded that the granite phases forming the Herberton Batholith represented sequential draughts from deeper magma cells which were evolving by crystal-liquid fractionation. The separate granite units are also commonly internally differentiated with highest temperature and least fractionated rock types in the core grading to lower temperature and fractionated rocks along the upper and outer margins (the reverse to the normal zoning pattern). Mineralised granites throughout the Cairns region commonly have this multiphase fractionated character.

The granites in the study area have been classified into their respective granite types, fractionation and oxidation states and displayed in Figure 62 against the distribution of tin and tungsten mineralisation.

Tin veins (Cornish style)

Deposit Description

These deposits are simple to complex quartz + cassiterite ± wolframite ± base metal sulphide fissure fillings or replacement lodes in or near felsic plutonic rocks. Deposit types include simple veins, sheeted veins, stockworks and breccia-hosted (disseminated) deposits. Mineralisation is typically fracture-controlled, with high fracture density and crosscutting fractures or vein systems indicating multiple fluid events.

There is a close spatial relation to multiphase granites. Specialised biotite and/or muscovite leucogranites and pelitic sediments generally host these mineral systems. Blevin & Chappell (1992) state that tin mineralisation (in granites of the eastern Australian Palaeozoic fold belts) is associated with both S- and I-type granites that are reduced and have undergone fractional crystallisation.

Tin vein deposits are extremely varied mineralogically. The main minerals that may be present include cassiterite, quartz, muscovite, biotite, K-felspar, topaz, tourmaline, fluorite, clays, wolframite, arsenopyrite, molybdenite, haematite, scheelite, beryl, galena, chalcopyrite, sphalerite, stannite, bismuthinite, carbonates, pyrite, pyrrhotite, haematite, lepidolite, zinnwaldite, tetrahedrite and silver minerals. Many deposits show an inner zone of cassiterite ± wolframite fringed with Pb, Zn, Cu and Ag sulphide minerals. This zonation is present at numerous localities throughout the Herberton Mineral Field.

Textures present may include brecciated bands, filled fissures, replacement textures and open cavities. Sericitisation (greisenisation) ± tourmalinisation is common adjacent to veins and granite contacts. Other alteration types include silicification, chloritisation, and haematisation. An idealised zonal alteration sequence might consist of quartz-tourmaline-topaz, quartz-tourmaline-sericite, quartz-sericite-chlorite, quartz-chlorite, chlorite (from closest to granite outwards). Iron-rich outcrops may form from weathering of tourmaline and/or chlorite. Deposits may form topographic highs where silicification is intense and/or extensive.

The lodes are generally associated with joints and fractures in the granite. Economic concentrations of tin tend to occur within or above the apices of granitic cusps and ridges. Mineralisation is generally fracture-controlled but localised controls may include variations in vein structure, lithologic and structural changes, vein intersections, dykes, and cross-faults. The cassiterite generally occurs in short pipe-like shoots or bunches. Mineralisation associated with regional fracture systems are common.

These vein systems are typical of mesozonal to hypabyssal plutons which have been emplaced at intermediate to shallow levels (cupolas, domes, and subvolcanic intrusions). They have commonly developed extensive greisen alteration halos. Extrusive rocks are generally absent, dykes and dyke swarms are however common. Most deposits are related to ilmenite series, S-type fractionated granites; some may occur in I- or mixed I/S-type provinces.

This deposit classification includes the numerous mineral assemblages used to subset the tin mineralisation in the Herberton area. These subsets were generally based on the alteration style developed such as chloritisation or tourmalinisation.

The Cairns region when compared with examples from the rest of the world contains numerous world class vein tin deposits (Figure 63). These deposits are all in the Herberton Tin field. The figures used are derived from grouping production for the mining centres throughout this region (data from Cox & Singer, 1992) and published resource information detailed in Appendix 3.

Several very large, low grade deposits occur in the Herberton Tin field which are currently well below economic but highlight the tin bearing potential of this region.

Known Deposits

Jeannie River Prospect, Cannibal Creek lodes, Cooktown Tin Field (Mount Amos, Mount Leswell and the Big Tableland), Herberton Mineral Field.

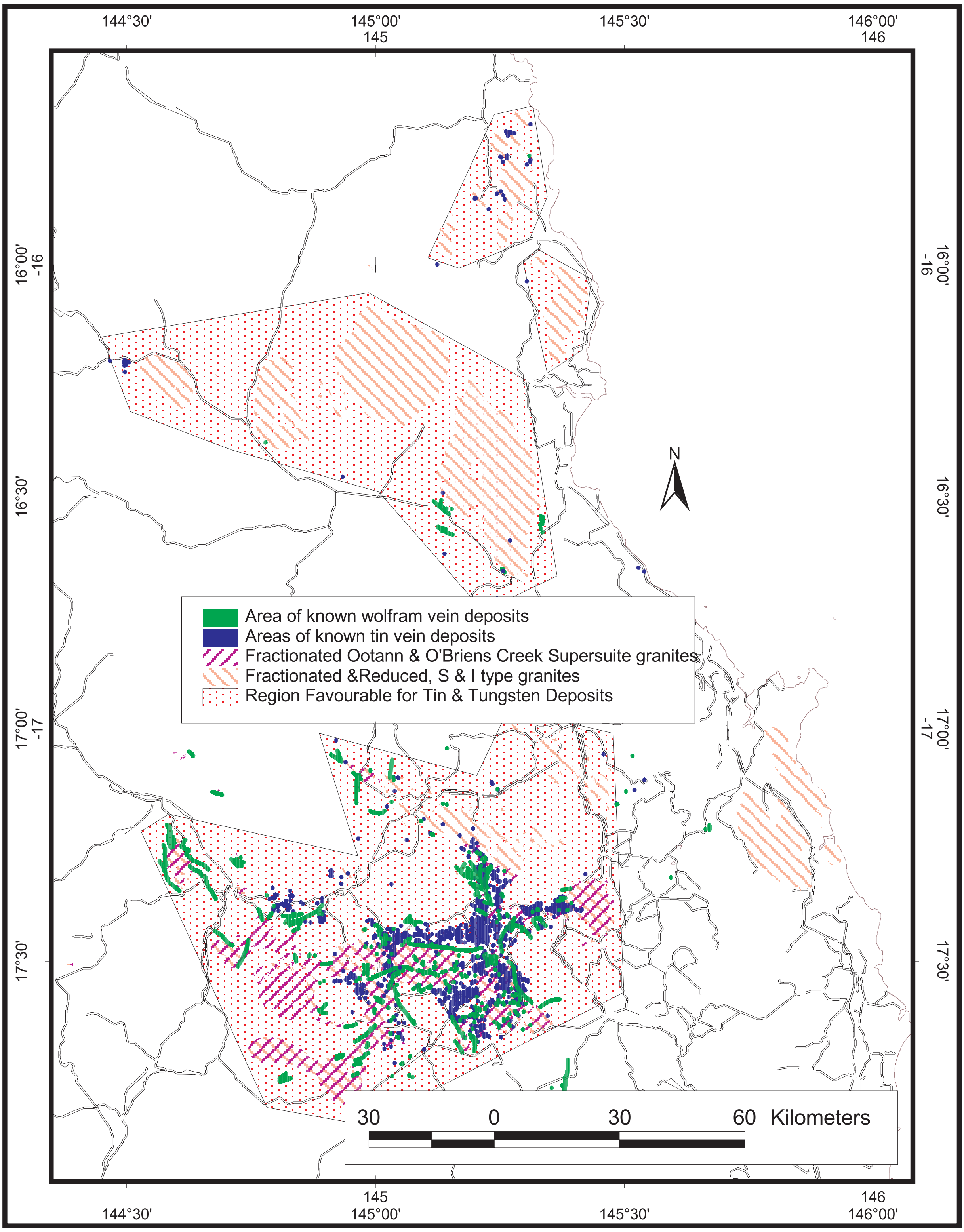


Figure 62. Distribution of known tin and tungsten vein deposits in the Herberton region and permissive resource potential regions.

Age

Palaeozoic and Mesozoic most common; may be any age.

Assessment criteria

- Fracture systems in and above the apical portions of fractionated, reduced S- and I-type granites,

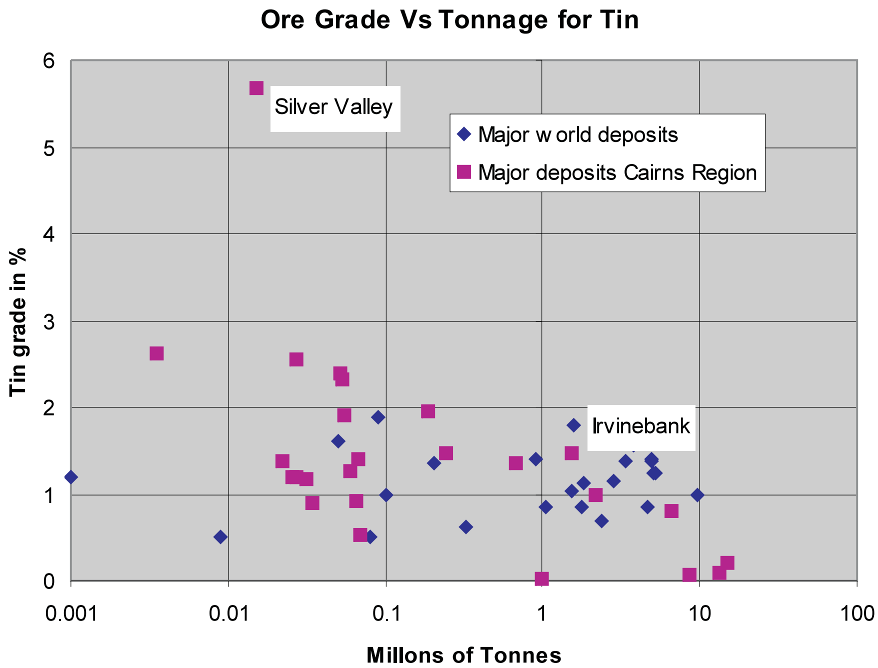


Figure 63. Grade-tonnage diagram for vein tin deposits in the Cairns region.

- distribution of known primary mineralisation and alluvial deposits, and
- most prospective areas may be where granite plutons are not exposed or are only partially unroofed.

Areas of Potential

Blevin & Chappell (1992) noted that the ore-element associations of granite-related ore deposits in nearly all eastern Australian Palaeozoic fold belts have tin mineralisation commonly associated with S- and I-type granites that have undergone crystal fractionation and are reduced. The distribution of these granites for the study is displayed in Figure 63 with the locations of known deposits.

A number of primary tin mineralisation styles are evident in the Cooktown Tin Field. These include sheeted quartz-tourmaline lodes and veins, greisen veins, greisen alteration zones and argillic alteration zones. Historically, the most important primary deposits were extensive greisen and argillic alteration zones on the margins of granite intrusions but quartz-tourmaline veins and lodes were also mined, notably at Mount Amos, Mount Leswell and the Big Tableland. These lode deposits would only be of interest to individual miners or small syndicates; greisen systems such as the Collingwood Prospect would be of more interest to companies. Whole rock geochemistry shows that the granites in the area are highly fractionated and contain relatively high SiO_2, K_2O, Rb, U, B, Cs and MO, low CaO and MgO, and a high Sn content (Bultitude & Champion, 1992).

Large areas in the Herberton Mineral Field are prospective for this deposit model. The abundance of historic mining activity and presence of fertile granite suites are favourable indicators for prospectivity. The distribution of these areas is displayed in Figure 62. The known mineralisation and fertile granite plutons, mainly O'Briens Creek Supersuite, form a large arcuate pattern fringing the south-eastern extremity of the Featherbed Volcanics.

Tungsten veins

Deposit Description

These deposits contain wolframite, scheelite, molybdenite, and minor base metal sulphides in quartz vein swarms in tensional fractures associated with epizonal felsic intrusions (monzogranite to granite stocks) intruding sandstone, shale and metamorphosed equivalents. Kwak(1986) suggests that the intrusive rocks are characterised by Na_2O/K_2O is 2.0–2.5, Fe_2O_3/FeO is low (0.3–0.6), Fe total/CaO is <1, and Rb/Sr is 0–4.0. Blevin & Chappell (1992) consider tungsten mineralisation (in granites of the eastern Australian Palaeozoic fold belts) can be associated with a variety of granite types with little dependence on the inferred magma redox state. The causative granitic plutons are commonly emplaced late in the tectonic cycle or anorogenic. These belts of granitic plutons are derived from remelting of continental crust and are emplaced into country rocks generally metamorphosed to greenschist facies (Cox & Singer, 1992).

Deposits comprise massive quartz (with minor vughs, parallel walls and local breccia) and swarms of parallel veins crosscutting granitic rock or sedimentary rocks near contacts. Minerals include wolframite, scheelite, molybdenite, bismuthinite, pyrite, pyrrhotite, arsenopyrite, bornite, chalcopyrite, cassiterite, beryl, and fluorite. Mineralisation tends to occur near igneous contacts and above irregularities in contacts (*e.g.* cupolas). Structural (fault) control is commonly necessary to focus the mineralising fluids.

Pervasive albitic alteration occurs in the deepest levels of mineralised systems. Pervasive to vein-controlled potassic alteration occurs at higher levels. In upper levels, vein selvedges comprise muscovite or zinnwaldite (greisen). Chloritisation and tourmalinisation are also common.

Known Deposits

Mount Carbine, Herberton Mineral Field which includes Wolfram Camp, Bamford Hill, Eight Mile, and Koorboora.

Age

Carboniferous to Permian.

Assessment criteria

- Contact zones associated with fractionated phases of the Ootann or O'Briens Creek Super Suite granites,
- distribution of known tungsten mineralisation, and
- fault systems close to known deposits or favourable intrusive units.

Areas of Potential

Areas of historic mining activity from Wolfram Camp through to Bamford Hill offer the potential for further mineralised targets, probably blind targets intruding the margins of the Featherbed Volcanic Group. The Mount Carbine deposit still contains unmined resources. Areas fringing the Mount Carbine Granite have a potential for discovery of further tungsten deposits.

The association of tungsten mineralisation with a variety of granite types precludes direct definition of prospective areas based on granite chemistry but in the Herberton-Chillagoe region the relationship between the major tungsten deposits with the felsic, fractionated and oxidised or reduced units of the Ootann and O'Briens Creek Super Suites focuses exploration on the distribution of these intrusives (Figure 62).

Tin greisen deposits

Deposit Description

Greisenisation is a high temperature (300–500°C) complex post-magmatic transformation of rock under the influence of acid late-fractionated melt, high in silica and volatile components. The process occurs close to or within the contact zone of an intrusive granite. These deposits are associated with specialised biotite and/or muscovite leucogranites (most commonly leucocratic S-types, but also A-types and leucocratic I-types). They commonly occur in fold-belts of thick sediments ± volcanic rocks deposited on stable cratonic shields or accreted margins.

Greisen lodes are located in or near cupolas and ridges developed on the roof or along the margins of granites and in associated breccia masses and dykes. Faults and fractures may be important ore controls. Granite textures may include miarolitic cavities, equigranular textures, aplitic textures and porphyritic textures. The granites generally are nonfoliated.

Related deposit types include disseminated cassiterite and cassiterite-bearing veinlets, sheeted veins, stockworks, lenses, pipes and breccia in greisenised granite and in country rock replacements (exogreisens). The most common deposit forms are disseminated cassiterite in massive greisen and quartz veins and stockworks. Pipes, lenses and tectonic breccia are less common. Mineralisation is generally fracture-controlled, with high fracture density and crosscutting fractures or vein systems indicating multiple events. An important parameter in the formation of large deposits appears to be a closed system in which the intruded rocks lack significant fracturing.

The intrusive rocks have Na_2O/K_2O = <1, low Fe_2O_3/FeO (<1.0, usually 0.5), Fe total/CaO high, and Rb/Sr = 2–85 (generally 5–10) (Kwak, 1986). Late specialised granites usually have >73% SiO_2 and >4% K_2O, and are depleted in CaO, TiO_2, MgO and total Fe. They are enriched in Sn, F, Rb, Li, Be, W, Mo, Pb, B, Nb, Cs, U, Th, Hf, Ta and most rare earth elements. They are depleted in Ni, Cu, C, Co, V, Sc, Sr, La and Ba. Geochemical exploration using As, F, and particularly B as pathfinder elements in the search for concealed mineralised systems has proved successful in the Cooktown region.

Distinctive accessory minerals include topaz, fluorite, tourmaline, and beryl. Other possible minerals include wolframite, albite, microcline, chlorite, arsenopyrite, pyrite, pyrrhotite, chalcopyrite, sphalerite, molybdenite, bismuth, bismuthinite and kaolinite. There is a general zonal development of cassiterite + molybdenite, cassiterite + molybdenite + arsenopyrite + beryl, wolframite + beryl + arsenopyrite + bismuthinite, Cu-Pb-Zn sulphides + sulphostannates, quartz veins ± fluorite, calcite, pyrite.

Massive greisen comprises quartz + muscovite + topaz ± fluorite ± tourmaline. Tourmalinisation, albitisation, potassic alteration, and hydrothermal-supergene kaolinisation may be locally prominent. Tourmaline can be ubiquitous as disseminations, concentrated or diffuse clots, or late fracture fillings. Greisen may form in any wallrock environment, producing exogreisens; typical assemblages are developed in aluminosilicates.

Greisen deposits are generally low-grade and consist of greisenised and argillised granite with disseminated cassiterite and cassiterite-bearing quartz-tourmaline veins and pods. In places, the granite is highly fractured or crushed. The disseminated deposits are enriched at the surface by leaching, and deep weathering of the greisenised granite has enabled sluicing to depths exceeding 30m (Martin, 1979). These residual deposits are commonly difficult to distinguish from overlying colluvial and alluvial deposits, and most sluicing operations were a combination of both types of deposits. The grade is erratic, but 0.9 kg/m^3 was a common average grade of cassiterite in the Cooktown Tin Field.

There is a gradational classification of deposits from a tin greisen deposit to greisen alteration developed around tin vein systems (Cornish type). They have a similar genetic setting with the exception that tin greisens are formed at deeper levels within the crust. This deeper crustal setting within a more closed system generates the pervasive massive greisen alteration and associated tin mineralisation typical of tin greisens instead of the more focused higher level tin vein deposits.

Known Deposits

Cooktown Tin Field (Collingwood, Mount Poverty, Daly's Face, Home Rule), China Camp, Herberton Mineral Field (Emuford area mainly), Bamford Hill, Captain Morgan, Eight Mile, Dingo Mountain.

Age

May be any age; tin mineralisation is temporally related to later stages of granite emplacement. In the Cairns region generally Carboniferous to Permian age.

Assessment criteria

- Fractionated reduced S and I type granites emplaced in a closed system,
- distribution of known primary mineralisation and alluvial deposits, and
- most prospective areas may be where granite plutons are not exposed or are only partially unroofed.

Areas of Potential

The Cooktown Tin Field has potential for small to medium-size tin greisen deposits. The known deposits are not massive greisens, as such, but are zones of vein-controlled greisenisation associated with the apical portions of S-type granites of the Cooktown Supersuite. These granites are highly fractionated and are geochemically suitable for the development of tin deposits. The most prospective areas for hard rock greisen deposits are where the granite is still capped by the Hodgkinson Formation.

The Herberton Mineral Field as a whole is prospective for these large low-grade systems. Areas of shallow emplacement of granites of the O'Briens Creek Supersuite into Hodgkinson

Formation metasedimentary rocks are particularly prospective.

The scattered mineral occurrences in the vicinity of Dingo Mountain have suggested that potential, although low, exists for the discovery of endogreisen systems in apical portions of granite plutons concealed by cover rocks of the Glen Gordon Volcanics (Morwood & Dash, 1996). Indications of such mineralisation may be small areas of greisen and/or minor vein style deposits in fractures above such endogreisen systems. This exploration model was used successfully to locate the Collingwood tin deposit, near Cooktown.

LATERITIC NICKEL

Deposit Description

These deposits are formed by the chemical weathering of ultramafic rocks, particularly peridotite, dunite, and serpentinised peridotite. The weathering products are commonly nickel-rich iron oxides but some deposits are predominantly Ni silicates.

These deposits are formed in areas with relatively high rates of chemical weathering (warm-humid climates) and low rates of physical erosion. The most favourable tectonic setting is convergent margins where oceanic crust has been obducted (ophiolites) and uplifted to expose the ultramafics to weathering.

The principal mineralogy is garnierite, poorly defined hydrous silicates, quartz, and goethite. The goethite commonly has a high nickel content. These minerals are developed in a red-brown pisolitic soils or silica-rich boxworks.

The Ni-laterite is commonly zoned — from top:

(1) Red, yellow, and brown limonitic soils (limonite zone);

(2) saprolites — continuous transition from soft saprolite below limonite zone, hard saprolite and saprolitized peridotite, to fresh peridotite. Boxwork of chalcedony and garnierite occurs near the bedrock-weathered rock.

The upper limonite zone typically contains 0.5–2% Ni in iron-oxides; lower saprolite and boxwork zone typically contains 2–4% Ni in hydrous silicates. The oxide and silicate ores are end members and most mineralisation contains some of both (Cox & Singer, 1992).

Known Deposits

Isolated slivers of serpentinite south of Mossman called Julatten, Cowley area, Sandalwood serpentinite.

Age

Precambrian to Tertiary parent rocks, typically Cainozoic weathering.

Assessment Criteria

- Presence of ultramafic rocks, and
- prolonged period of weathering in a tectonically stable region.

Areas of Potential

A small serpentinite sliver located near Julatten, south of Mossman, is the largest occurrence of suitable parent rock in the Hodgkinson Province to form a lateritic nickel deposit (Figure 64). The body is approximately nine kilometres long and 450m wide, and centred around grid reference 312663. Surface outcrop of the body varies between serpentinite, talc-carbonate schist, sphene–chlorite–epidote–albite schist and altered gabbro/dolerite.

Two diamond drill holes completed by Kennecott Exploration (Australia) Pty Ltd of 228.6m and 200.3m depth obtained a complete section across the body (Halliday, 1973). The drilling revealed that at 122m depth, the body was 137.2m wide. Petrographic study of drill core recovered from unoxidised sections of the body revealed that the serpentinite originally comprised peridotite and pyroxene–porphyritic peridotite. These rocks are of Permian or Triassic? Age and have been deeply weathered.

Anomalous concentrations of nickel were detected in the soil profile above this body. Nickel concentrations in 5 soil samples taken by Australian Ores and Minerals Ltd ranged from 1900–2500ppm nickel. These concentrations are greater than those in soil covering the Greenvale lateritic nickel deposit.

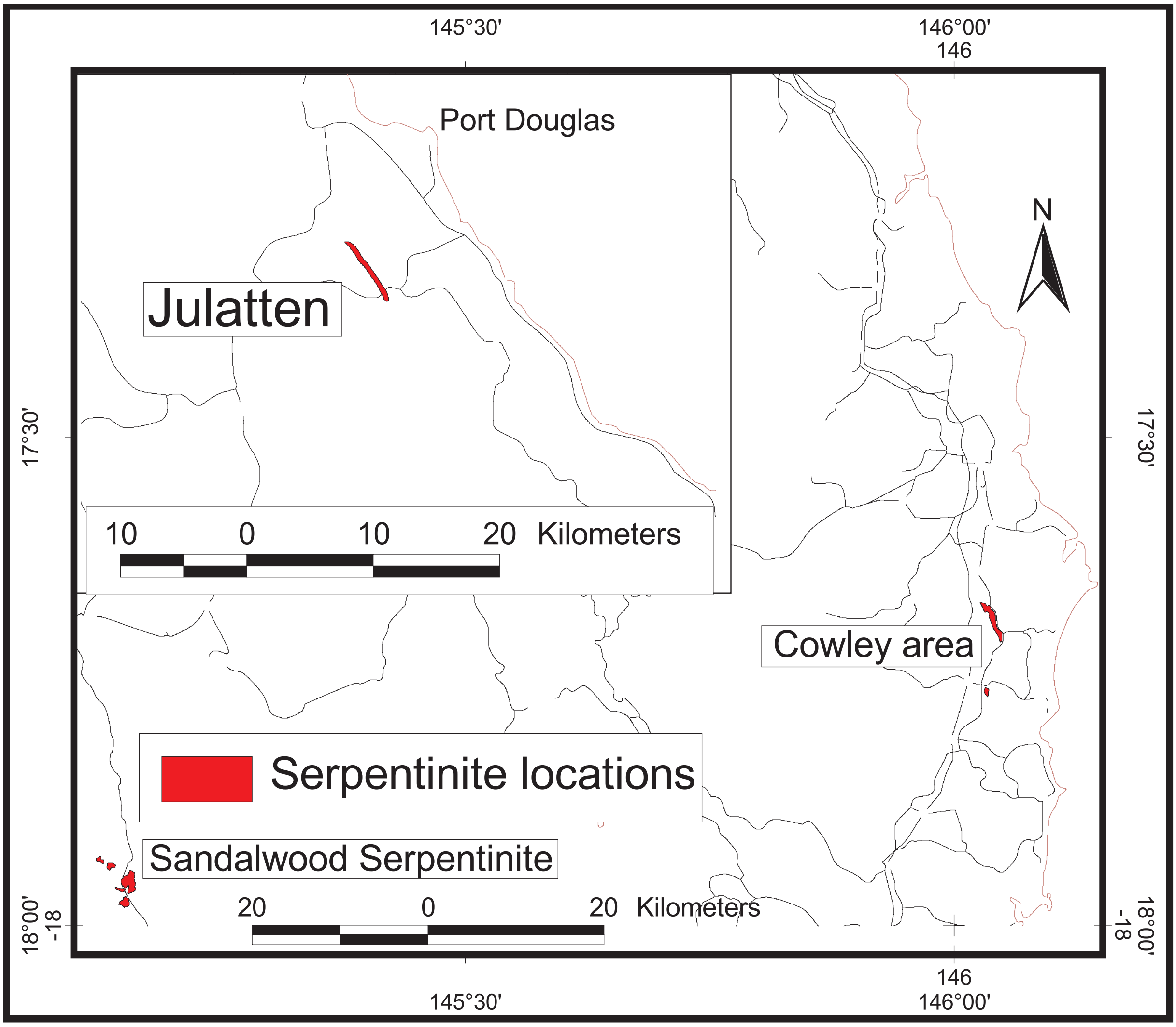


Figure 64. Distribution of known serpentinite rocks.

Further exploration by several companies failed to delineate an economic lateritic nickel orebody or nickel sulphide concentrations. Exploration has tested some of the region but potential still occurs in the area.

Small pods and lenses of serpentinite also occur in the Cowley area adjacent to the Russell–Mulgrave Shear Zone, in a quarry ~3.5km south-east of Silkwood. More information is included in the geology section of this report. The potential of these areas to have developed lateritic nickel concentrations is unknown but they are probably insignificant as a economic resource.

Outside the study area near Gunnawarra the Sandlewood Serpentinite crops out. This body of ultramafic rock has been investigated for its lateritic nickel potential with disappointing results.

LIMESTONE DEPOSITS

Deposit Description

These deposits are reefal carbonate accumulations formed within shallow water marine sedimentary sequences. Allocthonous blocks can also be dislodged from shallow water settings and fall down the reef margin into deeper water sequences.

They outcrop today as groups or belts of individual, limestone lenses within metasedimentary sequences. Extensive limestone outcrops occur in the Palaeozoic Chillagoe and Hodgkinson Formations.

Known Deposits

Melody Rocks, Mitchell River-Palmer River belt, Bolt Head, Chillagoe area, Fairchance quarry, White Gem, Ootann area.

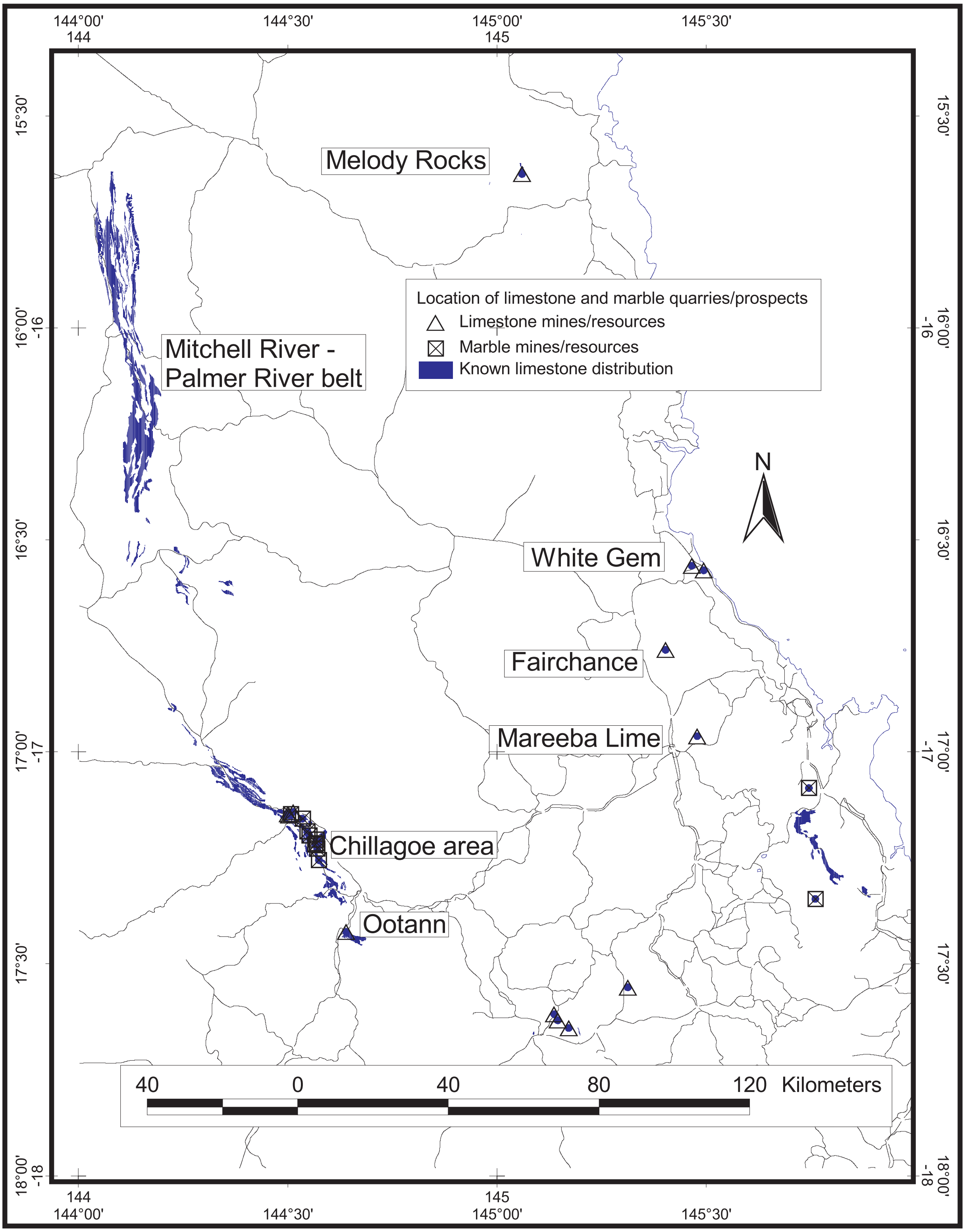


Figure 65. Distribution of limestone and limestone bearing units within the Cairns region and known limestone and marble operations.

Age

Palaeozoic.

Assessment criteria

- Presence of unaltered and unmineralised limestone outcrops.

Areas of Potential

Limestone has been mined from several areas in the study area (Figure 65). The prospective regions are easily defined as the outcropping distribution of limestone units in the Chillagoe Formation. Isolated limestone accumulations are also found throughout the Hodgkinson Formation, one such deposit is the Fairchance quarry east of Mareeba.

The Chillagoe Formation contains numerous large lenses of variably recrystallised limestone and marble in two main areas. A north trending belt up to 6km wide extending between the Mitchell and Palmer Rivers forms the northern group. The southern group of lenses crops out north and south of Chillagoe in a north-west-trending belt. Krosch (1990) estimated that ~1 500Mt of limestone is present in the northern belt. The southern belt has been mined in the past for flux in the Chillagoe smelters. More recently lime has been produced for chemical and agricultural purposes, and marble has been mined as a building stone (see Dimension stone section this report).

A 5km^2 roof pendant of Chillagoe Formation surrounded by Carboniferous granites is located at Ootann, 12km south of Almaden. Massive limestone is burnt for lime and coarsely crystalline marble is crushed for agricultural use. This area contains a large resource of limestone and marble within the current mine boundaries.

The Melody Rocks limestone deposit is a large body of high grade limestone north of Kings Plains Homestead. Limestone occurs as lenses (?bioherms) over a stratigraphic thickness of 700m and overall exposed strike length of 2700m. Eight bodies are of potential economic interest and five are of major significance. The five major lenses comprise approximately 900 000 t/vertical metre of limestone. Detailed geological mapping and core drilling indicated >100Mt of high to chemical grade limestone. Further resources exist in the vicinity of this deposit.

The Fairchance deposit has been sporadically quarried since the turn of the century, at which time the limestone was used in the Mount Molloy copper smelter. The deposit comprises a solitary bluff of pale grey recrystallised limestone. The Mareeba Lime deposit consists of small banded lenses which are totally recrystallised. The lenses range from a few centimetres to a few metres in width and extend discontinuously for up to 30m. The largest outcrop is approximately 20m in diameter. The only recorded production is 1 tonne in 1962, for testing purposes but there may have been some production in 1963. This deposit has very limited potential as a limestone resource.

The White Gem deposit is similar to the other limestone deposits at Fairchance and Mareeba Lime. The limestone is a white to light grey, granular recrystallised marble and conspicuously banded. A moderate resource of limestone remains in the area of the abandoned quarry.

MANGANESE DEPOSITS

Deposit Description

These deposits are lenses and stratiform bodies of manganese oxide and silicate deposited within volcanic-sedimentary sequences. Within the Hodgkinson Province they are commonly associated with metamorphosed mafic volcanics, chert, and greywacke sequences. These manganese accumulations are believed to have formed from sea-floor hot springs in a deep water environment. A high cobalt content is a typical elemental signature of these deposits. The deposits are commonly associated with basement structures which have acted as conduits for the mafic volcanics and hot-spring activity.

The deposits commonly have a thick capping of secondary Mn oxides produced from surface weathering processes. The main minerals present are psilomelane, pyrolusite, and rhodonite.

Known Deposits

Mount Martin, Victorian, Mount Sheridan, Trinity Beach Lode, and Mount Beauford.

Age

Palaeozoic with Cainozoic surficial enrichment.

Assessment criteria

- Proximity to known deposits,
- strong association with chert and/or mafic rocks, and

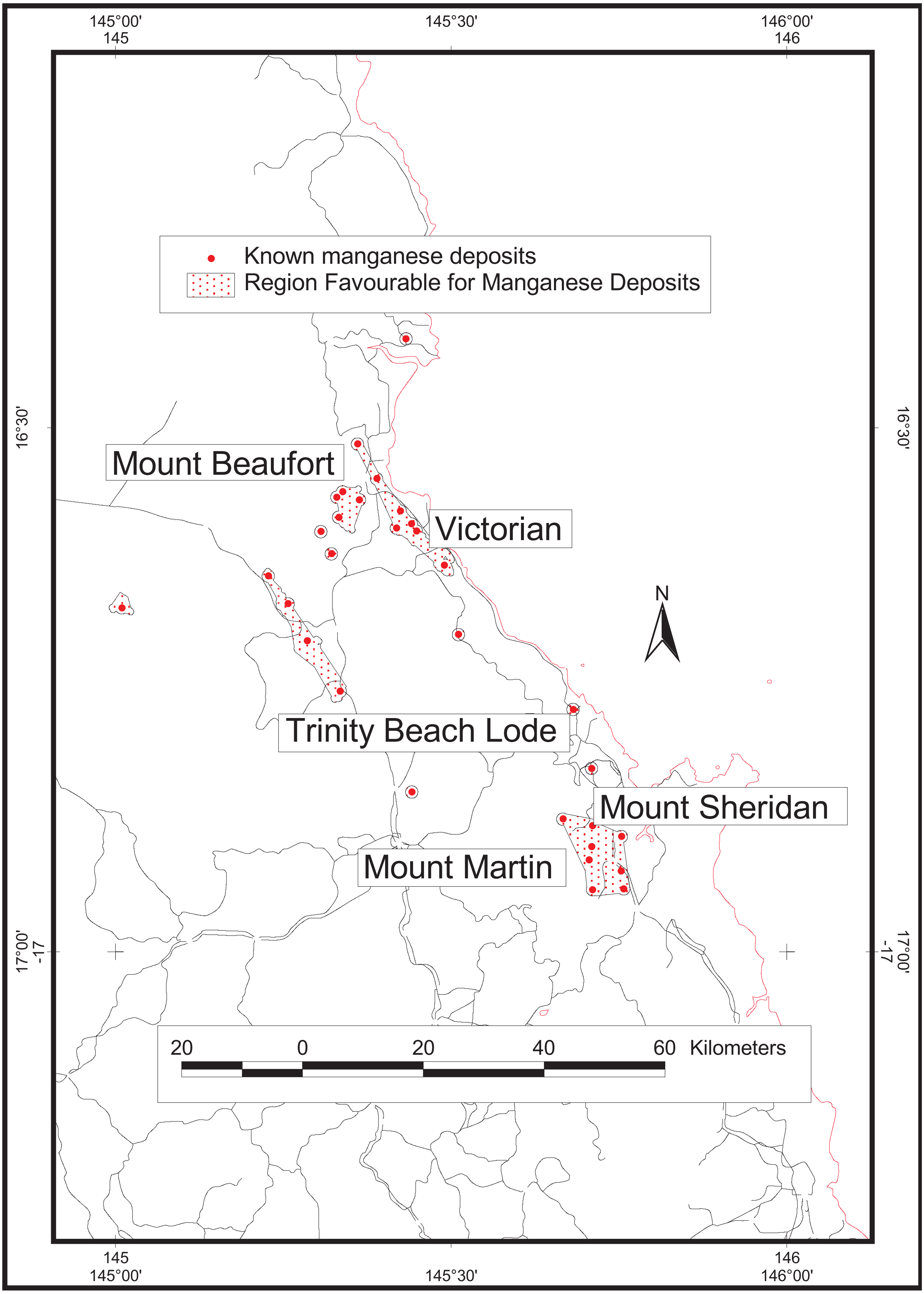


Figure 66. Distribution of known manganese deposits and favourable regions for manganese mineralisation.

- strong correlation to regional basement structures.

Areas of Potential

The region along the eastern margin of the Hodgkinson Province hosts most of the known Mn deposits (Figure 66). They form a general linear belt from the Gordonvale area north-west to Mossman. These deposits are all small and unlikely to form economic resources.

The association with chert and mafic volcanic lithologies restricts the distribution of potential areas of volcanogenic manganese development. The deep weathering in the tropical environment along the coastline has enriched most manganese deposits. The region has a favourable mineral resource potential for small pods of manganese mineralisation.

MESOTHERMAL DEPOSITS

Slate Belt Au quartz veins

Denaro & Ewers (1995) referred to this deposit model as Syntectonic Au-quartz and Au-Sb-quartz veins (Palmer type). This style of mineralisation has also been described as turbidite-hosted or shale-greywacke gold deposits.

Deposit Description

The veins occur as single, lenticular, *en echelon* and anastomosing (locally irregular) quartz veins which fill and are restricted to late brittle to brittle-ductile shear zones crosscutting previous deformations. Splays and spur veins are common. Within the Hodgkinson Province individual reefs may be >2m wide and several hundred metres long, strike between south to south-east (Figure 67) with subvertical to steep dips. The main quartz textures (buck, ribbon, breccia, and assimilation) are characteristic of the mesothermal environment, rare fine comb quartz is development within vughs. A laminated appearance to the quartz reefs due to the presence of graphitic selvedges is a characteristic feature. The laminated quartz is the result of incremental quartz deposition and multiple shear movement with a crack-seal process of formation. These reefs are restricted to the Hodgkinson Formation metasedimentary rocks and are both conformable and crosscutting to the dominant foliation.

The total sulphide content is generally low (<5%) and comprises pyrite, arsenopyrite, pyrrhotite and stibnite; base metal sulphides are present as accessory minerals only. The gold is typically of high fineness (+900) and occurs as small irregular masses and discrete grains in quartz and intermixed with pyrite and arsenopyrite. Grades mined averaged 30–60g/t Au. The best gold grades are commonly associated with the more laminated quartz material but massive quartz may also contain significant gold values. Gold is unevenly distributed and is generally concentrated in shoots associated with dilation zones, caused by changes in the faults strike direction, fault splays, rock competency variation due to lithologic changes, fault jogs, and intersection of other faults. Barren quartz commonly occurs along strike from economic ore shoots.

Narrow wall rock alteration comprising sericite ± carbonate ± pyrite ± chlorite selvedges are commonly developed, most veins show little alteration. Brecciated margins are common.

The veins probably formed from metamorphic fluids produced during devolatilisation of the sediment pile with fluids channelled to dilational sites in fault/shear zones (Phillips & Powell, 1992). Graphitic wall rock material appear to have controlled deposition of gold in some ore shoots. The presence of small vugh infill textures is possibly due to increased hydrostatic pressures generating favourable sites for crystal growth also producing wider bands of white more massive quartz.

In the Hodgkinson Gold Field, the calculated oxygen isotopic composition of the gold-bearing fluids is 10±2 per mil, which overlaps the fields for metamorphic and primary magmatic fluids (Golding & others, 1990). The calculated hydrogen isotopic composition for the hydrothermal fluid is -100±20 per mil at 300±50°C. Fluid inclusion studies, together with shear zone characteristics, indicate that the veins in the Hodgkinson Formation formed at 270–350°C (assuming a fluid pressure of ~1kbar).

In summary, Golding and others (1990) postulated that the veins were deposited during regional tectonism and channelled to dilational sites in shear zones. The stable isotopic characteristics of these mesothermal auriferous fluids mainly reflect extensive fluid-rock interaction, either at source or within fluid conduits.

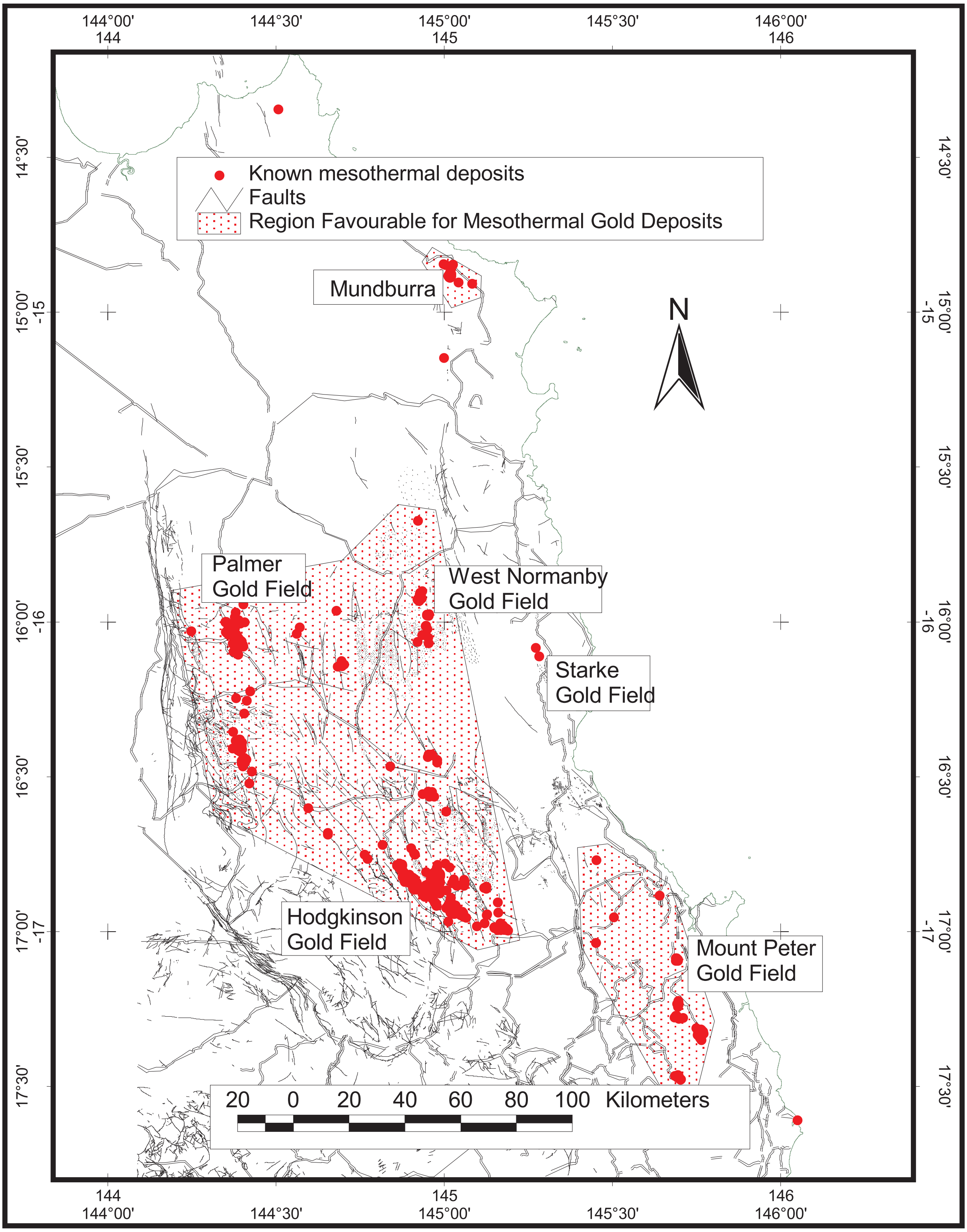


Figure 67. Distribution of known mesothermal mineralisation and regions favourable for mesothermal gold deposits.

Known Deposits

Hodgkinson Gold Field, Palmer Gold Field (includes Maytown and Groganville), Mount Peter Gold Field, Mulgrave Gold Field, Towalla area, West Normanby Gold Field, Starcke No. 1 and No. 2 Gold Fields.

Age

Host rocks Proterozoic to Devonian. Mineralisation age probably Carboniferous to Permian.

Morrison (1988) reported that alteration muscovite from veins in the Hodgkinson Gold

Field gave a K–Ar age of late Carboniferous. Peters (1987) suggested that the veins formed during Permian tectonism, following injection of dolerite dykes and sills and localised east-west shearing during the Early Carboniferous. The Permian tectonism was a melange-forming event, with localised high heat flows and intrusion of regional plutons (with associated Sn and W mineralisation).

Assessment criteria

- Presence of regional fault/shear zones,
- distribution of known deposits and gold fields, and
- distribution of alluvial placer gold deposits in the Hodgkinson Province.

Areas of Potential

The Hodgkinson Gold Field contains a permissive resource potential for small to medium sized deposits of this model. This gold field lies within a region which contains numerous north-west trending regional structures. Many of these structures are related to known mineralisation and form a regional *en echelon* structure. Regional structures further to the west such as the structure hosting the Atric prospect near the Mitchell River and the Kondaperinga Fault are highly prospective regions.

A broad band of country trending north-north-west to the Maytown area is known to contain numerous, small, discontinuous slate-belt Au-quartz veins. Despite extensive prospecting, no significant quartz reefs have been found. It has been the site of extensive historical and recent alluvial gold mining. There is potential for small to moderate sized Au-quartz veins. This region was classified by Denaro & Ewers (1995) as AuD1 & AuD2 (Map 4).

The area around the West Normanby Gold Field contains historic gold mining within a north-north-west-trending shear zone which follows the West Normanby River. The West Normanby River area is one of the few in the study area where lode gold mining is currently being carried out. The styles of mineralisation is consistent with this model of formation however Davis & others (1996) propose that the mineralisation has developed from emplacement of Permian Whypalla Supersuite granites. Either model requires a spatial relationship with regional structures and indicates that this region has potential for small Au-quartz veins. This region was classified by Denaro & Ewers (1995) as AuD4 (Map 4).

The Cocoa Creek area (Starcke No. 1 Gold Field) hosts Au-Sb-quartz veins trending north-north-west in the Hodgkinson Formation. Gold occurs associated with both quartz and stibnite. The mineralisation is relatively high level (certainly higher than that at Maytown and the West Normanby) but does not exhibit any significant epithermal characteristics (Denaro & Ewers, 1995). There is potential for discovery of small Au-Sb-quartz veins. This region was classified by Denaro & Ewers (1995) as AuD5 (Map 4).

The area around known gold mineralisation in the Starcke No. 2 Gold Field (Munburra) contains gold-quartz veins within steeply dipping, north-trending metasedimentary rocks of the Hodgkinson Formation (This region was classified by Denaro & Ewers (1995) as AuD6 (Map 4)). Extensive exploration in this region has to date not delineated any economic deposits. The best potential is in other areas of the field, particularly in the headwaters of Diggings Creek (Denaro & Ewers, 1995).

The small gold fields in the Cairns hinterland such as the Mount Peter Gold Field, Mulgrave Gold Field and Towalla area have potential for small Au-quartz vein systems. Most of these prospective areas have however been alienated by competing landuse classifications.

Quartz-Stibnite Veins

Deposit Description

These deposits typically consist of stibnite veins, pods, and lenses within quartz in or adjacent to brecciated or sheared fault zones. The vein deposits contain stibnite in pods, lenses, kidney forms, and pockets (locally). The veins tend to be discontinuous and display pinch and swell structures with mineralisation localised in dilational sites or tension gashes, cross fractures, and within shears crossing more competent lithologies. The stibnite may be massive or occur as streaks, grains and bladed aggregates in sheared or brecciated zones with quartz and calcite. Disseminated deposits contain streaks or grains of stibnite in host rock with or without stibnite vein deposits. Quartz textures are similar to those found in slate belt deposits detailed above.

Deposits in the Mitchell River and Dimbulah area also contain minor comb and saccharoidal quartz textures.

Veins are generally steeply dipping and range from a few tens of metres to kilometres in length. Buck and ribbon quartz, together with local comb quartz, are the main quartz types. Mineralogy comprises stibnite + quartz ± gold ± pyrite ± calcite. Stibnite typically constitutes 10–30% of the veins, often as lamellar bands in ribbon quartz. Other sulphides generally comprise <1% of deposits and include arsenopyrite ± cinnabar ± chalcopyrite ± sphalerite ± galena ± pyrrhotite. Other minerals may include visible gold, chlorite, Ag sulphosalts, and scheelite. Alteration commonly comprises proximal carbonate + quartz + sericite + pyrite ± arsenopyrite and peripheral chlorite + carbonate ± pyrite ± sericite.

The deposits near the Hodgkinson Gold Field tend to occur in separate domains from slate-belt style gold mineralisation, or on domainal boundaries which truncate these Au-quartz veins. It has been postulated that because antimony is highly mobile in the primary environment (Levinson, 1980) the domainal distribution of antimony mineralisation may not be due to a separate fluid source than the mesothermal gold mineralisation but rather to the dispersion of the antimony component away from zones of high strain to peripheral centres such as Northcote and Woodville which fringe the Hodgkinson Gold Field. The antimony-bearing veins are parallel to and spatially related to north-west-trending regional fault/shear structures (commonly D3h) and are associated with strong shearing in the country rock. Veins are commonly localised into secondary brittle shears associated with larger, often regionally significant, shear zones. The veins may be isolated into structural and lithological domains by post-mineralisation faulting.

Recent oxygen isotope studies by Golding & others (1990) and Peters & others (1990) indicate that the distinctive mainly heavier O^{18} values of antimony-gold-quartz relative to gold-quartz and barren quartz may reflect a more enriched fluid and/or deposition at a lower temperature from a fluid of similar oxygen isotopic composition. In either case, the differences support separate flow paths or a distinct and separate source for the antimony-bearing ore fluids. The truncation of gold quartz veins by those of stibnite bearing veins supports the idea of separate fluid sources and superimposed on, Au-quartz mineralisation. The similar quartz textures, structural controls, and spatial association with slate belt gold mineralisation however suggests the fluid source to be upward migrating metamorphic fluids.

In the Northcote area, quartz veins containing antimony and commonly gold are postulated to have been sourced from upwardly migrating metamorphic fluids generated during regional tectonism and deposited in favourable structural sites (Golding & others, 1990). They also consider that the antimony-gold-quartz veins formed from fluids following separate flow paths or are derived from a distinct and separate source than the fluids which formed the gold-quartz veins.

Stibnite bearing quartz lodes in the Herberton area are commonly developed in fractures associated with the Carrington Fault system (Clarke, 1995). These deposits are enclosed by an inner zone of topaz-quartz alteration and an outer sericitic alteration zone. This mineralisation is related to granite plutonism.

Known Deposits

Northcote, Woodville, Mitchell River Antimony mines (Retina), Uncle Sandy (Stake No. 2 Gold Field), Cocoa Creek (Starke No. 1 Gold Field), Groganville-Saint George River area, Six Mile workings, Belfast Hill, Zig Zag, and Black Bess.

Age

Host rocks Palaeozoic. Mineralisation younger than late Carboniferous.

Assessment Criteria

- Proximity to fluid channels such as faults and shears,
- presence of historic antimony production,
- north-west trending regional structures within Hodgkinson Formation metasedimentary rocks, and
- domainal association with mesothermal Au mineralisation.

Areas of Potential

Within the study area there is a strong linear zonation of known stibnite mineralisation

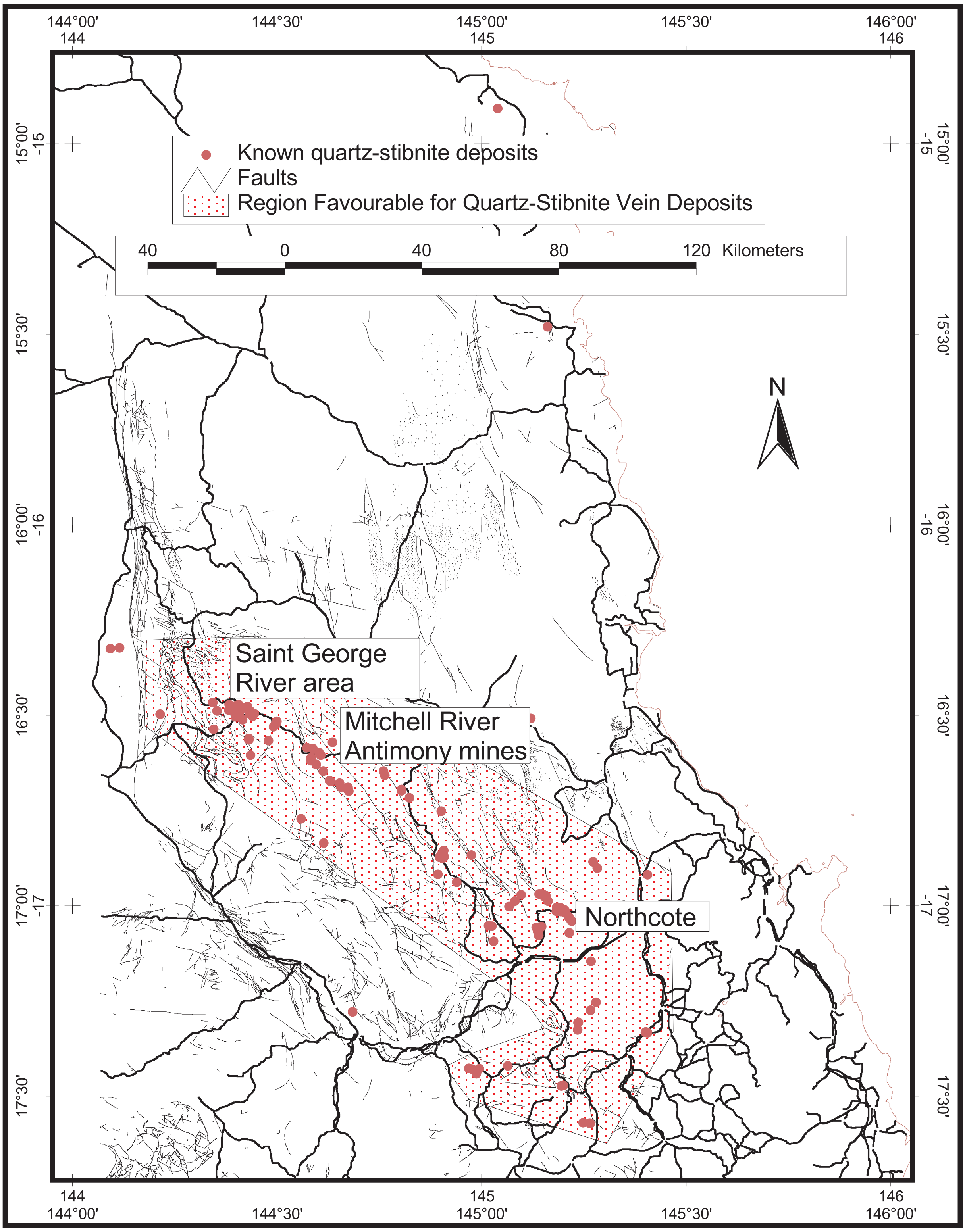


Figure 68. Distribution of known quartz-stibnite deposits and regions favourable for hosting quartz-stibnite deposits.

which trends from the Saint George River antimony mines south-east through the Mitchell River Antimony mines to the Woodville and Northcote areas. The structures hosting this mineralisation form a large scale *en echelon* structure trending north-westerly. Further antimony deposits occur to the south-east along this trend but are more widely separated. This region has potential for the discovery of further antimony deposits.

Antimony mineralisation occurs in gold-bearing quartz veins in a north-north-east-trending belt of acid to intermediate volcanics and intercalated sediments of the Normanby Formation in the Six Mile area (This region was classified by Denaro & Ewers (1995) as SbA2 (Map 4)). Stibnite occurs in small, discontinuous lenses which grade about 38–60% Sb. Gold contents are generally low in the stibnite-rich quartz. There is potential for small Sb-Au-quartz veins but they are unlikely to be economic.

The area extending from the Cocoa Creek workings to the Uncle Sandy mine contains Sb-Au-quartz veins hosted by Hodgkinson Formation. There is potential for small Sb-Au-quartz veins in this area. The region was classified by Denaro & Ewers (1995) as SbA3 & SbA4 (Map 4).

MOLYBDENUM AND BISMUTH

Molybdenum and bismuth are common accessory minerals to other deposit models such as tin vein or porphyry deposits. Traces of molybdenite (± bismuth minerals) occur in quartz, quartz-wolframite and quartz-cassiterite veins. In most cases, mineralisation is related to late Palaeozoic granitic intrusions.

Trace amounts of molybdenum are reported from several areas within the study area. The main centres of mining for molybdenum and bismuth were Wolfram Camp, Bamford Hill, Captain Morgan, Eight Mile, and The Glen area (north of Mount Garnet).

Blevin & Chappell (1992) have found the molybdenum mineralisation (in granites of the eastern Australian Palaeozoic fold belts) is associated with moderate to highly fractionated magnetite and/or sphene bearing, oxidised, intermediate I-type granites.

PLACER DEPOSITS

General Description

Placer deposits are formed by the "concentration of denser minerals by hydraulic mechanisms" (Force, 1991). This definition is narrower than that usually applied and would exclude eluvial and some colluvial deposits which are usually included among placers. A better definition is that of Dyson's (1990) "a placer is a deposit of residual or detrital mineral grains in which a heavy mineral of economic importance has been concentrated by a mechanical agent". This definition emphasises the economic significance and includes all deposits that form from geomorphic processes.

Placers can accumulate *in situ* (eluvial), in a moving solid medium (colluvial), moving water (fluvial, marine), wind (aeolian), and ice (glacial) or a combination of these.

Few placers exploited today are the product of modern processes, these have generally been exhausted from past mining conducted by armies of individuals and small syndicates. Most currently mined placer deposits are the products of previous geomorphic cycles and can range from surface exposures of buried alluvium (deep leads), palaeoplacer deposits or topographically elevated deposits.

Significant placer deposits, particularly gold, are generally associated with braided streams and distal fans (Day & Fletcher, 1991). Recycling is an important process in enriching concentrates. Falling base levels result in reworking of previously concentrated minerals. This process also moves authentic gold nuggets which form in eluvial deposits and soil profiles into the active alluvial environment.

Placer Gold

Deposit Description

This classification includes alluvium, eluvial, colluvial, perched alluvial gold concentrations and deep lead gold deposits.

Placer gold deposits are related to deeply weathered terranes which host primary gold mineralisation. These terranes have moderately incised stream valleys containing various types of alluvial deposits. The gold tends to accumulate in the high energy alluvial environment where gradients flatten and river velocities lessen, for example, at the inside of meanders, below rapids and falls, beneath boulders, and in vegetation mats.

In many placer deposits auriferous alluvium (particularly gold) is concentrated at the bedrock sediment interface. Mertie (1940) explained this feature as the result of erosion of the material from its source and transportation in the active juvenile portions of the river system. Gradually the gold migrates down through the active sediments (due to greater specific gravity) to the basal zone during transportation and is deposited in the basal portion of the alluvial system where the energy level is not sufficient to rework it. He termed this zone the critical zone and it occurs between the headwater stretch of intermittent basal alluvium movement and the downstream stretch of no movement of basal alluvium. This critical zone migrates upstream as the system matures and erosion progresses backward into its divide. In this model the most distal alluvial gold is the first preserved. This is an ideal model which may be modified if the system undergoes rejuvenation by a change in base level or flood activity etc.

This bedrock concentration of gold was considered by Tuck (1968) to mark the bottom of the valley when the stream reached a mature stage and ceased to dominantly downcut and began to instead cut laterally. He also stated that, if gold is available to the system throughout its erosion history, a narrow rich channel of gold would form, fringed by lower grade concentrations.

If, however, only a narrow high-grade channel is found in a broad valley, it would appear that there was a source of gold only during the youthful stage of the river's evolution. Deposits in the study area vary from narrow gold concentrations (pay streaks) on or near bedrock in narrow valleys to zones or layers of sparsely disseminated, very fine-grained gold in flood plain deposits.

Gold concentrations also occur in gravel deposits above clay layers that constrain the downward migration of gold particles. These horizons were often called false bottoms by early miners.

Grain size commonly decreases with distance from source. Tuck (1968) considered that commercial gold placer deposits have not travelled far from their source. He states that horizontal movement of gold appears to be related to the vertical distance that the gold has travelled during erosion. For example, 1.5km of vertical erosion which has liberated coarse gold at the beginning of this cycle would cause the gold to travel no more than 3-4.5km horizontally. Emery & Noakes (1968) and MacDonald (1983) suggest that the median distance at which economic placer deposits of coarse gold can form is less than 15km from the primary source. Some gold in placer deposits may be contributed to by chemical migration and accretionary processes.

The gold in placer deposits may be accompanied by tin, heavy mineral sands or platinum group alloys (rare). Alluvial gold concentrations can be preserved below deeper barren alluvium or volcanic rocks forming deep lead deposits. The capping rock is commonly basaltic lavas emplaced during the Mesozoic-Cainozoic Era preserving the palaeodrainage systems.

Known Deposits

Alluvial and eluvial gold shedding from lode deposits have been mined in many areas. Production has come from the Jimmy Ah Chee's Tableland, Palmer, West Normanby, Starcke Nos. 1 and 2, Mulgrave, Russell River (Boonjie Terraces), and Jordan Gold Fields. Colours of gold have been reported from alluvium in many rivers and major creeks draining the Hodgkinson Province.

Age

Tertiary to Holocene

Assessment Criteria

- Within ~15km of primary gold deposit or areas with the potential to host a primary gold deposit,
- active drainage system or palaeodrainage systems,
- areas previously worked for alluvial gold, and
- basaltic lava flows, areas of deep alluvium adjacent to areas of known gold mineralisation, and abandoned river channels.

Areas of Potential

Alluvial gold has been produced from numerous drainages within the Cairns region. More than 240 alluvial gold deposits have been recorded for the study area. The majority of these fall into the Palmer River catchment. Figure 69 displays the main drainages historically worked for alluvial gold and the location of reef gold mines within the study area.

Many of these historically worked placer deposits have been reworked profitably by the use of bulk earth moving methods and application of improved concentration

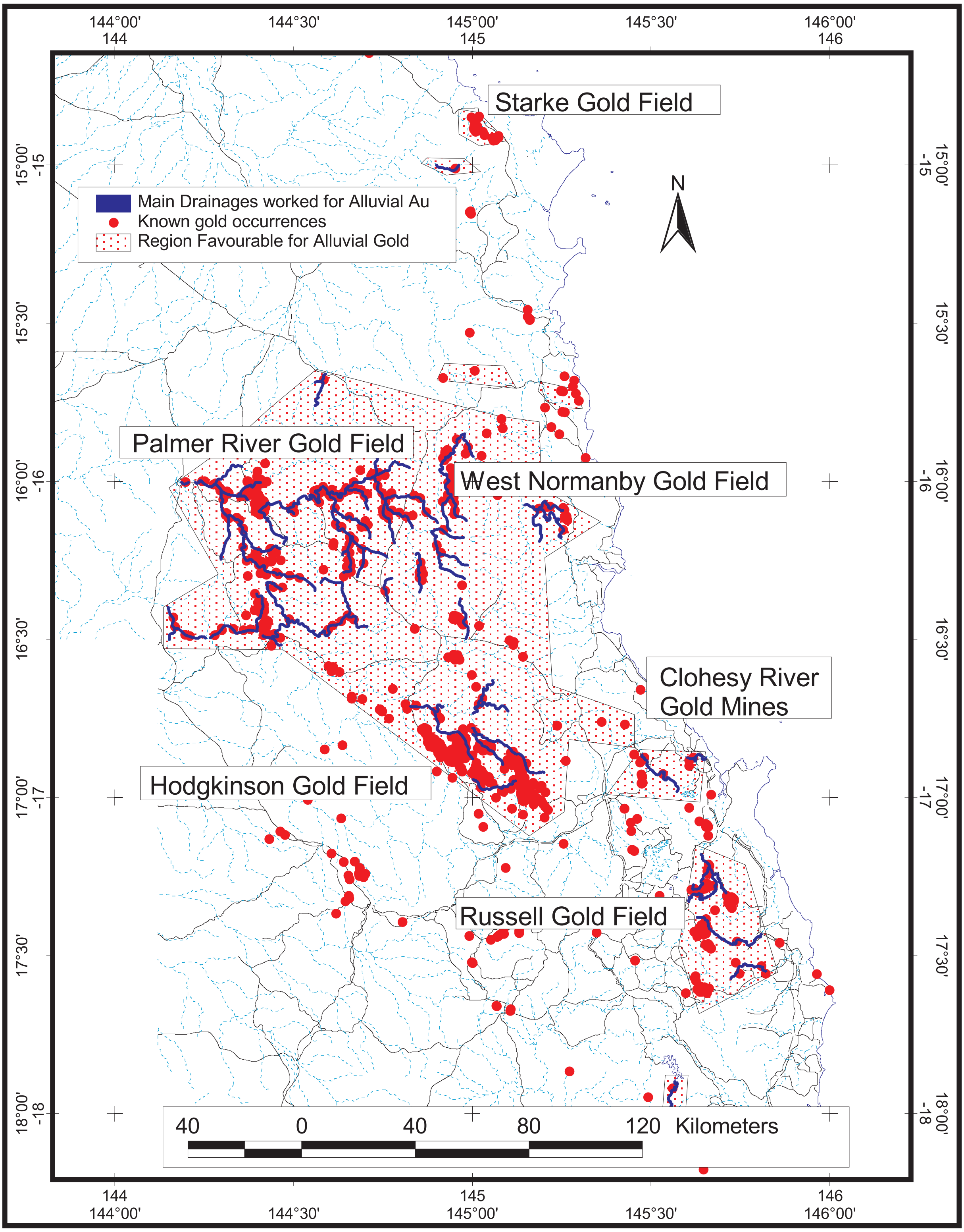


Figure 69. Distribution of known alluvial and hard rock occurrences and regions favourable for alluvial gold deposits.

techniques. The use of bulk mining methods has enabled much lower grade alluvium once considered uneconomic to be profitably worked *e.g.* Palmer River region.

Changes in material handling in the future may continue to lower the cut-off gold grade and extend the distribution of economic alluvial gold deposits from those already worked. Alluvium fringing these historic centres of alluvial gold production therefore have a higher mineral resource potential.

The proximity to primary gold bearing mineralisation is essential for the formation of an alluvial resource. For this reason alluvium present in drainages around primary gold deposits should also be considered to have a higher mineral resource potential.

The stretch of the Palmer River upstream from its junction with the Mitchell River, including its tributaries, and the upper reaches of the North Palmer River have a potential for small placer gold deposits. Small-scale mining has recently been conducted in the Palmer, North Palmer, South Palmer and Little Palmer Rivers areas. The Palmer and North Palmer Rivers in the Maytown area, as well as Chinky Creek in the Conglomerate Range are currently being mined at a number of locations, particularly along small gullies draining the old lode workings.

Deep lead gold deposits are present in the basal sediments of the Laura Basin to the north of Maytown. These deposits have been worked from adits during the peak of mining in this region, for example the Independent mine. There has been no study or exploration of these deposits but it is probable that further deep lead gold deposits occur in the region.

The West Normanby and Granite Normanby Rivers have potential for small alluvial gold deposits. There is a permissive resource potential for small alluvial placer gold deposits in the Munburra area (recorded as Area AuK13, map 4 by Denaro & Ewers, 1995).

The areas fringing the known deposits of the Russell River Gold Field contain subeconomic deep lead gold resources. Areas immediately west and north of these deposits have potential for deep lead Au deposits. The modern alluvium in the river systems draining the Russell River Gold Field are anomalous in gold. These areas also have a favourable resource potential.

The Herberton Deep lead was reported to have contained trace amounts of gold. It is considered to have no potential as a deep lead gold deposit but gold may be produced as a coproduct if tin mining were to ever recommence.

Placer Tin

Deposit Description

Cassiterite and associated heavy minerals occur as silt- to cobble-sized nuggets concentrated by the hydraulics of running water in modern drainage systems. This deposit classification includes alluvial, eluvial, colluvial, perched alluvial tin concentrations and deep lead tin deposits.

Concentrations generally occur in moderate to high-level alluvium, where stream gradients lie within the critical range for deposition of cassiterite (where stream velocity is sufficient to result in good gravity separation but not enough so that the channel is swept clean). These alluvial accumulations are occasionally preserved by the emplacement of basalt flows along the stream channels forming deep lead deposits. Deep lead deposits can also form when stream channels are abandoned and subsequently buried beneath younger sediments.

Emery & Noakes (1968) suggest that the median distance from the primary source at which economic placer tin deposits can form is approximately 8km. Any type of cassiterite-bearing primary tin deposit may act as a source. The size and grade of the exposed source may have little relation to that of the adjacent alluvial deposit.

Cassiterite tends to concentrate at the base of stream gravels and in traps such as natural riffles, potholes, and bedrock structures transverse to the direction of water flow. The richest placers are often developed immediately adjacent to the primary source. Streams that flow parallel to the margin of tin-bearing granite are particularly favourable for placer tin accumulation. The cassiterite becomes progressively coarser as the source is approached. Euhedral crystals indicate close proximity to the source. Associated minerals include magnetite, ilmenite, zircon, monazite, allanite, xenotime, tourmaline, columbite, garnet, rutile and topaz (very rarely diamond).

In the study region there are three main types of cassiterite-bearing alluvium. These are:

1. Recent alluvium consisting of sandy wash.

2. Reworked granite-derived sandy wash which is fairly clayey. The top 0.5m of silty material contains the most cassiterite, but is of very low grade. This alluvium is fairly extensive and with thicknesses of 5m or more.

3. Old alluvium, mostly granite-derived sandy wash, with granite boulders to several meters in diameter overlain by granite-derived alluvium. The old granite

wash is up to 4.5m thick with cassiterite concentrated in the bottom 0.5m. The cassiterite is angular to subangular, fine- to coarse-grained and is mainly a dark grey-mauve colour.

Blevin & Chappell (1992) state that tin mineralisation (in granites of the eastern Australian Palaeozoic fold belts) is associated with both S- and I-type granites that are reduced and have undergone fractional crystallisation. The distribution of these granite types is displayed in Figure 70.

Known Deposits

Alluvial deposits:
Wolverton Prospect, Cooktown Tin Field, Palmer Gold Field, Herberton Mineral Field, Annan River, Kings Plains, Trevetham Creek-Waterfall Creek, Leichhardt Creek.

Deep lead deposits:
Herberton Deep Leads, Bradlaugh Creek Deep Lead, Cassowary Creek Deep Lead, Kings Plains Prospect.

Age

Tertiary to Holocene.

Assessment criteria

- Streams draining known or potentially fertile granite bodies,
- distribution of alluvium, including abandoned stream channels,
- within approximately 8km of tin bearing granite,
- basaltic or thick sedimentary capping surrounding fertile granite bodies or palaeodrainages from these fertile bodies, and
- presence of lode tin deposits containing ruby tin (brown-reddish colour) with cassiterite high in tantalum and niobium content. This type of cassiterite is typical of the lower levels of mineralising systems in the Herberton area and may indicate the removal of extensive tin systems by erosion processes.

Areas of Potential

Only deposits in which tin is likely to be the major commodity are discussed here. Placer gold deposits, where cassiterite may be a potential by-product, are discussed in the 'Placer gold' section of this report.

The Cooktown Tin Field still contains small alluvial and colluvial deposits containing up to 1Mt of wash which offer potential for sluicing operations by individual miners and syndicates (Denaro & Ewers, 1995). There is a significant potential for a medium-size alluvial tin deposit within the Trevetham Creek-Waterfall Creek area of Mount Amos. There is a high resource potential for small alluvial tin deposits within the whole of the Cooktown Tin Field but most of the prospective areas are now within the Wet Tropics World Heritage area.

The Annan River, from its headwaters down to the Helenvale area, is known to contain alluvial cassiterite at subeconomic grades. Numerous companies have tested this resource and undertaken feasibility studies. Vimaction Pty Ltd carried out stream sediment sampling along the Annan River and its tributaries. A number of small alluvial tin deposits of reasonable grade were found in the upper reaches of the river. There is a high resource potential for larger, lower grade deposits in the lower reaches. The Kings Plains prospect is a former channel of the Annan River and has a high mineral resource potential for a medium-size alluvial tin deposit.

A high level of potential exists within the area of the Herberton Deep Leads for areas which were previously uneconomic to work. Historic mining activity often ceased prematurely within these deep leads because of excessive water.

Many of the drainages within the Herberton Mineral Field have been worked and reworked for alluvial cassiterite but this region is still likely to contain alluvial resources. These resources are probably at lower grades or present as small discrete patches of richer alluvium and eluvium. This whole region contains a permissive resource potential.

The Cannibal Creek area has been worked for alluvial tin but low grade resources are still present fringing the Cannibal Creek Granite and the previously worked drainages. Alluvial tin has also been recovered from areas to the west of the Mount Carbine Granite, for example Leichhardt Creek. Drainages in this area are known to contain scattered low-grade alluvial tin deposits.

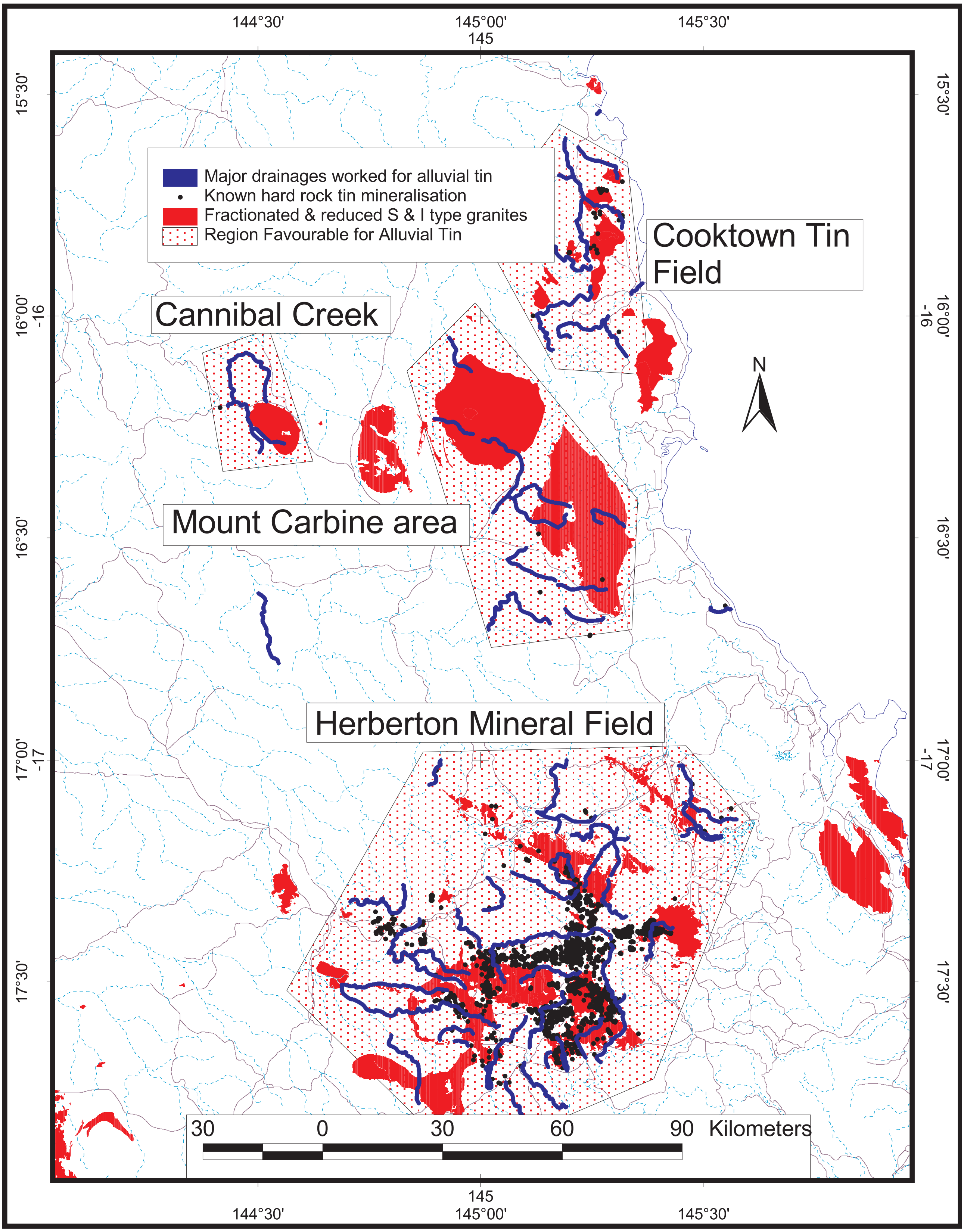


Figure 70. Distribution of known alluvial tin deposits and favourable regions.

PORPHYRY-TYPE COPPER OR PORPHYRY MOLYBDENUM

Deposit Description

The term 'porphyry copper' has been defined variously throughout the literature. In this report the definition of Horton (1982) is used. He refers to porphyry-type copper deposits as large, disseminated and fracture-controlled, low grade copper deposits which show close spatial association with felsic and intermediate epizonal intrusives in which the copper or molybdenum content has been upgraded significantly above background values for a particular host rock. Abundant dykes, breccia pipes, and faults are contemporaneous with these high-level (1.5–3km below surface at time of formation) intrusive rocks. Deposits not directly associated with intrusives have been excluded. Whilst porphyry copper and porphyry molybdenum deposits are distinctly different mineralising systems they have been grouped in this report for convenience.

Porphyry copper deposits are commonly developed within rift zones contemporaneous with Andean or island-arc volcanism along convergent plate boundaries. Porphyry systems are also developed in cupolas of batholiths. The typical porphyry system is characterised by felsic to intermediate (typically porphyritic) intrusive rocks which intrude any rock type but typically granitic, volcanic, and calcareous sedimentary sequences.

The alteration assemblages typical of these porphyry-type copper systems is:

1. Potassic alteration — characterised by secondary biotite, K-felspar, quartz, sericite, and to a lesser extent, anhydrite.

2. Phyllic alteration — characterised by quartz, sericite, pyrite, hydromica, minor chlorite, and traces of rutile.

3. Argillic alteration — characterised by quartz, kaolin, and chlorite.

4. Propylitic alteration — characterised by chlorite, epidote, and carbonate.

The classical model has alteration zoning (going from bottom, innermost zones outward) of sodic-calcic, potassic, phyllic, and argillic to propylitic. High-alumina alteration occurs in upper parts of some deposits. Propylitic or phyllic alteration may overprint early potassic assemblage. Brecciation may be produced from emplacement of the porphyry systems and in may cases form breccia pipes (Horton, 1982).

Blevin & Chappell (1992) have correlated Cu and Au mineralisation (in granites of the eastern Australian Palaeozoic fold belts) to be associated with magnetite and/or sphene-bearing, oxidised, intermediate I-type granite suites. Known deposits in Queensland tend to occur along well-defined trends or belts.

Common settings for mineralisation are as disseminated sulphide grains and stockwork veins in hydrothermally altered porphyry, along porphyry contact, and in favourable country rocks such as carbonate rocks, mafic igneous rocks and older granitic plutons. The mineralogy comprises chalcopyrite + pyrite ± molybdenite; chalcopyrite + magnetite ± bornite ± Au; assemblages may be superimposed.

Gangue minerals include quartz, K-felspar, biotite, anhydrite, sericite and clay minerals. Late veins of enargite, tetrahedrite, galena, sphalerite and barite occur in some deposits.

Green and blue Cu carbonates and silicates occur in weathered outcrops. Where leaching is intense, barren outcrops remain after Cu is leached and transported downwards, to be deposited as secondary sulphides at the water table or palaeowater table. Fractures in leached outcrops are coated with haematitic limonite. Deposits of secondary sulphides contain chalcocite and other copper sulphides replacing pyrite and chalcopyrite. Residual soils overlying deposits may contain anomalous amounts of rutile.

Horton (1982) has summarised the typical features of porphyry deposits in the Cairns region as:-

- granodiorite porphyries are the most common host rock but this is highly variable.

- a large percentage of the igneous hosts occur as dykes, either separately or associated with comagmatic individual or multiple stocks,

- rarely form part of larger comagmatic intrusives,

- pre-ore hosts vary from Carboniferous volcanics to calcalkaline intrusives,

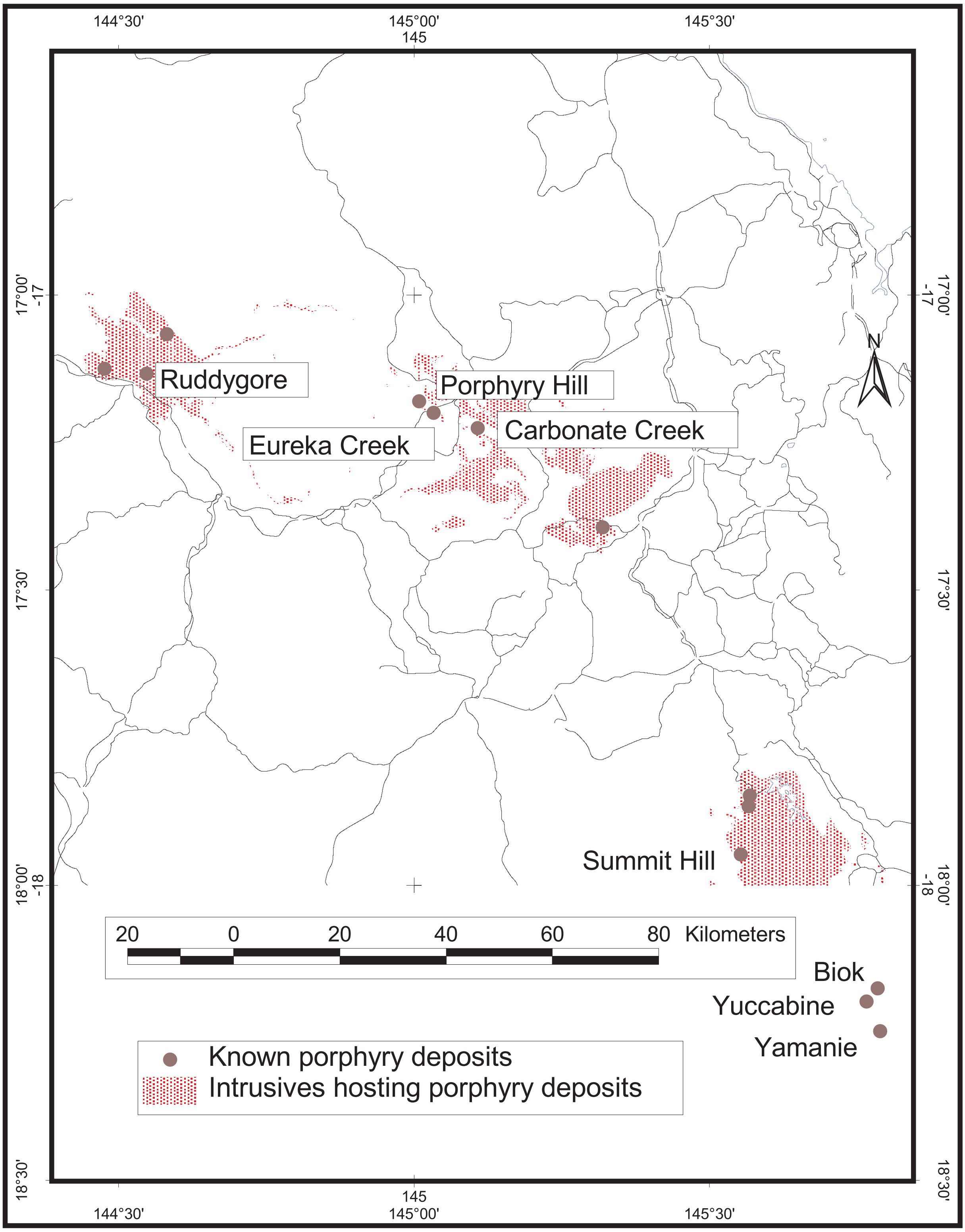


Figure 71. Distribution of known porphyry deposits and the host granite plutons.

- alteration zoning is rarely defined but where present is potassic-phyllic (argillic)-propylitic outward from the centre and fissure controlled,
- mineralisation is characterised by the presence of pyrrhotite (except in the molybdenum systems),
- small in size (<0.8km^2),
- relatively high grade, and
- secondary enrichment commonly developed.

Known Deposits

Ruddygore, Eureka Creek, Carbonate Creek, Summit Hill (Nitchaga), Yuccabine, Yamanie, Biok, Koombaloomba area, and Porphyry Hill.

Age

Permo-Carboniferous in the study area.

Assessment criteria

- Epizonal to mesozonal, felsic to intermediate, typically porphyritic intrusions that have developed extensive hydrothermal vein, stockwork or breccia systems,
- alteration consistent with zonal signature,
- metal and mineral zonation tends towards concentric patterns, but may be complex and somewhat irregular, and
- proximity to occurrences of base metals or within recognised deposit zones.

Areas of Potential

The distribution of the various granite types are displayed in Figure 71 against the known porphyry related mines and prospects.

It has been recognised for a long time that porphyry copper deposits tend to occur in linear belts which appear to be structurally controlled. Horton (1982) recognised two such belts within the study area of Permo–Carboniferous age; the Chillagoe trend (copper) and a weak north-west trend in the Innisfail–Cardwell area (molybdenum). The Chillagoe trend encloses the Carbonate Creek, Eureka Creek, Ruddygore, and Split Rock (west of the study area) deposits in an east-west trending zone. The Innisfail–Cardwell trend contains the Koombooloomba, Summit Hill (Nitchaga), Biok, Yuccabine, and Yamanie deposits.

The area surrounding the Ruddygore granite and plutons emplaced along the Palmerville Fault is considered most prospective. The deposits in the Chillagoe area commonly contain pyrrhotite making then amenable to detection by magnetic geophysical exploration techniques (Horton, 1982). The intrusives associated with known porphyry deposits are all felsic I types, some are also fractionated.

The Innisfail–Cardwell trend is oriented north-west and encloses five molybdenum prospects. This region is overlain by units of Glen Gordon Volcanics and all known deposits occur in windows through these cover sequences.

Disseminated molybdenum has been observed in many of the granites in the Koombooloomba Dam area. This trend has a permissive resource potential with the most likely targets being 'blind'. Horton (1982) has projected this porphyry trend north-westwards from the Koombooloomba area to intersect the porphyry deposits near Dimbulah.

This projection traverses the heavily mineralised regions around Irvinebank which have been documented elsewhere in this report.

SHORELINE DEPOSITS

Silica sand dunes

Deposit Description

Sand dune systems are formed by aeolian processes migrating sand-sized particles down wind or by progradation of sand barriers and foreshore dunes to accumulate in zones of lower wind velocity, often behind resistant obstacles. In the older sand masses deep leaching has created a soil profile with a deep, white A2 horizon of pure silica sand. This soil profile has been reworked to form the active dunes of silica sand which are the focus of mining at Cape Flattery.

In the study area dune deposits are formed along the east coast of Cape York Peninsula due to the prevailing south easterly winds. Silica sand occurs in high, transgressive, Pleistocene to Holocene dunefields averaging about 3km wide and reaching up to 15km inland, with average thicknesses from 25–30m.

Economic deposits generally are apical portions of active elongate parabolic dunes, formed by aeolian reworking of older, stabilised dunes in areas exposed to the prevailing south-easterly winds. Reworking produces a reduction in iron and heavy mineral contents. The resultant sand consists almost entirely of quartz, with up to 0.75% (generally $<0.05\%$) heavy minerals content. Dunes formed by wind action have grains winnowed (natural sorting) into a narrow size range.

Known Deposits

Cape Flattery, Cape Bedford, Mourilyan Silica Sand deposit.

Age

Pleistocene to Holocene

Assessment criteria

- Mapped extent of Quaternary dunefields,
- heavy mineral content, and
- presence of reworked dunes.

Areas of Potential

Only deposits in which silica sand is likely to be the major commodity are discussed here.

Extensive deposits of white dune sand occur at Archer Point, south of Cooktown. The sands occupy a 4km by 3km area and form a thin veneer on sedimentary rocks of the Hodgkinson Formation. These sands are considered chemically inferior to that at Cape Flattery.

The Cape Flattery–Cape Bedford dunefield extends from Cooktown north to Lookout Point (Figure 72). It is 55km long by up to 22km wide and covers an area of 580km^2. Within this area are large resources of silica sand.

Mining is currently carried out at the Cape Flattery Silica Mine, 60km north of Cooktown, where Cape Flattery Silica Mines Pty Ltd has proved reserves of 200Mt under mining lease (Cooper, 1993); the potential resource in the area is much greater. The optimum source of white silica sand is the bare apical mounds of the elongate parabolic dunes. The grainsize distribution is particularly suitable for glass manufacture and foundry moulding. Cooper & Sawers (1990) gave a chemical analysis for export quality sand of 99.82% SiO_2, 0.01% Fe_2O_3, 0.05% Al_2O_3, 0.02% TiO_2, <0.01% CaO, <0.01% MgO and 0.10% loss on ignition.

Small, scattered areas of sand dunes occur on the northern side of the Endeavour River. There is potential for medium-size deposits in this area. No information is available on the quality or characteristics of the sand.

Sand dunes in the Ninian Bay area have a potential for large silica sand deposits. Dunes along the western side of the Bay have been investigated and represent a silica sand resource that would require beneficiation to produce a marketable product. The bulk of the sand averages >99.5% SiO_2, but iron and titanium impurities exceed standards for glass manufacturing. An extensive area of vegetated dunes occur to the south and south-west of Ninian Bay; these dunes have not been investigated.

The Mourilyan silica sand deposit, located south-east of Innisfail, extends for 22km along the coastal sand plain. This deposit consists of an inner and outer beach ridge barrier complex. The inner barrier is of Pleistocene age and, in places, is covered by low, degraded, transgressive dunes. The outer Holocene age barrier is partly alienated by the Inarlinga Defence Reserve. The transgressive dune system contains indicated reserves of 10 739 500t of >99% silica to 0.5m depth (Cooper, 1993).

A small area at Red Point has a potential for medium-size deposits. There is no information available on the quality or characteristics of the sand.

The area around the mouth of the Jeannie River has a favourable resource potential for large deposits of sand. There is no information available on the quality or characteristics of the sand.

Shoreline placer heavy minerals

Deposit Description

These are heavy mineral concentrations (rutile, ilmenite, and zircon with lesser amounts of monazite) formed by beach processes and include beach placer, beach ridge and sand dune deposits. Well-sorted, medium to fine-grained sediments in dune, beach and inlet deposits, commonly overlying shallow marine deposits. Surf action, primarily during storm activity, removes the lighter fraction, leaving elongate 'shoe-string' ore bodies of black sand parallel to coastal dunes and beaches. These deposits are often buried by later beach accretion.

Deposits require a stable coastal region with efficient sorting and winnowing, receiving sediment from deeply weathered metamorphic terranes of sillimanite or higher grade. The

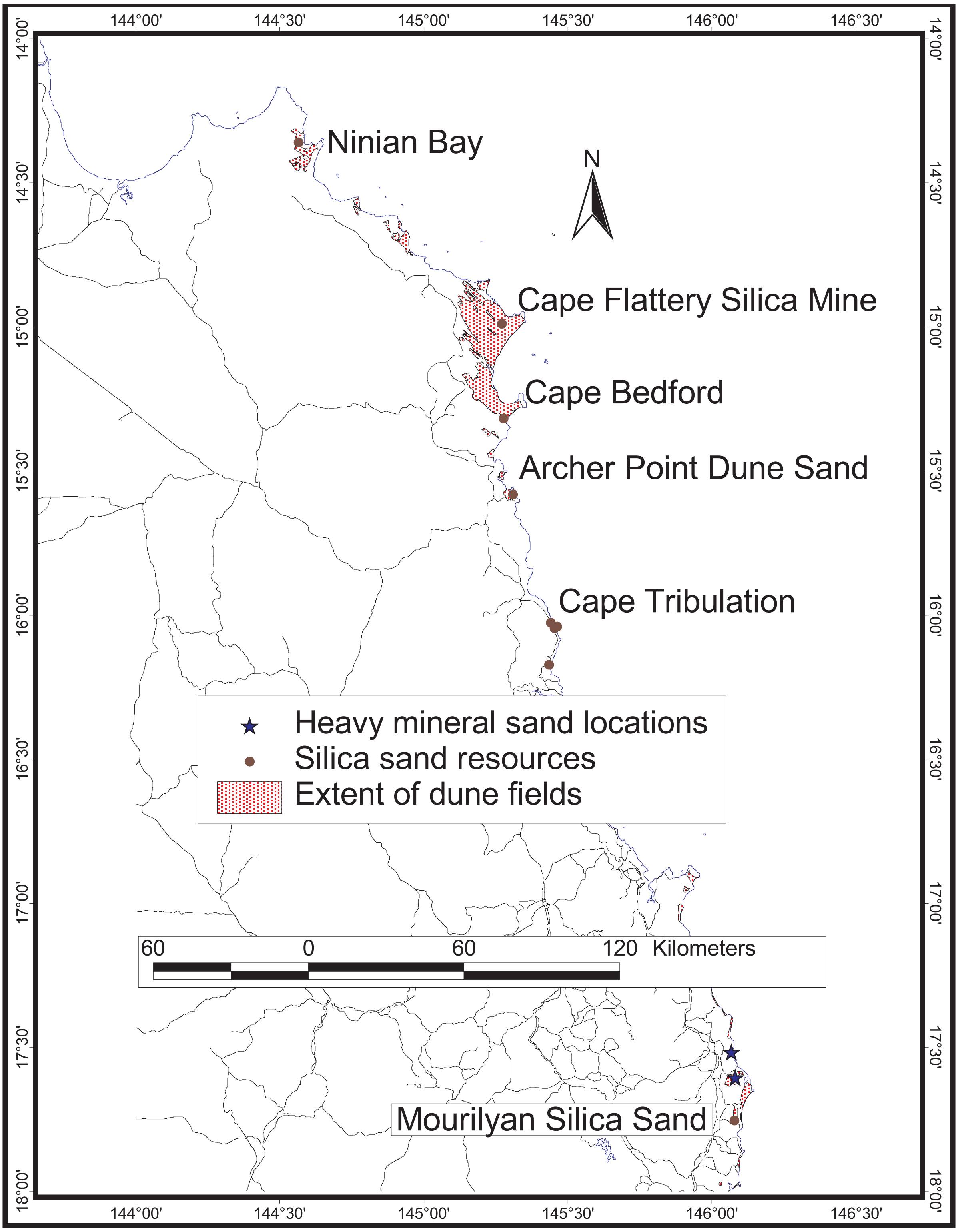


Figure 72. Distribution of known and potential silica sand and heavy mineral sand resources.

heavy minerals can also be derived from igneous rocks, or sedimentary rocks derived from these rocks. Leaching of iron from ilmenite and destruction of labile heavy minerals results in residual enrichment of deposits.

Known Deposits

Coquetta Point, Bathurst Bay, Cape Bowen, Princess Charlotte Bay, mouth of the Starcke River, north and south of the Daintree River mouth, Ramsay and Shepherd Bays (Cardwell area).

Age

Commonly Miocene to Holocene

Assessment criteria

- Appropriate coastal deposits and geomorphology,
- known distribution of heavy mineral concentrations, and
- coastal regions deriving sediments from fertile terranes.

Areas of Potential

Figure 72 identifies the known deposits of heavy mineral sands in the study area and the distribution of sand dune fields. Dunes on the east coast of Cape York Peninsula contain minor proportions of heavy minerals. Cape Flattery contains generally transgressive dune systems of silica sand but heavy mineral content ranges from a trace to 0.75% at Cape Flattery (Cooper & Sawers, 1990). The main minerals present are ilmenite and zircon.

Princess Charlotte Bay contains Holocene and Pleistocene beach ridges which extend along the coastline from First Red Rocky Point south and around Princess Charlotte Bay to Bathurst Heads. There is a favourable resource potential for small deposits. Heavy mineral content is generally <0.1%, which averaged 65% ilmenite, 30% heavy silicates, and minor rutile and zircon (Zimmerman, 1969).

Beach ridge systems at Bathurst Bay, Cape Bowen and the mouth of the Starcke River have potential for small heavy mineral deposits.

Sand dunes along the coastal areas to the north and the south of the Daintree River mouth are considered to have potential for economic heavy mineral sands deposits. In 1970, Discovery (Alpha) Pty Ltd investigated these dunes and tested them by drilling ten auger holes. Samples of up to 2.6% of heavy minerals concentrate, consisting of ilmenite, zircon and tourmaline, were recovered from one of the drill holes. The deposit was not investigated further.

Ramsay and Shepherd Bays of Hinchinbrook Island and Rockingham Bay north of Cardwell have been investigated for their mineral sands potential. Results from grab sampling by Ocean Mining A.G. in Ramsey Bay were 3ppm Sn, 500ppm Zr, 2000ppm Ti and 100ppm Va. In Shepherds Bay the results were 2ppm Sn, 50ppm Zr, 500ppm Ti and 3ppm Va. The best results of spectrographic analyses of Jet Lift sampling in Ramsey Bay (2 samples) were 4ppm Sn, 500ppm Zr, 1500ppm Ti and 20ppm Va; Rockingham Bay 4ppm Sn, 200ppm Zr, 1500ppm Ti and 20ppm Va and in Shepherds Bay 3ppm Sn, 200ppm Zr, 1500ppm Ti and 15ppm Va.

Dunes to the east of Mourilyan were investigated for their mineral sand potential. A thin wedge of sand containing low grades of heavy minerals (<0.5%) was defined. This deposit (up to 3m deep) overlies a clay rich, coarse-grained quartz gravel and thins both to the north and south. The area was however considered to be uneconomical.

SKARN DEPOSITS

The majority of skarn deposits in the study area are concentrated in the Chillagoe area. The intrusion of Permo–Carboniferous granitoids into Siluro-Devonian limestones of the Chillagoe and Hodgkinson formations has produced numerous mineralised skarns. The granitoids are mainly I-type and intruded at relatively shallow depths (1kbar or less in the Chillagoe area using hornblende geobarometry) (Rubenach, 1994).

General Description

The following deposit description is based upon the review article published by Meinert (1993).

Skarn deposits have been mined for a variety of elements, including Fe, W, Cu, Pb, Zn, Mo, Ag, Au, U, REE, F, B, and Sn. Skarns can occur in rocks of almost all ages although the majority are found in lithologies containing at least some limestone. They can form in almost any rock type, including shale, sandstone, granite, basalt, and komatiite. Skarns can form during regional or contact metamorphism and from a variety of metasomatic processes involving fluids of magmatic, metamorphic, meteoric, and/or marine origin.

They are found adjacent to plutons, along faults and major shear zones, in shallow geothermal systems, on the bottom of the sea floor, and at lower crustal depths in deeply buried metamorphic terranes. What links these diverse environments, and what defines a rock as skarn, is the mineralogy, which includes a wide variety of calcsilicate and associated minerals, but is usually dominated by garnet and pyroxene.

The dominant calcsilicate mineral assemblages are used to classify the different types of skarns. Mineral assemblage is also critical in understanding their origin and in distinguishing economically important deposits from interesting but uneconomic mineral localities. Skarn mineralogy is mappable in the field and serves as the broader 'alteration envelope' around a potential ore body. Because most skarn deposits are zoned, recognition of distal alteration features can be critically important in early exploration stages.

Skarn evolution occurs at temperatures of approximately 650°C to 400°C (and lower). Other features affecting the type of skarn produced include magma type and depth of emplacement, composition of the host rock and interaction of meteoric water.

Economic skarn deposits can be subdivided into several main types, based upon the dominant contained metal (*e.g.* W, Fe, Cu, *etc*). There have been numerous general review papers on skarn deposits in the past few decades (*e.g.* Watanabe, 1960; Phan, 1969; Zharikov, 1970; Smirnov, 1976; Burt, 1977; Einaudi & others, 1981; Meinert, 1983; Ray & Webster, 1991) more detailed information of skarn terminology and genesis is contained in these documents. Skarns can also be grouped according to the three main processes of formation.

Isochemical — no fluid input, heat only forming calcsilicate skarns and skarnoids.

Infiltration, two types — prograde skarn (fluids released into the carbonate host rock producing 'anhydrous skarn', and

— retrograde skarn (declining temperatures and influx of meteoric waters forming hydrous silicates, oxides and clay.

Most modern authors have adopted Einaudi & others (1981) suggestion to use skarn and skarn deposit as descriptive terms based upon their contained mineralogy, free of genetic implications.

Not all skarns have economic mineralisation, those which do are called skarn deposits. In most large skarn deposits, skarn and ore minerals result from the same hydrothermal system, even though there may be significant differences in the time/space distribution of these minerals on a local scale. Although rare, it is also possible to form skarn by metamorphism of pre-existing ore deposits, as has been suggested for Aguilar in Argentina (Gemmell & others, 1992) and Broken Hill in Australia (Hodgson, 1975).

Skarns can be subdivided according to several criteria. Exoskarn and endoskarn are common terms used to indicate a sedimentary or igneous protolith, respectively. Magnesian and calcic skarn can be used to describe the dominant composition of the protolith and resulting skarn minerals. Such terms can be combined, as in the case of a magnesian exoskarn, which contains forsterite-diopside skarn formed from dolostone. Calcsilicate hornfels is a descriptive term often used for the relatively fine grained, calcsilicate rocks that result from metamorphism of impure carbonate units such as silty limestone or calcareous shale

Magnesian skarns contain forsterite, diopside, spinel, garnet, vesuvianite, humite minerals, borate minerals, retrograde cassiterite, tourmaline, phlogopite, tremolite, talc, chlorite, calcite, fluorite, sellaite, serpentine, pyrrhotite, arsenopyrite, pyrite, chalcopyrite, magnetite, stannite, scheelite, quartz, siderite. Calcic skarns contain garnet (grossular-andradite), clinopyroxene, vesuvianite, wollastonite, cassiterite, retrograde tourmaline, axinite, cassiterite, fluorite, magnetite, Be minerals, pyrrhotite, chalcopyrite, scheelite, malayaite, sphalerite, arsenopyrite, datolite, epidote, amphiboles, quartz, calcite.

Reaction skarns can form from isochemical metamorphism of thinly interlayered shale and carbonate units, where metasomatic transfer of components between adjacent lithologies may occur on a small scale (perhaps centimetres) (*e.g.* Vidale, 1969; Zarayskiy & others, 1987). Skarnoid is a descriptive term for calcsilicate rocks which are relatively fine grained, iron poor, and which reflect, at least in part, the compositional control of the protolith (Zharikov, 1970). Genetically, skarnoid is intermediate between a purely metamorphic

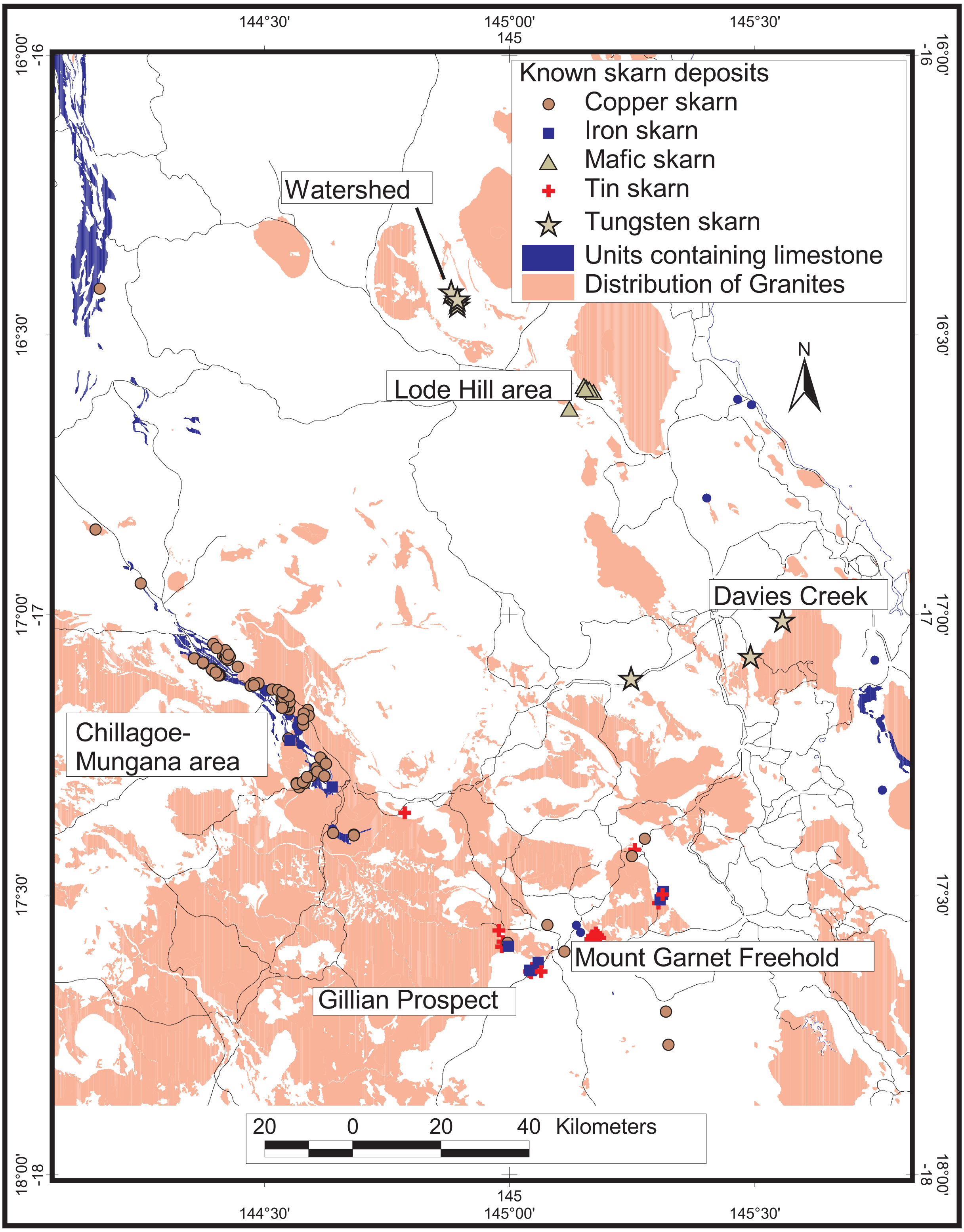


Figure 73. Distribution of known skarn deposits, granites and units containing limestone in the Cairns region.

hornfels and a purely metasomatic, coarse-grained skarn (sometimes termed infiltration skarn). For all of the preceding terms, the composition and texture of the protolith tend to control the composition and texture of the resulting skarn. In contrast, most economically important skarn deposits result from large-scale metasomatic transfer, where fluid composition controls the resulting skarn and ore mineralogy.

The identification and classification of skarn deposits is based on their mineralogy. Although many skarn minerals are typical rock forming minerals, some are less abundant and most have compositional variations that can yield significant information about the environment of formation. Some minerals, such as quartz and calcite, are present in almost all skarns. Others, such as humite, periclase, phlogopite, talc, serpentine, and brucite are typical of magnesian skarns, but are absent from most other skarn types. Additionally there are many tin, boron, beryllium, and fluorine-bearing minerals which have very restricted, but locally important, paragenesis.

In most skarns, there is a general zonation pattern of proximal garnet, distal pyroxene, and vesuvianite (or a pyroxenoid such as wollastonite, bustamite or rhodonite) at the contact between skarn and marble. Six zones have been recognised by Reid (1978) for calcic-limestone protoliths (1 furthest from intrusion and 6 closest):-

1) Marble,

2) Wollastonite,

3) Cristobalite,

4) Garnet – Clay,

5) Garnet – quartz,

6) Amphibolite – epidote.

In addition, individual skarn minerals may display systematic colour or compositional variations within the larger zonation pattern. For example, garnet is commonly dark red-brown in proximal occurrences, becomes lighter brown in more distal occurrences, and is pale green near the marble front (Atkinson & Einaudi, 1978). The change in pyroxene colour is less pronounced, but typically reflects a progressive increase in iron and/or manganese toward the marble front (Harris & Einaudi, 1982). For some skarn systems, these zonation patterns can be ‘stretched out’ for several kilometres and can provide a significant exploration guide (Meinert, 1987b).

Retrograde skarn mineralogy, in the form of epidote, amphibole, chlorite, and other hydrous phases, is typically structurally controlled and overprints the prograde zonation sequence, this is the case at the Red Dome deposit. Thus, there is often a zone of abundant hydrous minerals along fault, stratigraphic, or intrusive contacts. This superposition of later phases can be difficult to discriminate from a spatial zonation sequence due to progressive reaction of a metasomatic fluid. In general, retrograde alteration is more intense and more pervasive in shallower skarn systems. In some shallow, porphyry copper related skarn systems, extensive retrograde alteration almost completely obliterates the prograde garnet and pyroxene (Einaudi, 1982a,1982b). The main sulphide ore deposition commonly is associated with the retrograde alteration phase as the system wanes (temperatures ranging from 200–400°C).

In the Red Dome deposit the retrograde alteration assemblage is an insignificant amphibolite-epidote skarn alteration zone (Torrey & others, 1986). The epidote and actinolite replace andradite and tremolite forming patchy and disseminated replacement.

One of the more fundamental controls on skarn size, geometry and style of alteration is the depth of formation. Simple observations of chilled margins, grain size of porphyry groundmass, pluton morphology, and presence of brecciation and brittle fracture allow field distinctions between relatively shallow and deeper environments. The effect of depth on metamorphism is largely a function of the ambient wall rock temperature prior to, during and after intrusion. The greater extent and intensity of metamorphism at depth can affect the permeability of host rocks and reduce the amount of carbonate available for reaction with metasomatic fluids.

The depth of skarn formation also will affect the mechanical properties of the host rocks. In a deep skarn environment, rocks will tend to deform in a ductile manner, rather than fracture. Intrusive contacts with sedimentary rocks at depth tend to be subparallel to bedding; either the pluton intrudes along bedding planes or the sedimentary rocks fold or flow until they are aligned with the intrusive contact. Examples of skarns for which depth estimates exceed 5–10km include Pine Creek in California and Osgood Mountains in Nevada. In occurrences such as these, where intrusive contacts are subparallel to bedding planes, skarn is usually confined to a narrow, but vertically extensive, zone. At Pine Creek, skarn is typically <10m wide, but locally exceeds 1km in length and vertical extent (Newberry, 1982). Thus, skarn formed at greater depths can be seen as a narrow rind of small size relative to the associated pluton and its metamorphic aureole.

In contrast, host rocks at shallow depths will tend to deform by fracturing and faulting rather than folding. In most of the 13 relatively shallow skarn deposits reviewed by Einaudi (1982a), intrusive contacts are sharply discordant to bedding, and skarn cuts across bedding and massively replaces favourable beds, equalling or exceeding the (exposed) size of the associated pluton. The strong hydro-fracturing associated with shallow intrusions greatly increases the permeability of the host rocks, not only for igneous-related metasomatic fluids, but also for later, possibly cooler, meteoric fluids (Shelton, 1983). The influx of meteoric water and the consequent destruction of skarn minerals during retrograde alteration is one of the distinctive features of skarn formation in a shallow environment.

Groupings of skarn deposits can be based on descriptive features such as protolith composition, rock type, and dominant economic metal(s), as well as genetic features such as mechanism of fluid movement, temperature of formation, and extent of magmatic involvement. The general trend of modern authors is to adopt a descriptive skarn classification based upon the dominant economic metals, and then to modify individual categories based upon compositional, tectonic or genetic variations. Seven major skarn types (Fe, Au, W, Cu, Zn, Mo and Sr) have received significant modern study, and several others (including F, C, Be, Pt, U and REE) are locally important.

Einaudi & others (1981) and Meinert (1987a) indicate a correlation between skarn types and the type of igneous intrusion. Mafic igneous rock types produce Fe-rich skarns with associated Cu, Co, and Au deposits. Intermediate to silicic calcalkaline magmas produce W and Fe, Cu, Mo, Pb and Zn skarns. More evolved granite magmas produce Sn, W, Zn, Be and F skarns. The Red Dome mine area contains intrusives which are rhyolitic with A-type affinities (Torrey & others, 1986) and I-type granites.

The skarn deposits in the Hodgkinson Province fall into three populations. The largest group is located around the Chillagoe–Mungana area and are mainly copper skarns with some iron skarns. The second population is situated around the Mount Garnet area which contains the copper skarn of the Mount Garnet mine, tin skarns of the Gillian prospect, and scattered iron skarns. The last group are tungsten skarns located around the large Watershed Grid prospect and Lode Hill workings north-west of Mount Carbine. The Lode Hill workings are unusual in that the reactive lithology is mafic volcanics and as such have been classified as mafic skarns.

Copper skarn deposits

Deposit Description

Copper skarns are perhaps the world's most abundant skarn type. They are particularly common in orogenic zones related to subduction, both in oceanic and continental settings. Major reviews of copper skarns include Einaudi & others (1981) and Einaudi (1982a, 1982b). Most copper skarns are associated with I-type, magnetite series, calcalkalic, porphyritic plutons, many of which have cogenetic volcanic rocks, stockwork veining, brittle fracturing and brecciation, and intense hydrothermal alteration. These are all features indicative of a relatively shallow environment of formation.

Most copper skarns form in close proximity to the contacts of stocks, with a relatively oxidised skarn mineralogy dominated by andraditic garnet. Other phases include diopsidic pyroxene, vesuvianite, wollastonite, actinolite, and epidote. Haematite and magnetite are common in most deposits, and the presence of dolomitic wall rocks is coincident with massive magnetite lodes, which may be mined on a local scale for iron. As noted by Einaudi & others (1981), copper skarns commonly are zoned, with massive garnetite near the pluton, increasing pyroxene away from the contact, and finally, vesuvianite and/or wollastonite occurring near the marble contact. In addition, garnet may be colour zoned from dark reddish-brown proximal to the pluton, to green and yellow varieties in distal occurrences. Sulphide mineralogy and metal ratios may also be systematically zoned relative to the causative pluton. In general, pyrite and chalcopyrite are most abundant near the pluton, with chalcopyrite increasing away from the pluton, and bornite finally occurring in wollastonite zones near the marble contact. In copper skarns containing monticellite (*e.g.* Ertsberg, Irian Jaya in Indonesia; Kyle & others, 1991, and Maid of Erin in British Columbia; Meinert, unpublished data), bornite-chalcocite are the dominant Cu-Fe sulphides, rather than pyrite-chalcopyrite.

The largest copper skarns are associated with mineralised porphyry copper plutons. These deposits can exceed 1 billion tons of combined porphyry and skarn ore, with more than 5 million tons of copper recoverable from skarn. The mineralised plutons exhibit characteristic potassium silicate and sericitic alteration, which can be correlated with prograde garnet-pyroxene and retrograde epidote-actinolite, respectively, in the skarn. Intense retrograde alteration is common in copper skarns and may destroy most of the prograde garnet and pyroxene in some porphyry-related deposits. Endoskarn alteration of mineralised plutons is rare. In contrast, barren stocks associated with copper skarns contain abundant epidote-actinolite-chlorite endoskarn and less intense retrograde alteration of skarn. Some copper deposits have coarse-grained actinolite-chalcopyrite-pyrite-magnetite ores, but contain only sparse prograde garnet-pyroxene skarn. These deposits provide a link between some copper and iron skarns and deposits with volcanogenic and orthomagmatic affinities.

Copper skarns comprise chalcopyrite + pyrite ± haematite ± magnetite ± bornite ± pyrrhotite; molybdenite, bismuthinite, sphalerite, galena, cosalite, arsenopyrite, enargite, tennantite, loellingite, cobaltite and tetrahedrite may be present; Au and Ag may be important products. Alteration in copper skarns comprises diopside + andradite in the centre, wollastonite ± tremolite in the outer zone, and marble in the peripheral zone. Igneous rocks may be altered to epidote + pyroxene + garnet (endoskarn). Retrograde alteration to actinolite, chlorite and clays may be present.

Surface expression of copper skarns may be as an Fe-rich gossan with Cu carbonates and silicates. Lead-zinc skarns may form gossans with strong Mn oxide staining.

The grade tonnage diagram, Figure 74, plots the world class deposits against major deposits in the Cairns region. Figure 74 identifies the potential for bulk low grade deposits of this type and prospective nature of the Cairns region, particularly the Chillagoe-Mungana to Mount Garnet trend, for hosting this type of deposit.

Known Deposits

Copper skarns in the Hodgkinson Province occur mainly in a north-west trending belt centred around the Chillagoe-Mungana area. Another large copper skarn deposit occurs at Mount Garnet.

The Mungana–Chillagoe deposits (including Red Dome) parallel the Palmerville Fault. This structure probably controlled the emplacement of the mid-late Carboniferous granites which intruded the Chillagoe Formation and formed the skarn deposits.

The Mount Garnet skarn deposit is an isolated occurrence also hosted by the Chillagoe Formation. It is also very close to the south-east extrapolated position of the Palmerville fault.

Age

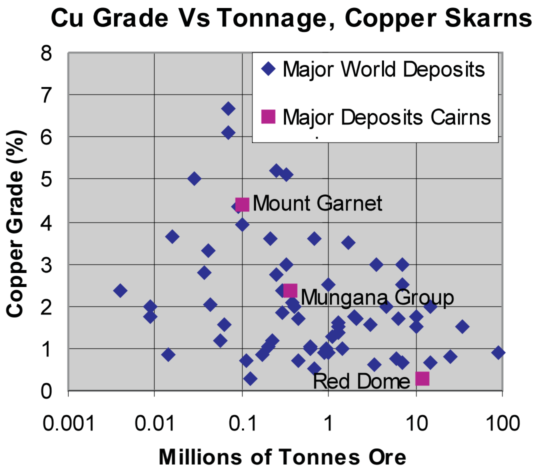
Carboniferous? (in the Cairns region)

Assessment criteria

- Thick limestone beds in otherwise Carbonate-poor sequences,
- close proximity to a magmatic-hydrothermal centre; large, well-mineralised skarns are rarely more than a few hundred metres from their associated intrusions,
- intermediate to silicic calcalkaline intrusives or more evolved granite magmas,
- outcrop distribution of calcsilicate skarn mineral assemblage,
- shallow-dipping pluton-limestone contacts,
- structural and stratigraphic traps in host rocks,
- presence of channel-ways for ore- forming fluids, for example, fractures, faults, stockworks, breccias and permeable stratigraphic units, and
- aeromagnetic anomalies indicating the presence of plutons or zones rich in magnetite.

Areas of Potential

Rubenach (1994) considers lithological contacts (intrusive, sedimentary, and basalt/limestone) and fractures are critical factors in the localisation of the skarns in the Chillagoe area. Highly irregular contacts and presence of north and north-west striking fractures have also



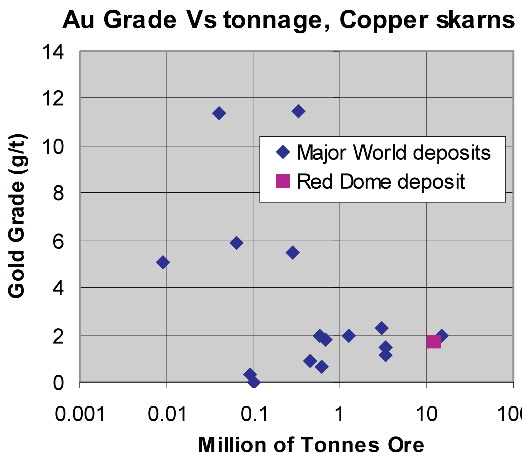


Figure 74. Grade-tonnage diagrams for Copper skarn deposits (data from Cox & Singer, 1992 and this report).

influenced mineral distribution in the Calcifer area.

The Chillagoe corridor of skarn mineralisation (Figure 73) is highly prospective for this deposit style but known occurrences have been found to be of limited size and highly variable in grade. The location of unexposed high level intrusives into the Chillagoe Formation may indicate the presence of further skarn mineralisation in conjunction with the structural controls detailed above. This region remains highly prospective for this style of mineralisation.

The area in the vicinity of the Mount Garnet mine is currently under investigation for extensions to the historically worked orebody. The surrounding area may contain 'blind' skarn deposits developed within the Chillagoe Formation but hidden by Tertiary cover.

Tin skarn deposits

Deposit Description

This deposit classification is characterised by tin, tungsten, and beryllium minerals in skarns, veins, stockworks and greisens generally associated with thick, pure and/or impure carbonate sequences intruded by felsic igneous rocks. The granites are generally leucocratic biotite and/or muscovite granite with specialised phase or end member granites most common. Geochemically, Na_2O/K_2O is <1.0 and may be as low as 0.4, Fe_2O_3/FeO is low (<1.0), Fe total/CaO is high, and Rb/Sr is 2.0–85.0 and generally 5.0–10.0 (Kwak, 1986). Deposits are most likely to be associated with ilmenite series, S-type (and A-type) granites; some occur in I- or mixed I/S-type provinces.

The host rocks are contact metamorphosed equivalents of relatively pure limestone beds, impure limestones, and calcareous to carbonaceous pelites (skarn, calcsilicate rock and biotite-pyrite hornfels).

Mineralogy of deposits generally comprises cassiterite ± minor scheelite ± sphalerite ± chalcopyrite ± pyrrhotite ± magnetite ± pyrite ± arsenopyrite ± fluorite. The majority of the tin may be in silicate minerals and therefore metallurgically unavailable.

Deposit forms include granoblastic skarns, wrigglite (chaotic laminar pattern of alternating light [fluorite] and dark [magnetite] lamellae), stockworks, and breccia. From Figure 75 it can be seen that this style of deposit forms large low grade resources with the Cairns region hosting significant mineralisation of this type.

Known Deposits

Gillian (Pinnacles) Prospect, Wriggly

Age

Carboniferous? (In the study area)

Assessment criteria

- Distribution of calcsilicate and/or relatively thick carbonate-rich rocks,
- exposed or subsurface plutons of suitable geochemistry
- pluton/limestone contacts and irregularities in contact,

- stockwork fracturing along pluton/limestone contact, and
- distribution of known mineralisation.

Areas of Potential

The Chillagoe Formation comprises limestone, muddy limestone, basalt, chert, sandstone, siltstone and mudstone. Potential exists for mineralising subsurface felsic plutons to have intruded this unit and generated further tin skarn assemblages.

Isolated limestone outcrops in the Hodgkinson Formation have potential to host small tin skarn deposits. These like the Chillagoe formation are reactive lithologies and may have fertile intrusive relationships.

The area containing the Gillian Prospect, near Mount Garnet, contains a large low-grade resource of tin and fluorite within a skarn mineral assemblage. This deposit contains a Indicated Resource of 1.3Mt grading 0.54%–0.69% tin and an Inferred Resource of 500 000t @ 0.54–0.69% tin. This area probably contains further extensions to the known mineralisation.

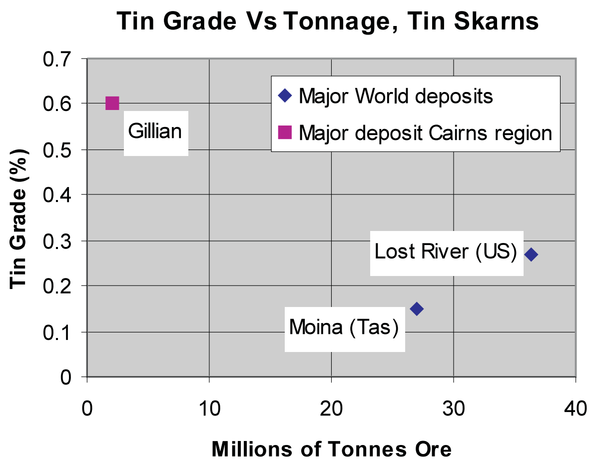


Figure 75. Grade-tonnage diagram for tin skarn deposits (data from Cox & Singer, 1992 and this report).

Tungsten skarn deposits

Deposit description

Tungsten skarns are found mostly association with calcalkalic plutons in major orogenic belts. Major reviews of tungsten skarns include Newberry & Einaudi (1981), Newberry & Swanson (1986), and Kwak (1987). As a group, tungsten skarns are associated with coarse-grained, equigranular batholiths (with pegmatite and aplite dykes) surrounded by large, high temperature, metamorphic aureoles. These features are collectively indicative of a deep environment. Plutons are typically fresh, with only minor myrmekite and plagioclase-pyroxene endoskarn zones near contacts. The high-temperature metamorphic aureoles common in the tungsten skarn environment contain abundant calcsilicate hornfels and skarnoid formed from mixed carbonate-pelite sequences. Such metamorphic calcsilicate minerals reflect the composition and texture of the protolith.

Newberry & Einaudi (1981) divided tungsten skarns into reduced and oxidised types, based on host rock composition (carbonaceous versus haematitic), skarn mineralogy (ferrous versus ferric iron), and relative depth (metamorphic temperature and involvement of oxygenated ground water). Early skarn assemblages in reduced tungsten skarns are dominated by hedenbergitic pyroxene and lesser grandite garnet, with associated disseminated, fine-grained, molybdenum-rich scheelite (powellite). Later garnets are subcalcic (Newberry, 1982) with significant amounts (up to 80 mole%) of spessartine and almandine. This subcalcic garnet is associated with leaching of early disseminated scheelite and its redeposition as coarse-grained, often vein-controlled, low-molybdenum scheelite. It is also associated with the introduction of sulphides, such as pyrrhotite, molybdenite, chalcopyrite, sphalerite and arsenopyrite, and hydrous minerals such as biotite, hornblende and epidote. In oxidised tungsten skarns, andraditic garnet is more abundant than pyroxene, scheelite is molybdenum poor, and ferric iron phases are more common than ferrous phases. For example, at the Springer deposit in Nevada, garnet is abundant and has andraditic rims, pyroxene is diopsidic (<Hd40), epidote is the dominant hydrous mineral, pyrite is more common than pyrrhotite, and subcalcic garnet is rare to absent. In general, oxidised tungsten skarns tend to be smaller than reduced tungsten skarns, although the highest grades in both systems typically are associated with hydrous minerals and retrograde alteration.

Known Deposits

Watershed Grid, Davies Creek prospect.

Age

Permian? in the Cairns region

Assessment criteria

- Distribution of calcsilicate and/or relatively thick carbonate-rich rocks in areas with suitable intrusives,
- extensive hornfels zone adjacent to an exposed or hidden pluton,
- shallowly dipping pluton/limestone contacts and irregularities in contact,
- stockwork fracturing along pluton/limestone contact, and
- distribution of known mineralisation, including tungsten veins.

Areas of Potential

At Watershed Grid (a reduced-type tungsten skarn) the tungsten mineralisation occurs as fine to coarse-grained disseminated scheelite in stratabound lenses of calcsilicate rocks of the Hodgkinson Formation. The scheelite also occurs as coarse crystals in quartz-calcite greisen veins in the calcsilicate rocks and intruding granites. The scheelite is accompanied by minor pyrite, pyrrhotite, arsenopyrite, fluorite, sphalerite, chalcopyrite, and molybdenite. The region surrounding this prospect has a high potential for extensions or satellite deposits similar to Watershed Grid. The hornfelsed margins of the plutons in this region are also prospective for this deposit style.

The potential for further tungsten skarn mineralisation exists throughout the Hodgkinson Province where S-type granites have formed moderate metasomatic aureoles within calcareous sediments of the Hodgkinson Formation. The region to the north-west of the Tinaroo Granite (Davies Creek prospect) is considered highly prospective as the area is known to host small scheelite deposits, a large contact aureole has developed and tungsten mineralisation is found associated with this granite. The granite contact also dips shallowly giving a larger metasomatic aureole increasing the chances for skarn formation.

Mafic Skarn

Deposit Description

This style of deposit displays similar features to the base metal skarn systems with the exception that the focus of mineralisation is the result of metasomatic fluids interacting with calcium-rich basic minerals within mafic rocks instead of calcareous sediments. The fluids are of a magmatic origin with deposits spatially associated with felsic intrusives. The mafic skarns are also commonly associated with fault/shear structures which act as a conduit for the hydrothermal fluids.

Known Deposits

Lode Hill area.

Age

Permian in the study area

Assessment Criteria

- Presence of mafic rock sequences,
- proximity to fertile intrusive,
- regional or local scale faulting, and
- distribution of known mineralisation.

Areas of Potential

In the Lode Hill area, extending to the south-east from the Mount Carbine tungsten mine, scheelite mineralisation occurs where faults cross-cut basic igneous dykes. These structures have introduced magmatic fluids from the nearby Mount Carbine Pluton. The fluids have metasomatised the calcium-rich basic minerals into a suite of calcsilicate minerals and scheelite (the coarser-grained rocks mainly comprise tremolite). Most of the lodes trend north-west, parallel to the granite boundary, which is generally <250m distant.

The scheelite occurs in seams, quartz veins and veinlets, felsite dykes and chloritised patches within basic igneous host rocks. Minor scheelite was also found in felsite dykes and quartz-tourmaline veins in sedimentary rocks.

VOLCANOGENIC MASSIVE SULPHIDE (VMS) DEPOSITS

Deposit Description

There are several classification systems of VMS deposits but for the purposes of this report I have used three groupings, Cyprus, Besshi-Kieslager, and Kuroko.

Cyprus VMS deposits display massive sulphide mineralisation (>60% sulphides) overlying a sulphide stockwork or stringer zone. Sulphides are commonly brecciated and recemented. The massive ore comprises pyrite + chalcopyrite + sphalerite ± marcasite ± pyrrhotite. Stringer (stockwork) mineralisation comprises pyrite + pyrrhotite + minor chalcopyrite and sphalerite (cobalt, gold and silver present in minor amounts). The alteration developed in the stringer zone comprises felspar destruction, abundant quartz, chalcedony and chlorite, and some illite and calcite. Some deposits are overlain by ochre (Mn-poor, Fe-rich bedded sediment containing goethite, maghemite and quartz). Host rock lithologies are generally pillow basalts or mafic volcanic breccias with diabase dykes below; ores are rarely localised in sediments above pillows but may be locally faulted. Deposits form massive limonite gossans.

Cyprus deposits are the result of submarine hot spring activity along axial grabens in oceanic or back-arc spreading ridges. Hot springs related to submarine volcanoes producing seamounts can also form cyprus VMS deposits. These deposits are typically associated with marine, predominantly tholeiitic mafic volcanic sequences (greenstone belts, ophiolite assemblages — tectonised dunite and harzburgite, gabbro, sheeted diabase dykes, pillow basalts) and fine-grained metasedimentary rocks such as chert and phyllite. Regionally associated with Mn- and Fe-rich cherts.

Besshi-Kieslager VMS deposits are characterised by thin, sheet-like bodies of massive to well-laminated pyrite, pyrrhotite, and chalcopyrite within thinly laminated clastic sediments and mafic tuffs. Fine-grained, massive to thinly laminated ore with colloform and framboidal pyrite. Ore minerals include pyrite + pyrrhotite + chalcopyrite + sphalerite ± magnetite ± valleriite ± galena ± bornite ± tetrahedrite ± cobaltite ± cubanite ± stannite ± molybdenite. Gangue minerals include quartz, carbonate, albite, white mica, chlorite, amphibole, and tourmaline. The ore may have a brecciated or stringer form. Cross-cutting veins commonly contain chalcopyrite, pyrite, calcite, galena, and sphalerite. Alteration is difficult to recognise because deposits are generally in strongly deformed metamorphic terrane. Chloritisation of adjacent rocks has been noted in some deposits. Deposits are thin but laterally extensive and tend to cluster in an *en echelon* pattern. Commonly form gossans when exposed at the surface.

Besshi-Kieslager VMS deposits are considered to have formed from submarine hot springs related to basaltic volcanism. Ores may be localised within permeable sediments and fractured volcanic rocks in anoxic marine basins. They are considered to form within continental margins or back-arc basin spreading ridges. They are commonly hosted by clastic sedimentary rocks and tholeiitic to andesitic tuff and breccia; locally associated with black shale, oxide facies iron formation, and red chert.

Kuroko VMS deposits are copper- and zinc-bearing massive sulfide deposits in marine volcanic rocks of intermediate to felsic composition. The common host rock assemblage is marine rhyolite, dacite, and subordinate basalt and associated sediments, principally organic-rich mudstone or shale. Pyritic, siliceous shale and some basalt. These rocks may display flow, pyroclastic, breccia and sedimentary structures, and in some cases felsic domes may have formed. Pyritic siliceous rock (exhalite) may define horizons at which mineralisation has occurred. Proximity to deposits may be indicated by sulfide clasts in associated volcanic breccias. Some deposits may be gravity transported and deposited in palaeodepressions in the seafloor. In Japan the best deposits have mudstone in the hanging wall.

These deposits are considered to have formed from hot springs related to marine volcanism, probably with anoxic marine conditions. Lead-rich deposits associated with abundant fine-grained volcanogenic sediments. These conditions have occurred within an island arc setting with local extensional tectonic activity, faulting or fracturing. These deposits are now commonly exposed in Archaean greenstone belts.

The deposits mineral assemblage consists of an

- upper stratiform massive zone (black ore) consisting of pyrite + sphalerite + chalcopyrite ± pyrrhotite ± galena ± barite ± tetrahedrite ± tennantite ± bornite,
- lower stratiform massive zone (yellow ore) consisting of pyrite + chalcopyrite ± sphalerite ± pyrrhotite ± magnetite, and

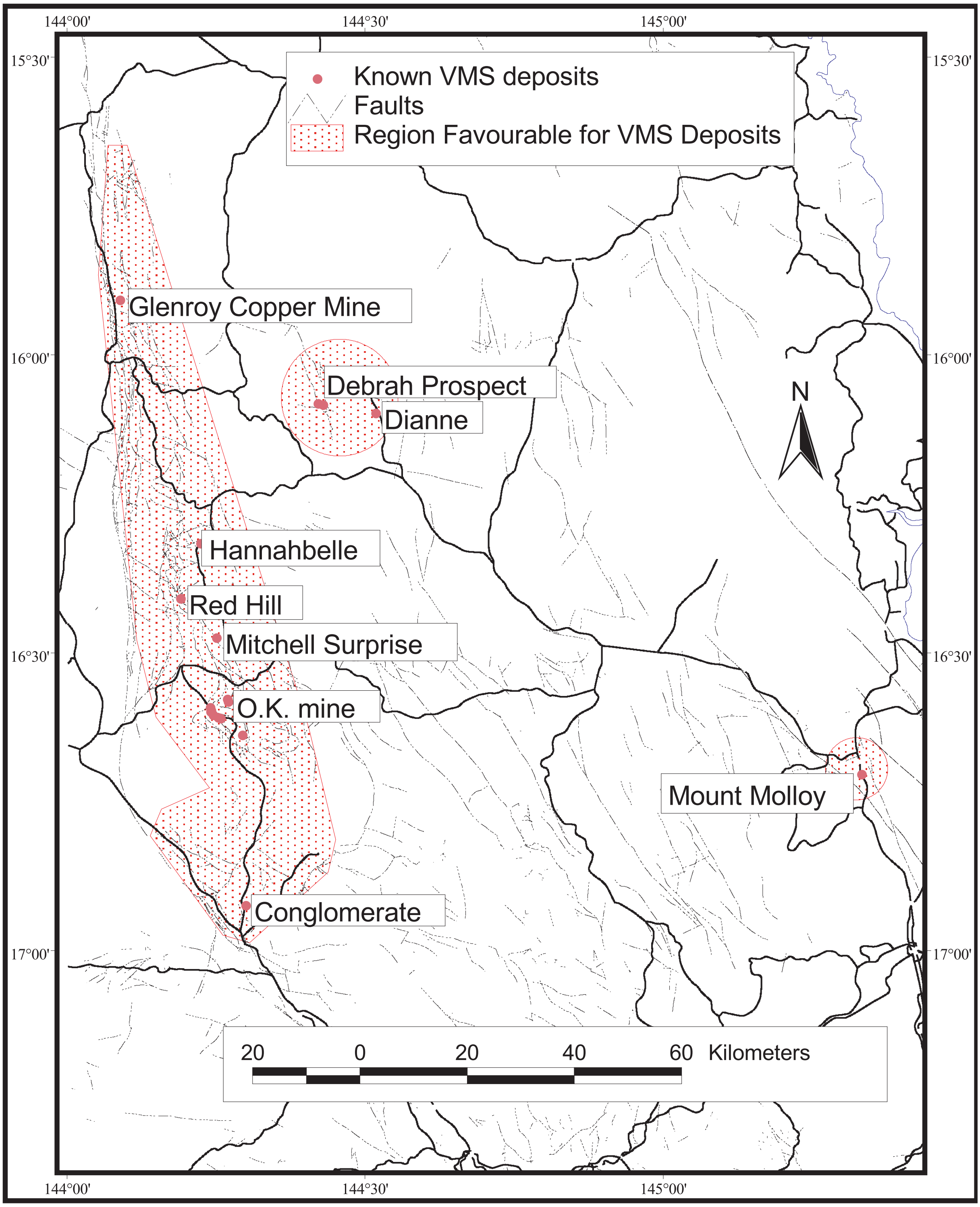


Figure 76. Distribution of known Volcanogenic Massive Sulphide deposits and regions favourable for hosting VMS deposits.

- stringer (stockwork) zone consisting of pyrite + chalcopyrite (gold and silver).

Sulphides are commonly >60 percent. Gahnite is common in metamorphosed deposits with gypsum/anhydrite occasionally present. In some cases, an underlying zone of ore stockwork, stringers, disseminated sulphides or sulfide-matrix breccia is developed. Slumped and redeposited ore with graded bedding may have formed during sulphide deposition.

An asymmetrical alteration assemblage is typical of Kuroko deposits with zeolites, montmorillonite (and chlorite?) alteration developed adjacent to and blanketing the massive sulfide. The stringer (stockwork) zone displays silica, chlorite, and sericite alteration whilst below the stringer zone chlorite and albite alteration is present. Metamorphosed deposits have cordierite and anthophyllite assemblage in the footwall with graphitic schist in the hanging wall.

Mineralisation is commonly focused toward the more felsic top of the volcanic or volcanic-sedimentary sequence. Areas near the centre of the felsic volcanism may also be more strongly mineralised. The surface expression of Kuroko deposits is commonly as yellow, red, and brown gossans. Gahnite present in stream sediments near some deposits.

Nethery & Barr (1996) consider that the VMS deposits of the Hodgkinson Basin developed at spacings of around 25km and are related to Silurian submarine tholeiitic volcanic centres. They consider that these sulphide lenses deposited on mafic volcanic flows at the interface with massive exhalative chert horizons.

Thrusting during the Late Devonian to Mid Carboniferous was commonly focused along these VMS sulphide horizons producing deformation and subsequent annealing (Nethery & Barr, 1996).

The grade-tonnage distribution for deposits in the Cairns region (Figure 77) when compared with deposits throughout the world suggests they are higher grade but this is probably the result of ore sorting process and selective mining techniques. This figure also illustrates the low grade nature of VMS deposits throughout the world with most recording <5% copper. Silver grades, displayed in Figure 77, are commonly <20g/t with the major deposits in the study area falling into this region also.

Known Deposits

All the deposits in the Hodgkinson Province are considered to be of the Besshi-Kieslager type. The main deposits are the Dianne, O.K., Mount Molloy, Mitchell Surprise, Red Hill, and Hannahbelle.

Age

Silurian (Nethery & Barr, 1996) to Devonian

Assessment criteria

- Along synvolcanic fractures in successions of submarine volcanic rocks,
- within a given district, deposits tend to preferentially occur at a specific stratigraphic horizon,
- deposits tend to occur in clusters (~25km spacing), proximity to known deposits, and
- association of basaltic volcanics and Mn/Fe-rich cherts or volcanogenic Mn deposits.

Areas of Potential

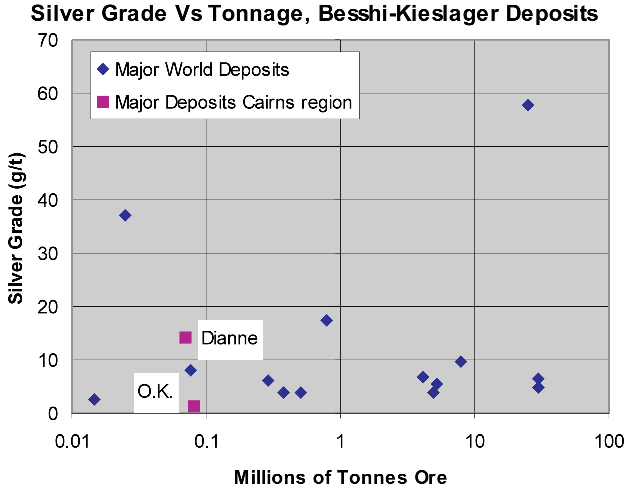
The Chillagoe Formation was probably deposited in either a continental rift or a back-arc basin with a thinned continental crust (Bultitude & others, 1993a). Denaro & Ewers (1995) consider that the presence of mafic volcanics, cherts and fine-grained sediments, as well as widespread copper mineralisation, indicate a geological environment conducive to the occurrence of volcanogenic massive sulphide deposits. There is potential for discovery of small VMS deposits in the Cairns region (Figure 73). This region was classified by Denaro & Ewers (1995) as BmD1 & BmD2 (Map 4).

Within the Hodgkinson Formation volcanogenic massive sulphide deposits are associated with basic volcanic sills or flows. The host lithologies comprise predominantly chert/quartzite beds associated with basic volcanic rocks. The tabular shaped orebodies are >100m long and are capped by ferruginous gossans. Prominent sulphide mineral zones, consisting of pyrite bands replaced by chalcopyrite, sphalerite, and galena, generally contain Fe>>Cu>Zn>>Pb and Ag>>Au. Historic mining activity has been confined to the secondary enriched carbonate zone which contained up to 20–25% Cu.

There are a number of ridges of manganiferous gossan and pyritic quartzites trending north-west throughout the study area. These gossans are occasionally anomalous in Cu (up to 800ppm) and Zn. There is a high potential for discovery of VMS deposits in this area. This region was classified by Denaro & Ewers (1995) as BmD2, Bmd3, Bmd4 and Bmd5 (Map 4).

Chert lenses in the Hodgkinson Formation in the Cape Bowen area are of possible exhalative origin, carry anomalous gold, and in some cases, base metals, and are commonly capped by manganese-iron gossans. Some of the cherts are propylitically altered, sheared and brecciated basalts/spilites. In many respects, the chert lenses are similar to gossanous cherts in the Mount Bennett area and could be related to small, volcanogenic massive sulphide deposits. Poorly exposed, carbonaceous, fine-grained sediments between the chert ridges might be potential targets. There is a limited potential for small volcanogenic massive sulphide deposits in this area. This region was classified by Denaro & Ewers (1995) as BmD6 & BmD7 (Map 4).

The OK Member of the Hodgkinson Formation hosts the O.K., Red Hill, and Mitchell Surprise VMS deposits. This unit is considered prospective for further VMS deposits. The Larramore Metabasalt Member is spatially close to the Dianne and Debrah prospect and the region around this mafic unit is considered prospective for VMS mineralisation. The Mount Molloy mine area has been extensively explored and small extensions to the known mineralisation have been found. The area may host blind VMS deposits. The regional association of manganiferous chert with cyprus style VMS mineralisation suggests that the manganese trend (discussed in volcanogenic manganese section) may be worthy of investigation.



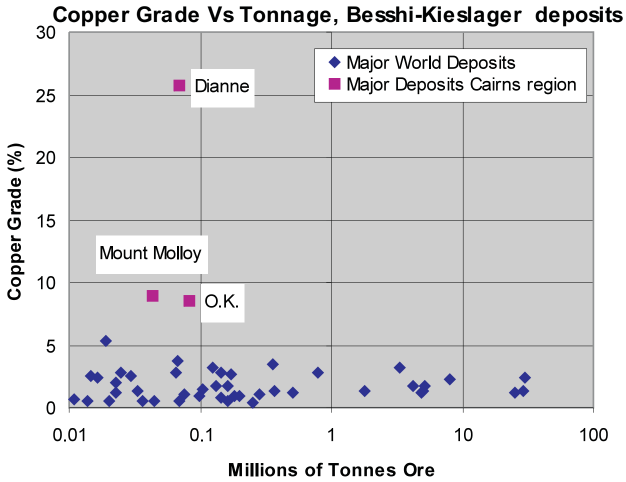


Figure 77. Grade-tonnage diagram for Besshi-Kieslager deposits (data from Cox & Singer, 1992 and this report).

DISTRICT ANALYSIS

MINE DISTRIBUTION

The distribution of mines in the Cairns region is shown in Figure 78. It can be seen that there are two areas with very extensive historic mining, namely the Herberton and Cooktown Tin Fields. Two prominent north-west trending zones of historic mining are also obvious. The south-western of these trends traces the Palmerville fault between the Herberton region in the south-east to the Chillagoe areas in the north-west. The central cluster of mineralisation follows major faults through the Hodgkinson Gold Field north-west to the Groganville area. A broad belt of mineralised country also exists in the northern exposed parts of the Hodgkinson Formation, extending from the Maytown (Palmer River) area east to the Cooktown Tin Field. Some mining activity has also occurred along the coastal area north of Cooktown and east of the Herberton Tin Field.

The distribution of the major commodities mined is also displayed on Figure 78. This figure highlights the domainal nature of mineralisation in the Cairns region. The extensive concentrations of tin and tungsten mineralisation in the Herberton and Cooktown Tin Fields are related to the fertile granites in these areas. Smaller concentrations of tin are also present around the Cannibal Creek and Mount Carbine Granites. The base metal and gold mineralisation associated with the Palmerville Fault south-east of Chillagoe implies a strong structural influence on the distribution of this mineralisation style. Gold mineralisation is concentrated along north-west trending structures in the central part of the Cairns region and in the Maytown (Palmer River) area. Antimony mineralisation is concentrated in the Mitchell–Saint George River and Northcote areas along major faults in the central Hodgkinson Province.

The very extensive Featherbed Volcanic Cauldron Complex is only sparsely mineralised, in contrast to the surrounding units which are characterised by a range of mineralisation styles. The only known mineralisation in the former is small, scattered uranium deposits related to hydrothermal scavenging of uranium from the silicic volcanic sequence.

PRODUCTION DISTRIBUTION

A series of grade tonnage graphs have been generated using available production details for the various commodities to derive ore grades (Figure 79). These graphs display information for all deposit types and are used to demonstrate the mineral wealth of the Cairns region on a commodity basis. It must be emphasised that the data for the smaller deposits has been skewed towards the higher grade end because of ore sorting techniques employed during mining. Relevant world class deposits have been included for comparative purposes for some of the ore deposit models.

The graph for gold grade and tonnage clearly shows that most of the mines worked in the region produced <1 000t of ore which ranged in grade from 10–100g/t. This equates to <100kg of gold produced by any individual mine. The consistent high-grade character of the deposits reflects selective mining practices. The Red Dome deposit forms an outlier as a large bulk low-grade deposit. The presence of several deposits with >10g/t grades which produced in excess of 100kg gold illustrates the presence of moderate sized resources in the Cairns region. These deposits are in the Hodgkinson Gold Field with the exception of one mine in the Mareeba Gold Field. The estimated average grade for all deposits in the Hodgkinson Gold Field is 33g/t gold which attests the consistent high-grade nature of these deposits which produced ~11.12t of gold.

The graph of tin production displays the abundance of small commonly extremely high-grade deposits present in the Cairns region. Ore grades in excess of 100kg/t cassiterite concentrates are largely due to selective mining of vein style mineralisation; but many deposits were often spectacularly rich. The largest deposits, which include the Tommy Burns, Vulcan, Arbouin and Governor Norman, are located in the Herberton tin field. An average grade in excess of 10kg/t cassiterite concentrates and the presence of numerous deposits which produced in excess of 1 000t cassiterite concentrates demonstrates the importance of the Cairns region as a major tin province.

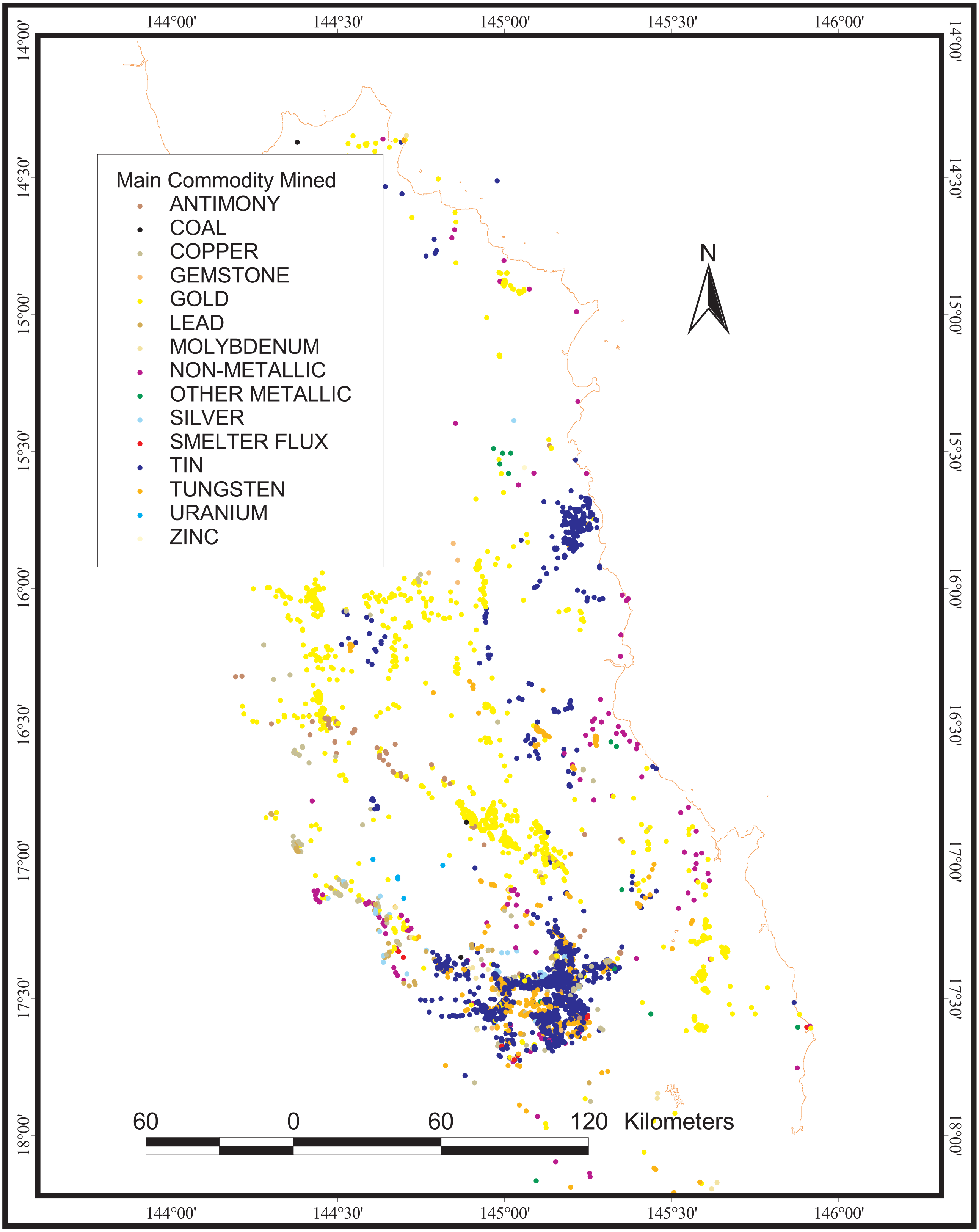


Figure 78. Distribution of mines classified by major commodity for the Cairns region.

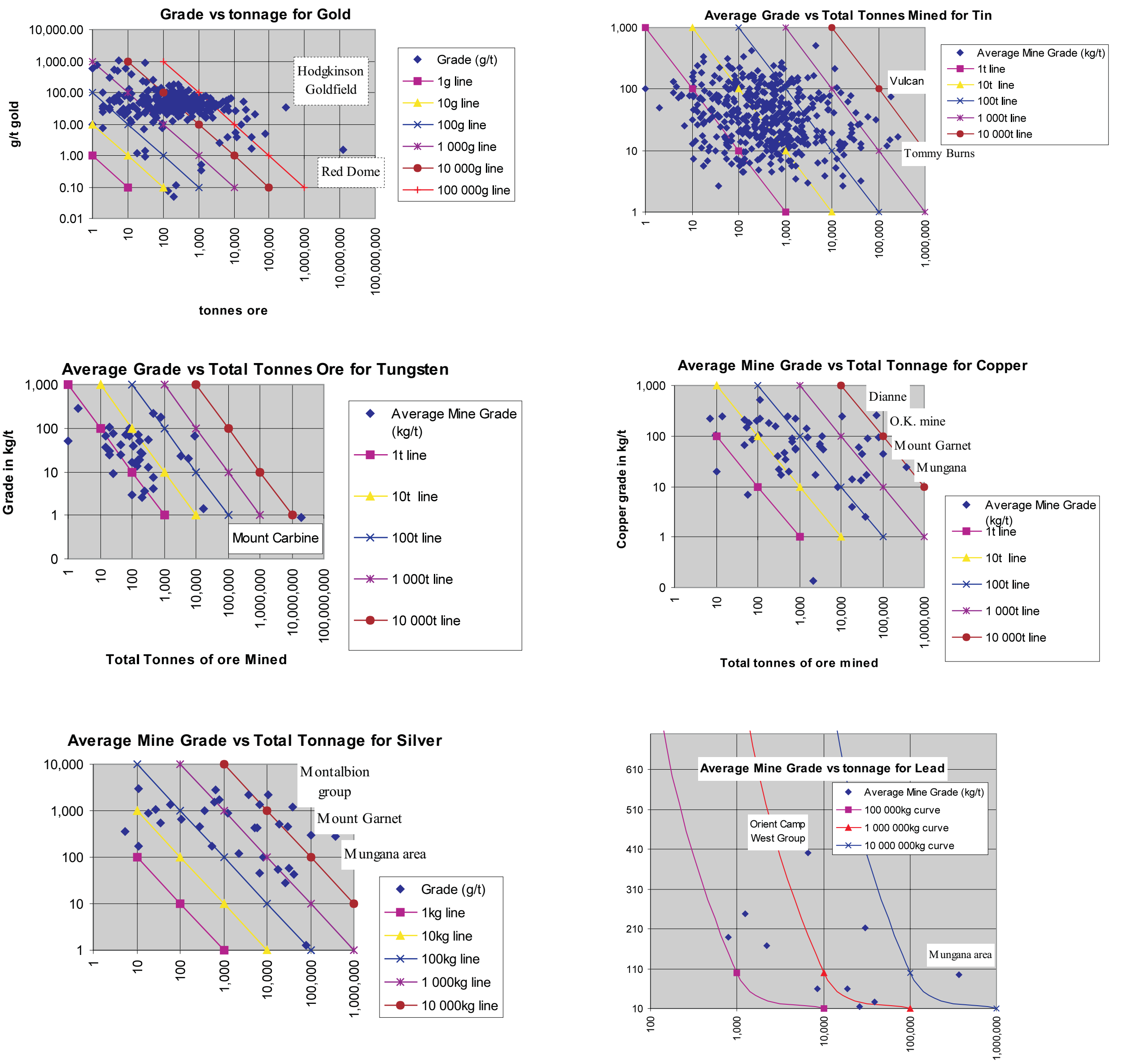


Figure 79. Grade-tonnage diagrams summarising known production of the main commodities mined in the Cairns region.

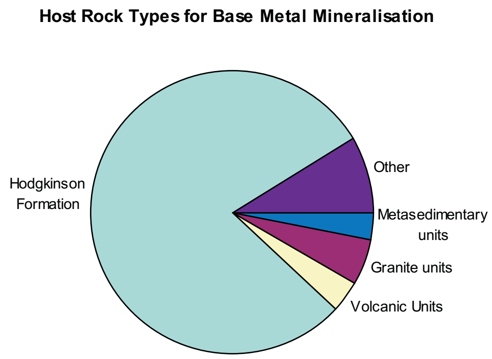
The production and grade of tungsten (Figure 79) reflects the presence of numerous small but commonly high-grade deposits in the Cairns region. The low grade and high tonnage outlier represents production from the Mount Carbine deposit. The higher grades for the smaller deposits again reflects selective mining and ore sorting techniques.

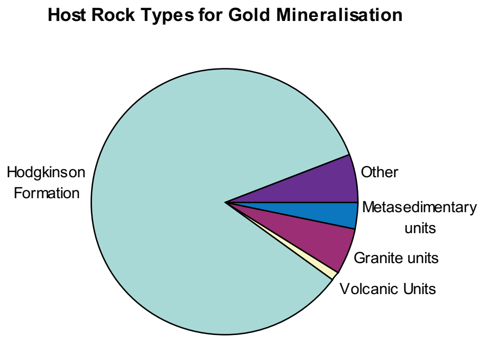
The production information for copper, lead, and silver are summarised in Figure 79. The lead data represent production mainly from the Mungana area. However, the highest grade ores were derived from the Orient Camp West group of mines, located west of Herberton. The moderate lead tonnages were derived from mixed sulphide ores and attest to the rich but small nature of the lead mineralisation mainly from skarn deposits.

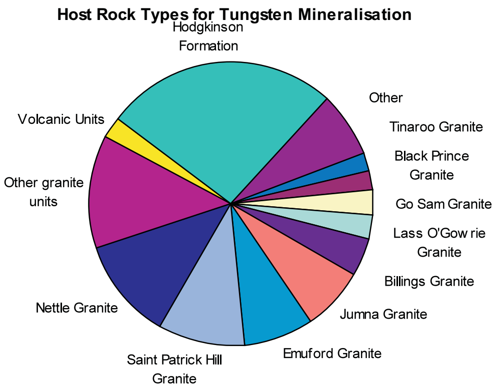
Copper and silver ores were mined mainly from the Mount Garnet and O.K. deposits. Smaller deposits at Montalbion and Mungana were characterised by significantly high-grade ores. Ores from all these mines were very rich but sorting has skewed the data towards higher grades. Several mines produced >10 000t copper and 10 000kg of silver. The Cairns region has the potential to host medium sized base-metal deposits.

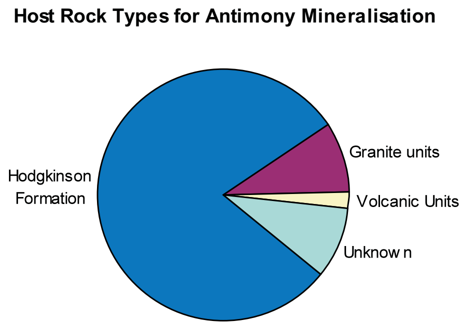
CORRELATION OF MINERALISATION AND GEOLOGICAL UNITS

The abundance of mineral deposits in a particular formation have been compiled and









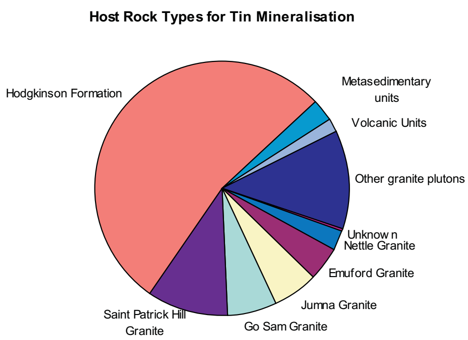


Figure 80. Host rock types for major commodity groups in the Cairns region.

used to generate the following pie charts. These charts attempt to better demonstrate the relationship between mineralisation and host rock types.

The host units for 2 092 tin deposits are displayed on Figure 80. This figure illustrates the concentration of tin mineralisation in metasedimentary rocks of the Hodgkinson Formation and in the Saint Patrick Hill, Go Sam, Jumna, Emuford and Nettle Granites. The mineralisation in the Hodgkinson Formation is developed mainly in zones adjacent to fertile granite plutons. The principal association of tin mineralisation with numerous granite plutons indicates multiple mineralising events occurred in the region. The five main granite plutons depicted in Figure 80 are all members of the O'Briens Creek Supersuite, which identifies this supersuite as highly prospective for tin mineralisation. Significant tin mineralisation is also associated with the Collingwood and Mount Hartley Granites (Cooktown Supersuite) in the Cooktown Tin Field.

Antimony mineralisation is mainly restricted to the Hodgkinson Formation. A total of 177 mineral occurrences in the region are displayed in Figure 80 illustrating this association. The granite-hosted deposits are in the Herberton area.

The host rocks for tungsten mineralisation are also shown in Figure 80. It is important to recognise that many tungsten deposits occur in the Hodgkinson Formation adjacent to granite plutons. The mineralisation source is therefore not recognised in the pie chart presented on Figure 80. The absence of the Mount Carbine Granite (which is thought to have been the primary source of the largest tungsten deposit in the study area) from this chart illustrates this point. The Nettle, Saint Patrick Hill and Emuford Granites have strong associations with tungsten mineralisation.

Gold mineralisation is predominantly hosted by the Hodgkinson Formation (Figure 80), mainly in the Hodgkinson and Palmer River Gold Fields. These occurrences are slate-belt gold deposits. The presence of relatively few gold deposits in other units emphasises the dominance of slate-belt gold occurrences over other styles of mineralisation such as volcanic-related epithermal deposits. This figure is based on the number of individual occurrences (1183 occurrences) ignoring deposit size. It therefore tends to be skewed towards the abundant small deposits, resulting in the under emphasis of host rocks such as the Chillagoe Formation (included under metasedimentary units) which hosts several significant gold deposits.

Hodgkinson Formation metasedimentary rocks (Figure 80) are the principal host rock for base-metal mineralisation. The mineral assemblages of 1 262 mines contain some base metal minerals. The largest base-metal deposits, such as the O.K. and Dianne mines, are hosted by Hodgkinson Formation metasediments. Numerous deposits in the Herberton area (*e.g.* Copper Firing Line) are related to granites but are hosted by Hodgkinson Formation metasediments. This under emphasises the granite-related base metal mineralising systems within the study area.

The mineralisation density against the distribution of the host rock types is displayed in Figure 81. This map is constructed by calculating the surface area of the major rock classes and dividing by the number of occurrences known to occur within these rocks. The Herberton, Cooktown and Chillagoe areas are centres of intense mineralisation. The large number of mines in the Herberton and Cooktown areas proportional to the area of the granites is also emphasised by this diagram. The Hodgkinson Formation depicted in Figure 88, when considered as a whole, has a density of mineralisation equivalent to one occurrence in every 10km^2. This very extensive unit is considered likely to contain additional, undiscovered mineral deposits. The very dark centres in the Herberton area are the result of a proportionally small area of outcrop and large number of occurrences which has given the high mineralisation density.

STRUCTURAL AND LINEAMENT ANALYSIS

The available structural information for the Cairns region is displayed with the distribution of all recorded mineralisation in the Cairns region as Figure 78. The strong structural influence on the mineralisation is apparent. Major centres of mineralisation clearly correlate with the prominent north-west-trending structures throughout the Hodgkinson Formation.

The concentration of gold and base metal mineralisation adjacent to the Palmerville Fault in the Chillagoe-Mungana area is pronounced. The marked concentration of gold mineralisation along major north-west-trending structures in the centre of the Hodgkinson Province is not surprising considering the structural dependence typically displayed by slate-belt gold mineralisation.

The distribution of tin mineralisation is largely unrelated to major structures. It is mainly influenced by granite chemistry and smaller scale structures (not shown on Figure 78) related to granite emplacement. The regional distribution of the granite plutons may however be the result of deep crustal structures. The presence of centres of tungsten mineralisation fringed by tin deposits forms a crude zonation which is probably related to elemental zonation away from the mineralising source (tungsten mineralisation closer to source).

POTENTIAL EXPLORATION MODELS APPLICABLE TO THE CAIRNS REGION

The presence of areas within the Cairns region which have experienced slightly higher grades of metamorphism than the regional greenschist facies have been noted during the geological mapping (*e.g.* Mount Madden dome west of the Cannibal Creek Granite). These areas probably indicate the presence of granitic intrusives at shallow depths. The presence of such intrusives may create a favourable environment for the formation of mineral deposits either directly related to fluids

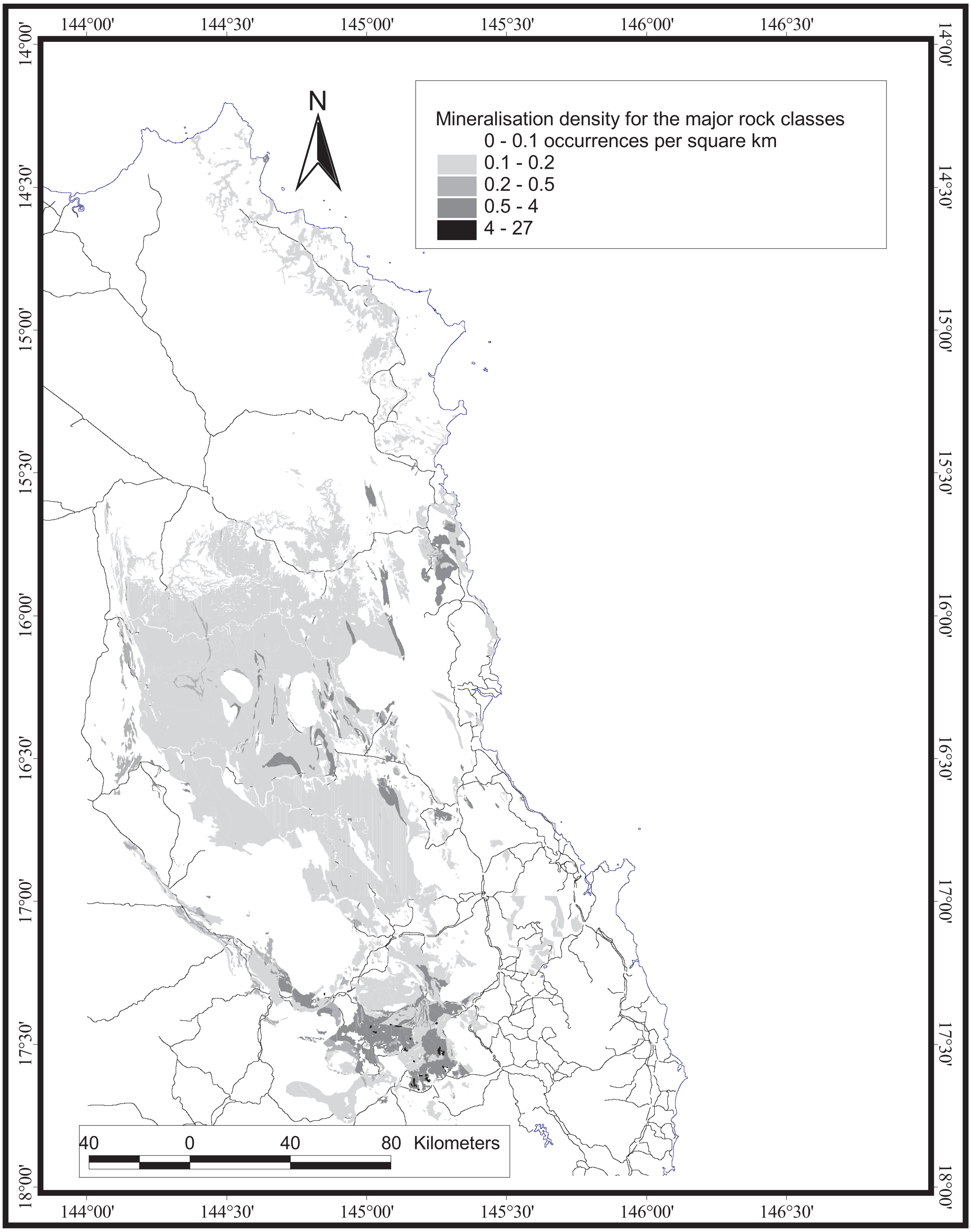


Figure 81. Mineralisation density for the major rock classes.

emanating from the intrusives or to convective systems established within the meteoric waters scavenging minerals from the enclosing country rocks.

The model proposed by Rowins & others (1997) for the Telfer Dome deposit in Western Australia is relevant to exploration within the Hodgkinson Province of the Cairns region. This model proposes that granites act as heat sources to drive thermal convection cells that circulate saline fluids to scavenge minerals from the enclosing sedimentary rocks. Regional-scale deep structures tap the mineralising fluids and channel them into higher-level trap sites. This model is similar to the porphyry copper (±gold) model but the absence of hornfels zones, proximal granites and characteristic porphyry alteration suggests the Telfer Dome system formed distal to the heat source. Rowins & others (1997) believe the Telfer lineament may have acted as the channel way for the system.

Deep regional structures in the Cairns region such as the Kingsborough, Retina, and Groganville Faults all traversing known gold mining centres may have acted in a similar fashion. These structures, possibly in conjunction with granitic intrusives at shallow depths, may have created a favourable environment for a Telfer model event to develop.

Ewers (1998) considers potential exists for carbonate-hosted lead-zinc mineralisation within the Chillagoe Formation. He also believes that the formation of the Little River Coal Measures, Mount Mulligan Coal Measures and Normanby Formation in fluvial-lacustrine-estuarine environments, the presence of carbonaceous material and proximity to felsic igneous rocks (uranium source) suggests that potential exists for sandstone-hosted uranium deposits.

Epithermal styles of mineralisation are another deposit model Ewers (1998) considers worthy of further study. The presence of extensive Carboniferous–Permian subaerial volcanic rocks and related high level intrusives provides a suitable setting for this style of mineralisation. Ewers (1998) believes that further studies into the oxygen isotope depletion patterns in high level igneous rocks may discriminate areas prospective for low sulphidation (adularia-sericite type) epithermal gold mineralisation.

These studies have been completed in the southern areas of the Featherbed Cauldron Complex and indicate that if epithermal systems did develop they have either been obscured by later volcanism or removed by erosion (Ewers, 1998).

MASS BALANCE CALCULATION FOR THE HODGKINSON FORMATION

The Hodgkinson Formation hosts numerous slate-belt gold deposits. The main centres of this style of mineralisation are the Hodgkinson and Palmer River Gold Fields. Studies of the Hodgkinson Gold Field indicate that these deposits formed from deeply sourced fluids probably generated during regional tectonism (Golding & others, 1990) at temperatures ranging from 285–335°C (Peters, 1987) during the late Carboniferous (Morrison, 1988).

In the following calculations the gold present in these deposits is considered to have been derived by scavenging processes from the host country rocks and transported in Au-S complexes. To represent the dominant rock type of the Hodgkinson Formation I have used the background gold content for sandstone and siltstone obtained from 105 samples published by Romberger (1988). These values range from 2.1–109ppb gold with an average of 3ppb gold. The total volume of Hodgkinson Formation metasediments in the region is estimated to be within the range of 24 000–~144 000km^3 (based on an area of 16 000km^2 and a minimum depth estimate of 1.5–9km). The best approximation of the total gold production from slate-belt style gold deposits in this region from both lode and alluvial sources is 61 000kg gold. This is probably an underestimation because of the poor recording procedures in the early mining history. Alluvial gold production is included as it is assumed that lode deposits were the primary source of this gold. Figure 82 shows these figures for a range of rock volumes and calculated gold endowment.

Using these figures the calculated volume of source rock necessary to derive the total known amount of gold produced from the Hodgkinson Formation metasediments is 80km^3. This is assuming a 10% leaching of gold from the source rock by circulating hydrothermal solutions. The efficiency of extraction and porosity of the source rocks influences the scavenging process significantly but as a guide to the potential of the region to produce further significant gold deposits this calculation is useful. The small volume of source rock necessary for scavenging processes to leach a significant amount of gold is illustrated in Figure 82. Given a favourable combination of factors to drive hydrothermal fluids and the presence of numerous major structures to act as suitable plumbing or trap sites it is highly probable that significant undiscovered gold deposits exist in the Hodgkinson Formation.

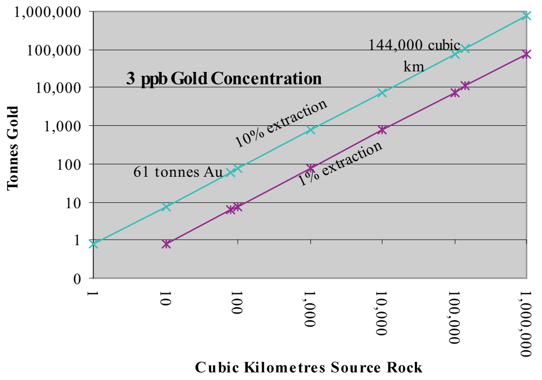


Figure 82. Volume of rock and gold endowment calculation for the Hodgkinson Formation.

CONCLUSIONS

The distribution of the major intrusive-related mineralising systems within the Cairns region is related to granite chemistry. Tin mineralisation in general is associated with fractionated, reduced S and I-type granites. Copper-gold mineralisation is associated with magnetite and/or sphene bearing oxidised, intermediate I-type granites and molybdenum is associated with the more fractionated and oxidised members of this type. The diversity of mineral assemblages present within the known centres of mineralisation is the result of elemental zonation within the mineralising systems. This zonation is typically expressed as an inner zone of tin-tungsten mineralisation, moving outwards from the intrusive base metals then arsenic minerals form with antimony representing the outer zone. Overprinting, initial elemental endowment and gradational/telescoping features complicate this simplistic zonation pattern. Potential exists to identify new prospective regions within the study area from the analysis of existing granite chemistry and compilation of further data, particularly from undivided or poorly studied plutons.

The influence of regional structures on the distribution of mineralisation is a consistent theme for all the deposit models studied. The focusing influence of faults on mineralising systems and the interaction with host rocks are critical components in the formation of many ore deposits in the Cairns region. This influence is particularly apparent for the slate-belt gold mineralisation in the Hodgkinson and Palmer River Gold Fields.

REFERENCES

AMOS, B.J., 1962: Palaeozoic structural geology of the Cooktown 1:250 000 Sheet area. Bureau of Mineral Resources, Australia, Record, 1962/136.

AMOS, B.J. & DE KEYSER, F., 1964: Mossman. *Queensland 1:250 000 Geological Series — Explanatory Notes*. Bureau of Mineral Resources, Australia.

ANONYMOUS, 1906: Mitchell River Antimony Mines. *Queensland Government Mining Journal*, **7**(78), 582.

ARNOLD, G.O., 1975: A structural and tectonic study of the Broken River Province, north Queensland. Ph.D. Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

ARNOLD, G.O. & FAWCKNER, J.F., 1980: The Broken River and Hodgkinson Provinces. *In* Henderson, R.A. & Stephenson, P.J. (Editors): *The geology and geophysics of northeastern Australia*. Geological Society of Australia, Queensland Division, Brisbane, 175–189.

ATKINSON, W.W. jr. & EINAUDI, M.T, 1978: Skarn formation and mineralization in the contact aureole at Carr Fork, Birtgham, Utah. *Economic Geology*, **73**, 1326–1365.

BAILEY, J.C., 1969: Geochemistry of Georgetown granites. Ph.D. Thesis, Australian National University, Canberra, Department of Geology.

BAILEY, J.C., 1977: Petrochemistry of the Claret Creek Ring Complex, northeast Queensland. *Journal of the Geological Society of Australia*, **24**, 1–14.

BAILEY, J.C., 1984: Geochemistry and origin of horneblende-bearing xenoliths in the I-style Petford Granite, north-east Queensland. *Australian Journal of Earth Sciences*, **31**, 7–23.

BAILEY, J.C., MORGAN, W.R. & BLACK, L.P., 1982: Geochemical and isotopic evidence for the age, orogenic setting and petrogenesis of the Nychum volcanic association, north Queensland. *Journal of the Geological Society of Australia*, **29**, 375–393.

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

BAIN, J.H.C., MACKENZIE, D.E., WITHNALL, I.W. & CHAMPION, D.C., 1997: Silurian–Devonian. *In* Bain, J.H.C. & Draper, J.J. (Compilers & Editors): North Queensland Geology. *Australian Geological Survey Organisation Bulletin* **240**, *and Queensland Department of Mines and Energy Queensland Geology*, **9**(3), 35–36.

BALL, L.C., 1909: Mercury, copper and coal mines, Little River, Cook District. *Queensland Government Mining Journal*, **10**(208), 281–284.

BALL, L.C., 1917: Mount Mulligan Coalfield. *Queensland Government Mining Journal*, **18**(208), 444–453.

BARR, M., 1994: Testing and Development — An Evolution from Deposit Definition to Mining at the Red Dome Mine and Environs. Report held by Economic Geology Research Unit, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

BARR, M., 1995: The Red Dome Au-Cu Skarn Deposit and the Mungana Au-Cu-Base Metal Deposit, Alteration-Mineralisation-Brecciation Textures. Report held by Economic Geology Research Unit, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

BARRON, L.M., LISHMUND, S.R., OAKES, G.M. & BARRON, B.J., 1994: Subduction diamonds in New South Wales: Implications for exploration in eastern Australia. *Geological Survey of New South Wales, Quarterly Notes* **94**, 1–23.

BARRON, P.T.C., 1990: AP 4403M, Mount Mulgrave, final report for the period ending 22.8.89. Held by the Department of Mines and Energy, Queensland as CR 21285.

BATEMAN, R., 1983: Structure, petrology and emplacement processes of the Cannibal Creek Granite, Queensland. Ph.D. Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

BATEMAN, R., 1985a: Aureole deformation by flattening around a diapir during *in situ* ballooning: the Cannibal Creek Granite. *Journal of Geology*, **93**, 293–310.

BATEMAN, R., 1985b: Progressive crystallisation of a granitoid and its relationship to stages of emplacement. *Journal of Geology*, **93**, 645–662.

BATEMAN, R., 1989: Cannibal Creek Granite: post-tectonic 'ballooning' pluton or pre-tectonic piercement diapir?: a discussion. *Journal of Geology*, **97**, 766–768.

BATES, R.L. & JACKSON, J.A., (Editors) 1980: *Glossary of Geology*. Second Edition. American Geological Institute, Falls Church.

BEAVIS, F.C., 1976: Ordovician. *In* Douglas, J.G. & Ferguson, J.A. (Editors): *Geology of Victoria*. Geological Society of Australia, Victorian Division, Melbourne, Special Publication No. 5, 25–44.

BELL, T.H., 1986: Foliation development and refraction in metamorphic rocks: reactivation of earlier foliations and decrenulation due to shifting patterns of deformation partitioning. *Journal of Metamorphic Geology*, **4**, 421–444.

BELL, T.H. & DUNCAN, A.C., 1978: A rationalised and unified shorthand terminology for lineations and fold axes in tectonites. *Tectonophysics*, **47**, T1–T5.

BERGE, J.S., BROWNLEE, J.H., & RINGROSE, R.C., 1899: List of minerals, Walsh and Tinaroo Mining District, north Queensland. *Proceedings of the Royal Society of Queensland*, **15**, 47–69.

BERNECKER, T., 1993: A sedimentation model for the Chillagoe Formation in the Mungana area, north Queensland. Ph.D. Thesis, La Trobe University, Bundoora (Victoria), Department of Earth Sciences.

BERTHÉ, D., CHOUKROUNE, P. & GAPAIS, D., 1979: Orientations préferentielles du quartz et orthogneissification progressive en régime cisaillant: l'example du cisaillement sud Americain. *Bulletin Mineralogique*, **102**, 265–272.

BEST, J.G., 1960: Some Cainozoic basaltic volcanoes in north Queensland. Bureau of Mineral Resources, Australia, Record, 1960/78.

BEST, J.G., 1962: Atherton. *Queensland 1:250 000 Geological Series — Explanatory Notes*. Bureau of Mineral Resources, Australia.

BHATIA, M.R. & CROOK, K.A.W., 1986: Trace element characteristics of greywackes and tectonic setting discrimination of sedimentary basins. *Contributions to Mineralogy and Petrology*, **92**, 181–193.

BHATIA, M.R., 1983: Plate tectonics and geochemical composition of sandstones. *Journal of Geology*, **91**, 611–627.

BIRCH, J.S., 1998: Atric Gold Deposit. *In* Berkman, D.A. & Mackenzie, D.H. (Editors): Geology of Australasian and Papua New Guinean Mineral Deposits. *Australasian Institute of Mining and Metallurgy, Monograph*, **22**, 663–668.

BIRD, E.C.F., 1970: Coastal evolution in the Cairns district. *The Australian Geographer*, **11**(3), 327–335.

BIRD, E.C.F., 1971: Holocene shore features at Trinity Bay, north Queensland. *Search*, **2**(1), 27–28.

BIRD, E.C.F., 1972a: Recent changes on the shoreline of the Barron delta. *North Queensland Naturalist*, **39**(157).

BIRD, E.C.F., 1972b: Beach-ridge plain at Cairns. *North Queensland Naturalist*, **39**(158).

BIRD, E.C.F., 1973: Depositional evidence of fluvial sediment yield: an example from north Queensland. *The Australian Geographer*, **12**(3), 250–253.

BLACK, L.P., 1974: Isotopic ages of rocks from the Georgetown–Mount Garnet–Herberton area, north Queensland. Bureau of Mineral Resources, Australia, Record 1974/138.

BLACK, L.P., 1978: Isotopic ages of rocks from the Georgetown/Mount Garnet/Herberton area, north Queensland. *Bureau of Mineral Resources, Australia, Report* **200** (BMR Microform MF28).

BLACK, L.P., 1980: Rb–Sr systematics of the Claret Creek Ring Complex and their bearing on the origin of Upper Palaeozoic igneous rocks in northeast Queensland. *Journal of the Geological Society of Australia*, **27**, 157–166.

BLACK, L.P., BLAKE, D.H. & OLATUNJI, J.A., 1978: Ages of granites and associated mineralisation in the Herberton Tinfield of northeast Queensland. *BMR Journal of Australian Geology and Geophysics*, **3**, 173–180.

BLACK, L.P., BULTITUDE, R.J., SUN, S-s., KNUTSON, J. & BLEWETT, R.S., 1992a: Emplacement ages of granitic rocks in the Coen Inlier (Cape York): implications for local geological evolution and regional correlation. *BMR Journal of Australian Geology and Geophysics*, **13**, 191–200.

BLACK, L.P., BULTITUDE, R.J., SUN, S-s., KNUTSON, J. & BLEWETT, R.S., 1992b: U–Pb zircon analytical results for granitic rocks from the Coen Inlier, north Queensland. *Australian Geological Survey Organisation Record*, **1992/64**.

BLACK, L.P. & McCULLOCH, M.T., 1990: Isotopic evidence for the dependence of recurrent felsic magmatism on new crust formation: An example from the Georgetown region of north-eastern

Australia. *Geochimica et Cosmochimica Acta*, **54**, 183–196.

BLAIR, T.C. & BILODEAU, W.L., 1988: Development of tectonic cyclotherms in rift, pull-apart, and foreland basins: sedimentary response to episodic tectonism. *Geology*, **16**, 517–520.

BLAKE, D.H., 1972: Regional and economic geology of the Herberton/Mount Garnet area — Herberton Tinfield, north Queensland. *Bureau of Mineral Resources, Australia, Bulletin*, **124**.

BLAKE, D.H., 1974: An analysis of metal distribution and zoning in the Herberton Tinfield, north Queensland. Discussion, *Economic Geology*, **69**, 557–562.

BLAKE, D.H., & SMITH, J.W., 1970: Mineralogical zoning in the Herberton Tinfield, north Queensland, Australia. *Economic Geology*, **65**, 993–997.

BLAKE, D.H., & SMITH, J.W., 1971: Discussion on mineralogical zoning in the Herberton Tinfield, north Queensland — a reply. *Economic Geology*, **66**, 815.

BLEVIN, P.L., 1990: The tungsten–molybdenum–bismuth hydrothermal mineralising system at Bamford Hill, north-east Queensland. Ph.D. Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

BLEVIN, P.L., 1994: Identification of favourable exploration/resource areas in eastern Australia using magma compositions. *In* Henderson, R.A. & Davis, B.K. (Editors): Extended Conference Abstracts, New Developments in Geology and Metallogeny: Northern Tasman Orogenic Zone, *EGRU Contribution* **50**, 137–140.

BLEVIN, P.L. & CHAPPELL, B.W., 1992: The role of magma sources, oxidation states and fractionation in determining the granite metallogeny of eastern Australia. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **83**, 305–316.

BLUNDY, J.D. & HOLLAND, T.J.B., 1990: Calcic amphibole equilibria and a new amphibole–plagioclase geothermometer. *Contributions to Mineralogy and Petrology*, **104**, 203–224.

BLUNDY, J.D. & WOOD, B.J., 1991: Crystal-chemical controls on the partitioning of Sr and Ba between plagioclase feldspar, silicate melts, and hydrothermal solutions. *Geochimica et Cosmochimica Acta*, **55**,193–209.

BRANCH, C.D., 1966: Volcanic cauldrons, ring complexes, and associated granites of the Georgetown Inlier, Queensland. *Bureau of Mineral Resources, Australia, Bulletin*, **76**.

BROADHURST, E., 1952: The Geology of the Mungana–Redcap area, Chillagoe district. *Australasian Institute of Mining and Metallurgy, Proceedings No.* **164–165**, 5–30.

BRUVEL, F.J., BULTITUDE, R.J., CULPEPER, L.G., GARRAD, P.D., LAM, J.S.F. & MORWOOD, D.A., 1991: Mineral Occurrences — Ravenshoe 1:100 000 Sheet area, Queensland. *Queensland Resource Industries Record* **1991/5**.

BULTITUDE, R.J., 1993: Granites of the Cape Melville 1:250 000 Sheet area. *Queensland Geological Record*, **1993/10**.

BULTITUDE, R.J., 1996: Palmerville Fault system. *In* Bultitude, R.J & Rees, I.D. (Compilers): Walsh, second edition. *Queensland 1:250 000 Geological Series — Explanatory Notes*. Geological Survey of Queensland, Department of Minerals & Energy, Queensland, 67.

BULTITUDE, R.J. & CHAMPION, D.C., 1992: Granites of the eastern Hodgkinson Province — their field and petrographic characteristics. *Queensland Resource Industries Record*, **1992/6**.

BULTITUDE, R.J., CHAMPION, D.C. & MACKENZIE, D.E., 1993b: New and revised intrusive units in the Chillagoe region, north Queensland. *Queensland Geological Record*, **1993/28**.

BULTITUDE, R.J., CRANFIELD, L.C., HEGARTY, R.A., HALFPENNY, R.W., RIENKS, I.P. & DOMAGALA, J., 1985: Summary of results of field work in the Mossman and Atherton 1:250 000 Sheet areas, 1984 field season — RGMP Progress Report. Geological Survey of Queensland Record, 1985/31.

BULTITUDE, R.J. & DOMAGALA, J., 1988: Geology of the Bellevue 1:100 000 Sheet area, northeastern Queensland — preliminary data. Queensland Department of Mines Record, 1988/5.

BULTITUDE, R.J. & DONCHAK, P.J.T., 1992: Pre-Mesozoic stratigraphy and structure of the Maytown region. *Queensland Resource Industries Record*, **1992/5**.

BULTITUDE, R.J., DONCHAK, P.J.T., DOMAGALA, J. & FORDHAM, B.G., 1993a: The pre-Mesozoic stratigraphy and structure of the western Hodgkinson Province and environs. *Queensland Geological Record*, **1993/29**.

BULTITUDE, R.J., DONCHAK, P.J., DOMAGALA, J., FORDHAM, B.G. & CHAMPION, D.C., 1990: Geology and tectonics of the Hodgkinson Province, north Queensland. *In Proceedings Pacific Rim Congress 90*. Australasian Institute of Mining and Metallurgy, Parkville (Victoria), **III**, 75–81.

BULTITUDE, R.J., DONCHAK, P.J.T., DOMAGALA, J., ROBERTSON, A.D., GRIMES, K.G. & JORGENSEN, P.J., 1991: Geology of the Cooktown 1:100 000 Sheet area, north Queensland. *Queensland Resource Industries Record*, **1991/7**.

BULTITUDE, R.J., FANNING, C.M., CHAMPION, D.C. & REES, I.D., 1996a: Pre-Silurian rocks of the Barnard Metamorphics: a basement? block on the SE margin of the Hodgkinson Province, north Queensland. *Geological Society of Australia Abstracts*, **41**, 69.

BULTITUDE, R.J. & GARRAD, P.D. (Compilers), 1997: Geology of the Innisfail region. *Queensland Geological Record*, **1997/2**.

BULTITUDE, R.J., GARRAD, P.D. & ROBERTS, C.W., 1997: *Hodgkinson Province Geology, Queensland* (1:500 000-scale map). Department of Mines and Energy, Queensland.

BULTITUDE, R.J., GARRAD, P.D. & ROBERTS, C.W., 1998b: *Mungana Region* (1:100 000-scale map). Department of Mines and Energy, Queensland.

BULTITUDE, R.J., GARRAD, P.D. & ROBERTS, C.W., 1998c: *Laura Region* (1:100 000-scale map). Department of Mines and Energy, Queensland.

BULTITUDE, R.J., GARRAD, P.D. & ROBERTS, C.W., 1998d: *Maytown Region* (1:100 000-scale map). Department of Mines and Energy, Queensland.

BULTITUDE, R.J., GARRAD, P.D., ROBERTS, C.W. & WEGNER, S., 1998a: *Innisfail, Queensland* (second edition 1:250 000-scale map). Department of Mines and Energy, Queensland.

BULTITUDE, R.J., REES, I.D. & GARRAD, P.D., 1995: *Bellevue Region, Sheet 7764, part Sheet 7864, Queensland, 1:100 000 Geological Map Commentary*. Department of Minerals and Energy, Queensland, Brisbane.

BULTITUDE, R.J., REES, I.D., GARRAD, P.D., CHAMPION, D.C. & FANNING, C.M., 1996b: Mossman, second edition. *Queensland 1:250 000 Geological Series — Explanatory Notes*. Geological Survey of Queensland, Department of Minerals and Energy, Queensland.

BURNHAM, C.W. & OHMOTO, H., 1980: Late-stage processes of felsic magmatism. *In* Ishihara, S. & Takenouchi, S. (Editors): Granitic magmatism and related mineralization. *Society of Mining Geologists of Japan, Tokyo, Mining Geology Special Issue*, **8**, 1–11.

BURT, D.M., 1977, Mineralogy and petrology of skarn deposits. *Society Italiana Mineralogia Petrolgia Rendiconti*, **33**, 859–873.

CARR, A.F., 1975: Little River–Oakey Creek district, Queensland. *In* Traves, D.M. & King, D. (Editors): Economic Geology of Australia and Papua New Guinea — Part 2: Coal. *Australasian Institute of Mining and Metallurgy, Monograph Series No.* **6**, 251–252.

CAS, R.A.F. & WRIGHT, J.V., 1987: *Volcanic successions: modern and ancient*. Chapman & Hall, London.

CAWOOD, P.A., 1976: Cambro–Ordovician strata, northern New South Wales. *Search*, **7**, 317–318.

CHAMPION, D.C., 1991: The felsic granites of far north Queensland. Ph.D. Thesis, Australian National University, Canberra, Department of Geology.

CHAMPION, D.C. & BULTITUDE, R.J., 1994: Granites of the eastern Hodgkinson Province. II. Their geochemical and Nd–Sr isotopic characteristics and implications for petrogenesis and crustal structure in north Queensland. *Queensland Geological Record*, **1994/1**.

CHAMPION, D.C. & CHAPPELL, B.W., 1992: Petrogenesis of felsic I-type granites: an example from northern Queensland. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **83**, 115–126.

CHAMPION, D.C. & HEINEMANN, M. A., 1994: Igneous rocks of northern Queensland: 1:500 000 map and explanatory notes. *Australian Geological Survey Record*, **1994/11**.

CHAPPELL, B.W. & CHAMPION, D.C., 1994: Determination of felsic granite types and its application to north Queensland. *In* Henderson, R.A. & Davis, B.K. (Editors): Extended Conference Abstracts, New developments in geology and metallogeny: northern Tasman Orogenic Zone. *EGRU Contribution* **50**, 141–145.

CHAPPELL, B.W. & WHITE, A.J.R., 1984: I- and S-type granites in the Lachlan Fold Belt, southeastern Australia. *In* Xu Keqin & Tu Guanchi (Editors): *Geology of granites and their metallogenetic relations*. Science Press, Beijing, 87–101.

CHAPPELL, B.W. & WHITE, A.J.R., 1992: I- and S-type granites in the Lachlan Fold Belt. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **83**, 1–26.

CHAROY, B., & POLLARD, P.J., 1989: Albite rich and silica-depleted metasomatic rocks at Emuford, north-east Queensland: mineralogical, geochemical, and fluid inclusion constraints on hydrothermal evolution and tin mineralisation. *Economic Geology*, **84**, 1850–1874.

CLARKE, G.W., 1990: The role of fluids in the evolution of granites and associated Mo, W and Sn deposits, Herberton district, north Queensland. Ph.D thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

CLARKE, G.W., 1995: Geological and geochemical characteristics of granite-related mineralising systems in the Herberton District. *In* Beams, S.D. (Editor): Mineral deposits of north-east Queensland: geology and geochemistry. *EGRU Contribution* **52**, 247–277.

CLIMIE, A.J.,1974: Exploration of ML Application 2991-2992, Chillagoe, north Queensland. Report by Noranda Australia Ltd.

COMPSTON, W., WILLIAMS, I.S., ZHANG ZICHAO, J.L. & GUOGAN, M.A., 1992: Zircon U–Pb ages for the Early Cambrian time-scale. *Journal of the Geological Society of London*, **149**, 171–184.

CONEY, P.J., EDWARDS, A., HINE, R., MORRISON, F. & WINDRIM, D., 1990: The regional tectonics of the Tasman orogenic system, eastern Australia. *Journal of Structural Geology*, **12**, 519–543.

CONNAH, T.H., 1954: Iron deposit, Wild River. Report to the Chief Government Geologist, Queensland.

CONNAH, T.H., 1958: Summary Report — Limestone Resources of Queensland. *Geological Survey of Queensland Publication,* **292**, 20.

COOK, L., 1987: ML 5262, 5263, 7889, 8227 (Herberton), Geology of the Orient Area. Great Northern Mining Corporation NL. Held by the Department of Mines and Energy, Queensland as CR 22149.

COOPER, J.A., WEBB, A.W. & WHITAKER, W.G., 1975: Isotopic measurements in the Cape York Peninsula area, north Queensland. *Journal of the Geological Society of Australia*, **22**, 285–310.

COOPER, W., 1993: Queensland Mineral Commodity Report — silica sand. *Queensland Government Mining Journal*, **94**(September), 7–15.

COOPER, W., & SAWERS, J.D., 1990: Cape Flattery and Shelburne Bay silica sand deposits. *In* Hughes, F.E. (Editor): *Geology of the Mineral Deposits of Australia and Papua New Guinea*. Australasian Institute of Mining and Metallurgy, Parkville (Victoria), 1665–1667.

COX, D.P. & SINGER, D.A. (Editors) 1992: Mineral Deposit Models. *U.S. Geological Survey Bulletin* **1693**.

COXHEAD, B.A., 1997: Queensland Coals, Physical and Chemical Properties, Colliery and Company Information. Queensland Coal Board, Brisbane, Queensland, Australia.

CRANFIELD, L.C., 1990: Mossman 1 — preliminary and detailed lithological logs. *Queensland Resource Industries Record*, **1990/11**.

CRANFIELD, L.C. & HEGARTY, R.A., 1989: Geology of the Rumula 1:100 000 Sheet area (7964), northeast Queensland — preliminary data. *Queensland Department of Mines Record*, **1989/20**.

CROOK, K.A.W., 1974: Lithogenesis and geotectonics: the significance of compositional variation in flysch arenites (greywackes). *In* Dott, R.H. & Shaver, R.H. (Editors): Modern and Ancient Geosynclinal Sedimentation. *Society of Economic Palaeontologists & Mineralogists, Special Publication*, **19**, 304–310.

CROOK, K.A.W. & POWELL, C. McA., 1976: The evolution of the southeastern part of the Tasman Geosyncline. *25th International Geological Congress, field guide for Excursion 17A.*

CULPEPER, L.G., DENARO, T.J., MORWOOD, D.A., & BURROWS, P.E., 1994: Mineral occurrences — Butchers Hill, Cooktown, Battle Camp and Kennedy Bend 1:100 000 Sheet areas, Cape York Peninsula, Queensland. *Queensland Geological Record*, **1994/12**.

CULPEPER, L.G., LAM, J.S., MORWOOD, D.A. & BURROWS, P.E., 1990: Mineral Occurrence Data Sheets — Bellevue 1:100 000 Sheet area. *Queensland Resource Industries Record,* **1990/4**.

CUNEY, M. & FRIEDRICH, M., 1987: Physiochemical and crystal-chemical controls on accessory mineral paragenesis in granitoids: implications for uranium metallogenesis. *Mineralogical Bulletin*, **110**, 235–247.

CUTTLER, L.G., 1972: Herberton deep lead. *In* Blake, D.H., 1972: Regional and economic geology of the Herberton/Mount Garnet area — Herberton Tinfield, north Queensland. *Bureau of Mineral Resources, Australia, Bulletin*, **124**.

DARBY, P.R., 1993: EPM 8796 (Violet Vale), 8797 (Lily Vale), final report. Held by the Department of Mines and Energy, Queensland as CR 24546.

DASH, P.H. & CRANFIELD, L.C., 1993: Mineral occurrences — Rumula 1:100 000 Sheet Area, north Queensland. *Queensland Geological Record*, **1993/17**.

DASH, P.H. & MORWOOD, D.A., 1994: Mineral occurrences — Cairns 1:100 000 Sheet Area, north Queensland. *Queensland Geological Record,* **1994/6**.

DASH, P.H., 1991: A review of mineral occurrence data collection for metallogenic studies. Thesis submitted for progression to senior geologist. Queensland Department of Mines and Energy, Brisbane.

DASH, P.H., BARKER, R.M., MORWOOD, D.A., CULPEPER, L.G. & LAM, J.S., 1991: Mineral occurrences — Atherton 1:100 000 Sheet area. *Queensland Resource Industries Record,* **1991/14**.

DASH, P.H., GARRAD, P.D. & MITCHELL, G., 1988: Mineral occurrence data sheets — Chillagoe 1:100 000 Sheet area. *Queensland Department of Mines Record,* **1988/17**.

DAVIS, B.K., 1993: Mechanism of emplacement of the Cannibal Creek Granite with special reference to timing and deformation history of the aureole. *Tectonophysics*, **224**, 337–362.

DAVIS, B.K., 1994: Synchronous syntectonic granite emplacement in the South Palmer River region, Hodgkinson Province, Australia. *Australian Journal of Earth Sciences*, **41**, 91–103.

DAVIS, B.K., HENDERSON, R.A. & WYSOCZANSKI, R., 1998: Timing of granite emplacement under conditions of low strain in the northern Tasman Orogenic Zone, Australia. *Tectonophysics*, **284**, 179–202.

DAVIS, B.K., LINDSAY, M. & HIPPERTT, J.F.M., 1996: Gold mineralisation in the northern Hodgkinson Province, north Queensland, Australia. *James Cook University of North Queensland, Economic Geology Research Unit News — December Edition*, 14.

DAY, R.W., WHITAKER, W.G., MURRAY, C.G., WILSON, I.H. & GRIMES, K.G., 1983: Queensland Geology. A companion volume to the 1:2 500 000 scale geological map (1975). *Geological Survey of Queensland Publication*, **383**.

DAY, S.J. & FLETCHER, W.K., 1991: Concentration of magnetite and gold at bar and reach scales in a gravel-bed stream, British Columbia. *Journal of Sedimentary Petrology*, **61**, 871–882.

DE KEYSER, F., 1961: Geology and mineral deposits of the Mossman 1:250 000 Sheet area, north Queensland. Bureau of Mineral Resources, Australia, Record, 1961/110.

DE KEYSER, F., 1963: The Palmerville Fault — a 'fundamental' structure in north Queensland. *Journal of the Geological Society of Australia*, **10**(2), 273–278.

DE KEYSER, F., 1964: Innisfail, Queensland. *1:250 000 Geological Series — Explanatory Notes*. Bureau of Mineral Resources, Australia.

DE KEYSER, F., 1965: The Barnard Metamorphics and their relation to the Barron River Metamorphics and the Hodgkinson Formation, north Queensland. *Journal of the Geological Society of Australia*, **12**, 91–103.

DE KEYSER, F., 1966: Arfvedsonite in granites of the Ingham District, north Queensland. *Contributions to Mineralogy and Petrology*, **12**, 315–324.

DE KEYSER, F., FARDON, R.S.H. & CUTLER, L.G., 1965: Ingham, Queensland. *1:250 000 Geological Series — Explanatory Notes*. Bureau of Mineral Resources, Australia.

DE KEYSER, F. & LUCAS, K.G., 1968: Geology of the Hodgkinson and Laura Basins, north Queensland. *Bureau of Mineral Resources, Australia, Bulletin*, **84**.

DE KEYSER, F. & WOLFF, K.W., 1964: The geology and mineral resources of the Chillagoe area, Queensland. *Bureau of Mineral Resources, Australia, Bulletin*, **70**.

DEMPSEY, F., 1980: *Old mining towns of north Queensland*. Rigby Publishers Ltd, Brisbane.

DENARO, T,.J., CULPEPER, L.G., MORWOOD, D.A., & BURROWS, P.E., 1994a: Mineral occurrences — Helenvale 1:100 000 Sheet area, Cape York Peninsula, Queensland. *Queensland Geological Record*, **1994/13**.

DENARO, T.J., CULPEPER, L.G., MORWOOD, D.A. & BURROWS, P.E., 1994b: Mineral occurrences — Laura 1:100 000 Sheet area, Cape York Peninsula, Queensland. *Queensland Geological Record*, **1994/14**.

DENARO, T.J. & EWERS, G.R., 1995: Mineral Resource Assessment — Cape York Peninsula Land Use Strategy. *Queensland Minerals and Energy Review Series*, Department of Minerals and Energy, Queensland.

DENARO, T.J., MORWOOD, D.A., DUGDALE, J.S. & GARRAD, P.D., 1992: Mineral occurrences — Cape Melville 1:250 000 Sheet area, Cape York Peninsula, Queensland. *Queensland Resource Industries Record*, **1992/1**.

DENARO, T.J. & SHIELD, C.J., 1993: Coal and petroleum exploration, Cape York Peninsula. *Queensland Geological Record,* **1993/15**.

DENMEAD, A.K., 1932: Alluvial gold mining in Queensland. *Queensland Government Mining Journal*, **33**, 142–143.

DENMEAD, A.K., 1947a: Re coal Malanda. Report to Chief Government Geologist, Brisbane.

DENMEAD, A.K., 1947b: Mount Peter gold field. *Queensland Government Mining Journal*, **48**, 225–231.

DENMEAD, A.K., 1949: Mowbray River limestone. *Queensland Government Mining Journal*, **50**, 42–43.

DENMEAD, A.K., 1971: The Atherton Tableland. *In* Playford, G. (Editor): *Geological excursions handbook*. Australian and New Zealand Association for the

Advancement of Science and Geological Society of Australia, Queensland Division, Brisbane, 1–19.

DE ROO, J.A., 1988: Structural controls on the enhancement of the vein-type tungsten–tin ore at Mount Carbine, Queensland, Australia. *Economic Geology*, **83**, 1170–1180.

DERRICK, G.M. & OGIERMAN, J., 1990: AP 4276M, Starcke, north Queensland, Annual Report for the Period 12.05.87–11.05.88. Held by the Department of Mines and Energy, Queensland as CR 17673.

DOMAGALA, J., 1991: Geology of the Chillagoe Formation in the Mitchell River area, north Queensland. *Queensland Resource Industries Record*, **1991/17**.

DOMAGALA, J., 1997a: Mulgrave Formation. *In* Bain, J.H.C. & Draper, J.J. (Compilers & Editors): North Queensland Geology. *Australian Geological Survey Organisation Bulletin* ***240****, and Queensland Department of Mines and Energy Queensland Geology*, **9**(7), 229–231.

DOMAGALA, J., 1997b: Mountain Creek Conglomerate. *In* Bain, J.H.C. & Draper, J.J. (Compilers & Editors): North Queensland Geology. *Australian Geological Survey Organisation Bulletin* ***240****, and Queensland Department of Mines and Energy Queensland Geology*, **9**(7), 231.

DOMAGALA, J., 1997c: Van Dyke Litharenite. *In* Bain, J.H.C. & Draper, J.J. (Compilers & Editors): North Queensland Geology. *Australian Geological Survey Organisation Bulletin* ***240****, and Queensland Department of Mines and Energy Queensland Geology*, **9**(7), 231–232.

DOMAGALA, J., 1997d: Hodgkinson Formation. *In* Bain, J.H.C. & Draper, J.J. (Compilers & Editors): North Queensland Geology. *Australian Geological Survey Organisation Bulletin* ***240****, and Queensland Department of Mines and Energy Queensland Geology*, **9**(7), 232–233.

DOMAGALA, J. & FORDHAM, B.G., 1997: Chillagoe Formation. *In* Bain, J.H.C. & Draper, J.J. (Compilers & Editors): North Queensland Geology. *Australian Geological Survey Organisation Bulletin* ***240****, and Queensland Department of Mines and Energy Queensland Geology*, **9**(7), 232.

DOMAGALA, J., ROBERTSON, A.D. & BULTITUDE, R.J., 1993: Geology of the Butchers Hill 1:100 000 Sheet area, northern Queensland. *Queensland Geological Record*, **1993/30**.

DONCHAK, P.J.T., 1997: Hodgkinson Province. *In* Bain, J.H.C. & Draper, J.J. (Compilers & Editors): North Queensland Geology. *Australian Geological Survey Organisation Bulletin* ***240****, and Queensland Department of Mines and Energy Queensland Geology*, **9**(7), 263–267.

DONCHAK, P.J.T.& BULTITUDE, R.J., 1994: Geology of the Atherton 1:250 000 sheet. *Queensland Geological Record,* **1994/05**.

DONCHAK, P.J.T. & BULTITUDE, R.J., 1998: Atherton, second edition. *Queensland 1:250 000 Geological Series — Explanatory Notes*. Geological Survey of Queensland, Department of Mines and Energy, Queensland.

DONCHAK, P.J.T., BULTITUDE, R.J., ROBERTSON, A.D., HEGARTY, R.A. & HALFPENNY, R.W., 1992: Geology of the Helenvale and Mossman 1:100 000 Sheet areas, northern Queensland. *Queensland Resource Industries Record*, **1992/15**.

DRAPER, J.J., BAIN, J.H.C. & PAIN, C.F., 1997: Introduction. *In* Bain, J.H.C. & Draper, J.J. (Compilers & Editors): North Queensland Geology. *Australian Geological Survey Organisation Bulletin* ***240****, and Queensland Department of Mines and Energy Queensland Geology*, **9**(1), 1–7.

DUCK, B.H. & WALKER, M.D., 1983: Annual report on AP3309M, Mount Carbine, north Queensland. Pahminco Pty Ltd. Held by the Department of Mines and Energy, Queensland as CR 12772.

DUGDALE, J.L., 1989: AP4130M (Hodgkinson), 4283M (Mount McGann), 4992M (Mount Mulligan), Final Report for the period ended 30/10/89. Western Mining Corporation Ltd. Held by the Department of Mines and Energy, Queensland as CR 21223.

DUGDALE, J.S., 1991: A compilation of mine production data for the Cooktown, Thursday Island and Weipa mining districts from annual reports of the Department of Mines (1884–1988/89). *Queensland Resource Industries Record,* 1991/1.

DUNSTAN, B., 1905a: Monazite sand from Queensland. *Queensland Government Mining Journal*, **6**, 174–175 and *Geological Survey Publication*, **196**.

DUNSTAN, B., 1905b: Ironstone at Mount Lucy, Chillagoe district. *Geological Survey of Queensland Publication,* **196**, 6–10.

DUNSTAN, B., 1906: The ironstone of Mount Lucy, Chillagoe district. *Queensland Government Mining Journal*, **7**, 137–138.

DYSON, I.A., 1990: Fluvial models in placer gold exploration and their evaluation. *In Placer Deposits: A Symposium*, Australasian Institute of Mining and Metallurgy (Sydney Branch), 11–44.

EINAUDI, M.T, 1982a: Descriptions of skarns associated with porphyry copper plutons, southwestern North America. *In* Titley, S.R. (Editor): *Advances in Geology of the Porphyry Copper Deposits, Southwestern North America*. University of Arizona Press, 139–184.

EINAUDI, M.T, 1982b: General features and origin of skarns associated with porphyry copper plutons, southwestern North America. *In* Titley, S.R. (Editor): *Advances in Geology of the Porphyry Copper Deposits, Southwestern North America*. University of Arizona Press, Tucson, Arizona, 185–210.

EINAUDI, M.T., MEINERT, L.D. & NEWBERRY, R.J., 1981: Skarn Deposits. *Economic Geology, Seventy-Fifth Anniversary Volume 1905–1980*, 317–391.

EL BOUSEILY, A.M. & EL SOKKARY, A.A., 1975: The relation between Rb, Ba and Sr in granitic rocks. *Chemical Geology*, **16**, 207–219.

EMERY, K.O. & NOAKES, L.C., 1968: Economic placer deposits of the continental shelf. United Nations, Economic Commission for Asia and the Far East, Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas, *Technical Bulletin*, **1**, 95–111.

EWART, A., 1978: Some aspects of the geology of Hinchinbrook Island. *The Queensland Naturalist*, **22**(1–4), 25–30.

EWART, A., 1979: A review of the mineralogy and chemistry of Tertiary–Recent dacitic, latitic, rhyolitic and related salic volcanic rocks. *In* Barker, F. (Editor): *Trondhjemites, Dacites and Related Rocks*. Elsevier, Amsterdam, 13–121.

EWART, A., 1985: Altitudinal transect studies at Cape Tribulation, north Queensland. II: geological notes. *The Queensland Naturalist*, **28**, 49–52.

EWART, A.E., 1989: Major element chemistry and chemical affinities. *In* Johnston, R.W. (Editor): *Intraplate volcanism in eastern Australia and New Zealand*. Cambridge University Press, Cambridge, 190–197.

EWART, A.E., CHAPPELL, B.W. & MENZIES, M.A., 1988: An overview of the geochemical and isotopic characteristics of the eastern Australian Cainozoic volcanic provinces. I*n* Menzies, M.A. & Cox, K.G. (Editors): Oceanic and continental lithosphere: similarities and differences. *Journal of Petrology, Special Publication*, 225–274.

EWERS, G.R., 1998: Mineral and Energy Deposit Styles and Potential Resources. *In* J.H.C. Bain & J.J. Draper (Compilers & Editors): North Queensland Geology. *Australian Geological Survey Organisation Bulletin* ***240**, and Queensland Department of Mines and Energy Queensland Geology*, **9**, 529–545.

FAWCKNER, J.F., 1975: Geology of the O.K. mine area, north Queensland. B.Sc. Honours Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

FAWCKNER, J.F., 1978: The O.K. — a cupreous pyrite volcanogenic massive sulphide deposit formed in a marginal sea setting? *In North Queensland Conference, September 1978*. Australasian Institute of Mining and Metallurgy, Parkville (Victoria), 43–55.

FAWCKNER, J.F., 1981: Structural and stratigraphic relations and a tectonic interpretation of the western Hodgkinson Province, northeastern Australia. Ph.D. Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

FEARY, D.A., CHAMPION, D.C., BULTITUDE, R.J. & DAVIES, P.J., 1993: Igneous and metasedimentary basement lithofacies of the Queensland Plateau. *Proceedings of the Ocean Drilling Program, Scientific Results*, **133**, 535–540.

FERGUSSON, C.L. & COLQUHOUN, G.P., 1996: Early Palaeozoic quartz turbidite fan and volcaniclastic apron, Mudgee district, northeastern Lachlan Fold Belt, New South Wales. *Australian Journal of Earth Sciences*, **43**, 497–507.

FERGUSSON, C.L., 1991: Thin-skinned thrusting in the northern New England Orogen, central Queensland, Australia. *Tectonics*, **10** (4), 797–806.

FINLAYSON, D.M., 1968: First arrival data from the Carpentaria region upper mantle project (CRUMP). *Journal of the Geological Society of Australia*, **15**, 33–50.

FLETCHER, R.J., 1971: Final and annual report for year ending 31/12/71, AP789M, Clarke, South of Ravenshoe. Carpentaria Exploration Company Pty Ltd. Held by the Department of Mines and Energy, Queensland as CR 3955.

FORCE, E.R., 1991: Placer Deposits. *In* FORCE, E.R., EIDEL, J.J. & MAYNARD, J.B. (Editors): Sedimentary and Diagenetic mineral deposits: a Basin analysis approach to exploration. *Review in Economic Geology*, **5**, 131–140.

FORDHAM, B.G., 1994: Complex structure in the Mungana region of the Hodgkinson Province, and significance for exploration programs. *In, Handbook for two-day symposium highlighting Queensland's exploration potential*. Department of Mines and Energy, Queensland, 32.

FORSYTHE, D.L. & HIGGINS, N.C., 1990: Mount Carbine tungsten deposit. *In* Hughes, F.E. (Editor): *Geology of the mineral deposits of Australia and Papua New Guinea*. Australasian Institute of Mining and Metallurgy, Parkville (Victoria), 1557–1560.

FRASER, A.R., DARBY, F. & VALE, K.R., 1977: The reconnaissance gravity survey of Australia: qualitative analysis of results. *Bureau of Mineral Resources, Australia, Report*, **198** (BMR Microform MF15).

GAIR, J.E., 1989: Criteria for assessment of mineral-resource potential. *In* Gair, J.E. (Editor): Mineral resources of the Charlotte 1 degree by 2 degree quadrangle, North Carolina and South Carolina. *United States Geological Survey, Professional Paper* **1462**, 51–55.

GALLO, J.B., 1995: The geology and geochemistry of the Triple Crown gold prospect near Mount Garnet. *In* Beams, S.D. (Editor): Exploring the Tropics, Mineral Deposits of Northeast Queensland: Geology and Geochemistry. *EGRU Contribution* **52**, 231–238.

GARRAD, P.D., 1991: A compilation of mine production data for Herberton Mining District from Annual Reports of the Department of Mines (1883–1989). *Queensland Resource Industries Record*, **1991/4**.

GARRAD, P.D., 1993: Mineral occurrences — Mount Mulligan 1:100 000 Sheet area, north Queensland. *Queensland Geological Record*, **1993/11**.

GARRAD, P.D. & REES, I.D., 1995: Mineral occurrences — Innisfail 1:250 000 Sheet Area, north Queensland. *Queensland Geological Record*, **1995/3**.

GARSIDE, F., 1988: Six monthly report, AP 4805M (Cooktown), period ending 2.1.88 and final report. Held by the Department of Mines and Energy, Queensland as CR 19023.

GARTH, B.E., 1971: Final report on Authority to Prospect 685M McLeod and Hodgkinson River localities. Alluvial Gold Limited. Held by the Department of Mines and Energy, Queensland as CR 3614.

GEMMELL, J.B., ZANTOP, H. & MEINERT, L.D., 1992, Genesis of the Aguilar zinc–lead–silver deposit, Argentina: Contact metasomatic versus sedimentary exhalative. *Economic Geology*, **87**, 2085–2112.

GOLDING, S.D., BULTITUDE, R.J., PETERS, S.G., MYERS, I.A., & DOWLING, K., 1990: Stable isotope constraints on genetic models for gold–quartz, antimony–gold–quartz, tin and tungsten–tin mineralisation, Hodgkinson Province, northern Queensland. *In*: *Proceedings of the Pacific Rim Congress 90*, Australasian Institute of Mining and Metallurgy, Parkville (Victoria), **III**, 325–335.

GORTER, J.D., 1992: Ordovician petroleum in Australia in relation to eustasy. *In* Webby, B.D. & Laurie, J.R. (Editors): *Global perspectives on Ordovician geology*. Proceedings of the sixth international symposium on the Ordovician System, University of Sydney, Australia, 15–19 July, 1991. A.A. Balkema, Rotterdam, 433–443.

GOULD, R.E., 1976: The succession of Australian pre-Tertiary megafossil floras. *Botanical Review*, **41**, 453–483.

GREAVES, G.J.G., 1975: Exploration for lode tin deposits in the Herberton Mineral Field. M.Sc. Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

GREAVES, G.J.G., 1964: Trace element chemistry of cassiterite and related minerals, predominantly from the Herberton Mineral Field. Table held by the Department of Mines and Energy, Queensland.

GREAVES, G.J.G., STEVESON, B.G., & TAYLOR, R.G., 1971: Magnetic cassiterites from Herberton, north Queensland, Australia. *Economic Geology*, **66**, 480–487.

GREEN, P.M., 1990: Evidence for allochthonous blocks, Chillagoe Formation, Queensland. *Queensland Government Mining Journal*, **91**(1065), 357–366.

GREEN, P.M., DOMAGALA, J. & BULTITUDE, R.J., 1988: Chillagoe Formation — a record of a collapsed Silurian–Devonian carbonate shelf. *Geological Society of Australia, Abstracts*, **21**, 162–163.

GREENWOOD, C., 1943: Effect of chemical impurities on scheelite fluorescence. *Economic Geology*, **38**, 56–64.

GREGORY, P.W., 1980: The Dianne and Mt. Molloy massive sulphide deposits. *In, Recent developments in far north Queensland*. Australasian Institute of Mining and Metallurgy, Far North Queensland Branch, 60–67.

GREGORY, P.W. & ROBINSON, B.W., 1984: Sulphur isotope studies of the Mount Molly, Dianne and O.K. stratiform sulphide deposits, Hodgkinson Province, north Queensland. *Mineralium Deposita*, **19**, 36–43.

GUNTHER, M.C., 1993: A district analysis of the Kangaroo Hills Mineral Field, north Queensland. M.Sc. Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

GUNTHER, M.C. & WITHNALL, I.W., 1995: New and revised igneous rock units of the Rollingstone and Ewan 1:100 000 Sheet areas. *Queensland Government Mining Journal*, **96**(1129), 16–25.

HALFPENNY, R.W. & HEGARTY, R.A., 1991: Geology of the South Palmer River 1:100 000 Sheet area (7865), north Queensland. *Queensland Resource Industries Record*, **1991**/**6**.

HALLIDAY, A.L., 1973: Termination report, Julatten examination, north Queensland. Kennecott Exploration (Aust) Pty Ltd. Held by the Department of Mines and Energy, Queensland as CR 14718.

HAMMARSTROM, J.M. & ZEN, E-An., 1986: Aluminium in hornblende: an empirical igneous barometer. *American Mineralogist*, **71**, 1297–1313.

HAMMOND, R.L., 1986: Large scale structural relationships in the Palaeozoic of northeastern Queensland: melange and mylonite development, and the regional distribution of strain. Ph.D. Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

HAMMOND, R.L., BELL, T.H., BLACK, L.P., JONES, P.A. & RUBENACH, M.J., 1986: The Barnard Metamorphics: an Early Palaeozoic terrane in far northeastern Queensland. *In* Hammond, R.L.: Large-scale structural relationships in the Palaeozoic of northeastern Queensland, and the regional distribution of strain. Ph.D. Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

HANDLEY, G.A., 1975: Tin mineralisation and albitisation at the Mt Misery prospect, Irvinebank, north Queensland. B.Sc. (Hons.) Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

HANN, W.M., 1873a: *Report from Mr W Hann, leader of the northern expedition party*. Queensland Government Printer, Brisbane.

HANN, W.M., 1873b: *Copy of the diary of the northern expedition under the leadership of Mr William Hann*. Queensland Government Printer, Brisbane.

HARRIS, N.B. & EINAUDI, M.T, 1982: Skarn deposits in the Yerington District, Nevada: Metasomatic skarn evolution near Ludwig. *Economic Geology*, **77**, 877–898.

HARTLEY, J.S. & WILLIAMSON, G., 1995: Mount Garnet zinc rich skarn. *In* Beams, S.D. (Editor): Mineral Deposits of Northeast Queensland: Geology and Geochemistry. *EGRU Contribution* **52**, 239–245.

HAWTHORNE, W.L., 1975: Mount Mulligan Coal-Field, Queensland. *In* Traves, D.M., King, D. & Knight , C.L. (Editors): Economic Geology of Australia and Papua New Guinea — Part 2: Coal. *Australian Institute of Mining and Metallurgy, Monograph Series No.* **6**, 252–254.

HEINRICH, C.A., 1990: The chemistry of hydrothermal tin (–tungsten) ore deposition. *Economic Geology*, **85**, 457–481.

HENDERSON, R.A., 1980: Structural outline and summary geological history for north-eastern Australia. *In* Henderson, R.A. & Stephenson, P.J. (Editors): *The geology and geophysics of northeastern Australia*. Geological Society of Australia, Queensland Division, Brisbane, 1–26.

HENDERSON, R.A., 1987: An oblique subduction and transform faulting model for the evolution of the Broken River Province, northern Tasman Orogenic Zone. *Australian Journal of Earth Sciences*, **34**, 237–249.

HENDERSON, R.A., FERGUSSON, C.L., LEITCH, E.C., MORAND, V.J., RHEINHARDT, J.J. & CARR, P.F., 1993: Tectonics of the northern New England Fold Belt. *In* Flood, P.G. & Aitchison, J.C. (Editors): *New England Orogen, eastern Australia*. University of New England, Armidale, Department of Geology and Geophysics, 505–515.

HERR, W., WOLFE, K.W., EBERHARDT, P. & KOPP, E., 1967: Development and recent applications of the Re/Os dating method. Radioactive dating and methods of low level counting. Vienna: International Atomic Energy Agency.

HIGGINS, N.C., FORSYTHE, D.L., SUN, S-s., & ANDREW, A.S., 1987: Fluid and metal sources in the Mt. Carbine tungsten deposit, north Queensland, Australia. *In Proceedings of the Pacific Rim 90 Congress*, Australasian Institute of Mining and Metallurgy, Parkville (Victoria), **III**, 173–177.

HODGSON, C.J., 1975, The geology and geological development of the Broken Hill lode in the New Broken Hill Consolidated mine, Australia; Part 11, Mineralogy. *Geological Society of Australia Journal*, **22**, 33–50.

HOLLINGSWORTH, J.S., 1974: Final report on AP1114M, Cairns district, Townsville Block identification map, series B, Queensland. Australia & New Zealand Co. Held by the Department of Mines and Energy, Queensland as CR 4776.

HOLLISTER, L.S., GRISSOM, G.C., PETERS, E.K., STOWELL, H.H. & SISSON, V.B., 1987: Confirmation of the empirical correlation of Al in hornblende with pressure of solidification of calc-alkaline plutons. *American Mineralogist*, **72**, 231–239.

HOOPER, C., 1993: *Angor to Zillmanton, stories of north Queensland's deserted towns*. AEBIS Publishing, Brisbane.

HORTON, D.J., 1982: Porphyry copper and molybdenum mineralisation in eastern Queensland. *Geological Survey of Queensland Publication*, **378**.

HUGHES, K.K., 1971: Consolidated Mining Industries Ltd, Report on AP725M, Russell River. Held by the Department of Mines and Energy, Queensland as CR 3929.

HUGHES, K.K., 1972: AP 511M, Lloyd Bay, progress report for period 1.1.71 – 31.12.71. Held by the Department of Mines and Energy, Queensland as CR 4213.

HUTTON, L.H. & CROUCH, S.B.S., 1993: Geochemistry and petrology of the western Ravenswood Batholith. *Queensland Geological Record*, **1993/22**.

HUTTON, L.J., DRAPER, J.J., RIENKS, I.P., WITHNALL, I.W. & KNUTSON, J., 1997: Charters Towers Region. *In* Bain, J.H.C. & Draper, J.J., 1997 (Compilers & Editors): North Queensland Geology. *Australian Geological Survey Organisation Bulletin **240**, and Queensland Department of Mines and Energy Queensland Geology*, **9**(6), 165–224.

ICHIKAWA, K. & McCONNELL, W., 1992: EPM 4006, Bulls Pinnacle, Combined partial relinquishment report on seven sub-blocks for periods ended 16/5/91 and 16/5/92. Held by the Department of Mines and Energy, Queensland as CR 23838.

IDRIESS, I.L., 1938: *The tin scratchers — the story of tin mining in the far north*. Angus and Robertson, Sydney.

ISHAQ, S., DASH, P., SAWERS, J., KAY, J., COOPER, W., KROSCH, N., LAM, J., GARRAD, P. & MITCHELL, G., 1987: Mineral occurrence data sheets — Mungana 1:100 000 Sheet area. Geological Survey of Queensland Record, 1987/29.

ISHIHARA, S., SAWATA, H., ARPORNSUWAN, S., BUSARACOME, P. & BUNGBRAKEARTI, N., 1979: The magnetite-series and ilmenite-series granitoids and their bearing on tin mineralization, particularly on the Malay Peninsular region. *Geological Society of Malaysia, Bulletin* **11**, 103–110.

JACK, R., 1990: EPM 5975, east coast of Cape York, final report. Held by the Department of Mines and Energy, Queensland as CR 22211.

JACK, R.L., 1879a: On the progress of the search for coal in the Cook district. *Geological Survey of Queensland Publication*, **6**, 1–2.

JACK, R.L., 1879b: Second report on the progress of the search for coal in the Cook district. *Geological Survey of Queensland Publication*, **7**, 1–3.

JACK, R.L., 1882: On the Little River Coalfield, near Cooktown. *Geological Survey of Queensland Publication,* **11**, 1–4.

JACK, R.L., 1888: Palmer Goldfield, Annual progress report of the Government Geologist for the year 1887. *Annual Report of the Department of Mines for 1887*, 81–92.

JACK, R.L., 1889: On Limestone District, part of the Palmer Goldfield. *Geological Survey of Queensland Publication*, **46**.

JACK, R.L., 1896: Map of the Palmer River. *Geological Survey of Queensland Publication*, **110**.

JACK, R.L., 1899: Report on a visit to the Palmer Goldfield. *Geological Survey of Queensland Publication*, **144**.

JACK, R.L., 1893: Russell River goldfield. *Geological Survey of Queensland Publication*, **89**.

JACK, R.L. & ETHERIDGE, R., 1892: The geology and palaeontology of Queensland and New Guinea. *Geological Survey of Queensland Publication*, **92**.

JACOBI, R.D., 1984: Modern submarine sediment slides and their implications for melange and the Dunnage Formation in north-central Newfoundland. *In* Raymond, L.A. (Editor): Melanges: Their nature, origin and significance. *Geological Society of America, Special Paper* **198**, 81–102.

JENSEN, H.I., 1939: The Hodgkinson district. *Aerial, geological and geophysical survey of northern Australia, Queensland Report*, **39**.

JENSEN, H.I., 1941a: The Chillagoe district. *Aerial, geological and geophysical survey of northern Australia, Queensland Report*, **53**.

JENSEN, H.I., 1941b: The manganese deposits of the Cairns district. *Aerial, geological and geophysical survey of northern Australia, Queensland Report*, **52**.

JENSEN, H.I., 1941c: The antimony deposits of the Hodgkinson district. *Aerial, geological and geophysical survey of northern Australia, Queensland Report,* **50**.

JOHNSON, M.C. & RUTHERFORD, M.J., 1988: Experimental calibration of an aluminium-in-hornblende geobarometer applicable to calcalkaline rocks. *EOS*, **69**, 1511.

JOHNSON, R.W. & DUGGAN, M.B., 1989: Rock classification and analytical data bases. *In* Johnston, R.W. (Editor): *Intraplate volcanism in eastern Australia and New Zealand*. Cambridge University Press, Cambridge, 12–13.

JOHNSTON, C., 1984: Granitoids of the Coolgarra Batholith, Mount Garnet, north Queensland. Ph.D. Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

JOHNSTON C. & BLACK, L.P., 1986: Rb–Sr systematics of the Coolgarra Batholith, north Queensland. *Australian Journal of Earth Sciences*, **33**, 309–324.

JOHNSTON, A.C. & HAMMOND, J.M., 1984: AP3509M, Kingsborough, First Half Yearly Report. Amax Australia (Gold) Pty Ltd. Held by the Department of Mines and Energy, Queensland as CR 12774.

JONES, M.R., 1985: Quaternary geology and coastline evolution in Trinity Bay, north Queensland. *Geological Survey of Queensland Publication*, **386**.

JONES, M.R., 1995: Perlite. Mineral Information Leaflet No 24. Data held by the Department of Mines and Energy, Queensland.

JONES, M.R. & STEPHENS, A.W., 1983. Transport of beach sand around headlands, Trinity Bay, north Queensland: implications for coastal change. *Queensland Government Mining Journal*, **84**(975), 5–11.

JONES, M.R. & STEPHENS, A.W., 1984: Quaternary sediments in the Cairns region; results of shallow drilling in Trinity Bay. Geological Survey of Queensland Record, 1984/69.

JONES, P.A., 1978: The structural analysis and metamorphism of the Barnard and Barron River Metamorphics in the Tully–Innisfail (N.Q.) area. B.Sc. Honours Thesis, James Cook University of

North Queensland, Townsville, Department of Earth Sciences.

JONES, P.J. (Compiler), 1995: *AGSO Phanerozoic timescale 1995: wall chart and explanatory notes*. Oxford University Press, South Melbourne.

JONES, T.R., MOELLER, T. & TRUELOVE, A.J., 1990: Collingwood tin deposit. *In* Hughes, F.E. (Editor): *Geology of the mineral deposits of Australia and Papua New Guinea*. Australasian Institute of Mining and Metallurgy, Parkville (Victoria), 1549–1555.

JORGENSEN, P.J., 1990: GSQ Cooktown 1–3R — preliminary lithological logs. *Queensland Resource Industries Record*, **1990/5**.

KARJALAINEN, H., ERCEG, M. & JOYCE, P.J., 1987: The geology of the Red Dome deposit. *In* Herbert, H.K. (Editor): Gold in Queensland. *University of Queensland, Geology Department Papers*, **12**, 100–109.

KELLY, G.R., 1976: Oxidation and supergene enrichment of the 'Siberia Lode' vein systems, Emuford, north Queensland. M.Sc. Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

KERR, R.S., 1979: *John Moffat's Empire*. J.D. & R.S. Kerr, Brisbane.

KERR, R.S., 1989: The advent of tin dredges in eastern Australia. *Australian Journal of Historical Archaeology*, **7**, 70–72.

KERR, R.S., 1991: The german demand for wolfram, tin and copper from north Queensland, 1890–1914. *Journal for Business History (Zeitschrift fr Unternehmensgeschichte), German Society for Business History (Gesellschaft fr Unternehmensgeschichte), Franz Steiner Verlag Stuttgart*, **36**(2), 61–75.

KERSHAW, A.P., 1970: A pollen diagram from Lake Euramoo, northeast Queensland, Australia. *New Phytology,* **75**, 173–191.

KERSHAW, A.P. & SLUITER, I.R., 1982: Late Cainozoic pollen spectra from Atherton Tableland, northeastern Australia. *Australia Journal of Botany*, **30**(3), 219–295.

KINNANE, N.R., 1982: AP3104M, Hartley's Creek, north Queensland, Final Report and relinquishment report including six monthly report to 23.07.82. Held by the Department of Mines and Energy, Queensland as CR 11374.

KINNANE, N.R., 1985: ML 2234, 2235,2266, 2267, 2268, 2269, 2270, 2271 (Mareeba), Northcote Antimony prospects, Progress report. Held by the Department of Mines and Energy, Queensland as CR 22508.

KIRKMAN, N. 1982: Mining on the Hogkinson. *In* Kennedy, K.H. (Editor): *Readings in north Queensland mining history*, **2**, 171. James Cook University of North Queensland, Townsville, Department of History.

KONTAK, D.J., 1990: The East Kemptville topaz–muscovite leucogranite, Nova Scotia. I. Geological setting and whole-rock geochemistry. *Canadian Mineralogist*, **27**, 818–825.

KROSCH, N.J., 1990: Queensland mineral commodity report — limestone. *Queensland Government Mining Journal*, **91**, 93–102.

KWAK, T., 1986: Granites associated with W–Sn skarns. *In* Genesis of tin–tungsten deposits and their associated granitoids. Bureau of Mineral Resources, Australia, Record 1986/10, 38.

KWAK, TA.P., 1987: W–Sn skarn deposits and related metamorphic skarns and granitoids. *Developments in Economic Geology*, **24**, Elsevier, Amsterdam, 451.

KYLE, J.R., RUBIN, J.N., MCMAHON, T.P. & MCDOWELL, F., 1991: Preliminary investigations of porphyry–skarn copper–gold orebodies, Ertsberg (Gunung Bijih) district, Irian Jaya, Indonesia. *Geological Association of Canada, Mineralogical Association of Canada-Society of Economic Geologists, Program with Abstracts*, **16**, A69.

LACY, W.C., 1980: Mineralisation along the extension of the New England Fold Belt into north Queensland. *In* Henderson, R.A. & Stephenson, P.J. (Editors): *The geology and geophysics of north-eastern Australia*. Geological Society of Australia, Queensland Division, Brisbane, 269–277.

LAING, W.P., 1990: ML 1418, 1449, 1450, 1451 (Chillagoe), final report for the period ending 30/12/72. Hastings Exploration N.L. Held by the Department of Mines and Energy, Queensland as CR 21702.

LAM, J.S., 1993: A summary of mineral occurrences of the Mossman 1:100 000 Sheet area, north Queensland. *Queensland Geological Record*, **1993/13**.

LAM, J.S., DENARO, T.J., BURROWS, P.E., & GARRAD, P.D., 1991: A summary of the mineral occurrences of the Maytown 1:100 000 Sheet area (7765), north Queensland. *Queensland Resource Industries Record*, **1991/10**.

LAM, J.S., DENARO, T., GARRAD, P., HOLMES, P. & KAY, J., 1989: Mineral occurrence data — Lyndbrook 1:100 000 Sheet area. *Queensland Department of Mines Record*, **1989/6**.

LAM, J.S., GARRAD, P. & MITCHELL, G., 1988: Mineral occurrence data sheets — Bullock Creek 1:100 000 Sheet area. *Queensland Department of Mines Record*, **1988/12**.

LAM, J.S., & GENN, D.L.P., 1993: A summary of the mineral occurrences of the South Palmer River 1:100 000 Sheet area, north Queensland. *Queensland Geological Record*, **1993/26**.

LANGMEAD, R.P., 1983: Chinky Creek A to P 3337M — first and final report, January 1983. Newmont Holdings Pty Ltd. Held by the Department of Mines and Energy, Queensland as CR 11713.

LAW, S.R., 1989: Geology of the eastern parts of the Mossman and Helenvale 1:100 000 Sheet areas — results of the 1987 field season. *Queensland Department of Mines Record*, **1989/5**.

LE MAITRE, R.W., 1984: A proposal by the IUGS Subcommission on the Systematics of Igneous Rocks for a chemical classification of volcanic rocks based on the total alkali silica (TAS) diagram. *Australian Journal of Earth Sciences*, **31**, 243–255.

LE MAITRE, R.W. (Editor), 1989: *A classification of igneous rocks and glossary of terms: recommendations of the International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks*. Blackwell Scientific Publications, Oxford.

LEVINGSTON, K.R., 1955: Wolfram–molybdenite–bismuth workings, Bamford Hill, Petford. *Queensland Government Mining Journal*, **56**, 768–775.

LEVINGSTON, K.R., 1970: Fluorspar deposits, Chillagoe area: Mines Department diamond drilling, 1963–69. *Queensland Government Mining Journal*, **71**, 481–494.

LEVINGSTON, K.R., & CARRUTHERS, D.S., 1953: Mount Perseverance wolfram workings. *Queensland Government Mining Journal*, **54**, 262–268.

LEVINSON, A.A., 1980: *Introduction to Exploration Geochemistry. Second edition — the 1980 supplement*. Applied Publishing Ltd, Wilmette, USA.

LINDGREN, W., 1933: *Mineral Deposits*. McGraw-Hill Book Company, Inc. New York and London.

LORD, J.R., & FABRAY, J.F., 1990: Jeannie River tin prospects. *In* Hughes, F.E. (Editor): Geology of the Mineral Deposits of Australia and Papua New Guinea. *Australasian Institute of Mining and Metallurgy, Monograph 14*, **24**,1545–1548.

LUCAS, K.G., 1964: The geology of the Cape Melville 1:250 000 Sheet area, SD 55/9, north Queensland. Bureau of Mineral Resources, Australia, Record, 1964/93.

LUCAS, K.G. & DE KEYSER, F., 1965a: Cape Melville, Queensland. *1:250 000 Geological Series — Explanatory Notes*. Bureau of Mineral Resources, Australia.

LUCAS, K.G. & DE KEYSER, F., 1965b: Cooktown, Queensland. *1:250 000 Geological Series — Explanatory Notes*. Bureau of Mineral Resources, Australia.

MACDONALD, E.H., 1983: *Alluvial Mining*. Chapman & Hall.

MACKENZIE, D.E., 1987: Geology, petrology and mineralization of the Permo–Carboniferous Featherbed Volcanics Complex, northern Australia. *In Pacific Rim Congress 87*, Australasian Institute of Mining and Metallurgy, Parkville (Victoria), 297–301.

MACKENZIE, D.E., 1990: Contrasting magma types, eruptive styles and mineral deposits of the Permo–Carboniferous Featherbed Volcanics, northeastern Queensland. *Geological Society of Australia Abstracts*, **25**, 293.

MACKENZIE, D.E., 1993: Geology of the Featherbed Cauldron Complex, north Queensland: Part 1. Eruptive rocks and post-volcanic sediments. *Australian Geological Survey Organisation Record*, **1993/82**.

MACKENZIE, D.E., 1997: Featherbed Volcanic Group. *In* Bain, J.H.C. & Draper, J.J. (Compilers & Editors): North Queensland Geology. *Australian Geological Survey Organisation Bulletin* **240**, *and Queensland Department of Mines and Energy Queensland Geology*, **9**(7), 236.

MACKENZIE, D.E., BLACK, L.P. & SUN, S-s., 1988: Origin of alkali–feldspar granites: an example from the Poimena granite, northeast Tasmania, Australia. *Geochimica et Cosmochimica Acta*, **52**, 2507–2524.

MACKENZIE, D.E., BULTITUDE, R.J. & RIENKS, I.P., 1993: *Geology of the Featherbed Cauldron Complex, Queensland* (1:100 000 scale map). Australian Geological Survey Organisation.

MACKENZIE, D.E., CHAMPION, D.C. & AGSO–GSQ project team, 1994: Permian–Carboniferous magmatism and metallogeny in north Queensland — a new perspective. *In* Henderson, R.A. & Davis, B.K. (Editors): Extended Conference Abstracts, New Developments in Geology and Metallogeny: Northern Tasman Orogenic Zone. *EGRU Contribution* **50**, 67–68.

MACKENZIE, D. E. & KNUTSON, J.,1992: Igneous rocks of the Ebagoola 1:250 000 Sheet area, Cape York Peninsula, north Queensland: field, petrologic, and geochemical data. *Australian Geological Survey Organisation Record*, **1992/75**.

MANCKTELOW, N.S., 1974: The geology of the Tinaroo area, north Queensland. B.Sc. Honours Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

MANCKTELOW, N.S., 1982: The geology of the Tinaroo area, north Queensland. *Proceedings of the Australasian Institute of Mining and Metallurgy*, **281**, 1–13.

MANNING, D.A.C. & HILL, P.I., 1990: The petrogenetic and metallogenetic significance of topaz granite from the southwest England orefield. *In* Stein, H.J. & Hannah, J.L. (Editors): Ore-bearing granite systems; petrogenesis and mineralizing processes. *Geological Society of America Special Paper*, **246**, 51–69.

MARTIN, J.E., 1979: Mineral potential of Timber Reserves 141 and 165, Cooktown–Daintree area. Geological Survey of Queensland Record, 1979/6.

MARTIN, J.E., 1980: Investigation of dune sand at Archer Point, Cooktown. Geological Survey of Queensland Record, 1980/4.

MARTON, A.S., 1993: Final Report for Mt. Cameron. Company report on A to P 5204M from Juldex Pty Ltd. Held by the Department of Mines and Energy, Queensland as CR 24214.

MASON, A.A.C., 1953: The Vulcan tin mine; in Edwards, A.B. (Editor): *Geology of Australian Ore Deposits. Fifth Empire Mining and Metallurgical Congress, Australia and New Zealand*. Australasian Institute of Mining and Metallurgy, Parkville (Victoria), 718–721.

MATHESON, S.G., 1995: Mount Mulligan Coalfield, Queensland. *In* Ward, C.R., Harrington, H.J., Mallett, C.W. & Beeston, J.W. (Editors) : Geology of Australian Coal Basins. *Coal Geology Group, Geological Society of Australia, Special Publication* **No. 1**, 431–434.

McCONNELL, W.D., 1983: Cannibal Creek, six monthly report ended 9/9/1983. Held by the Department of Mines and Energy, Queensland as CR 12587.

McCONNELL, W.D., 1992: Northcote Project. Summary of exploration. Report held by Nittoc International Co. Ltd, Mareeba.

McCONNELL, W.D. & CARVER, R.N., 1984a: Cannibal Creek, six monthly report ended 9/3/1984. Held by the Department of Mines and Energy, Queensland as CR 13235.

McCONNELL, W.D. & CARVER, R.N., 1984b: Authority to Prospect 3168M, Mulgrave River. Report for six months ending 5th May, 1984. Western Mining Corporation. Held by the Department of Mines and Energy, Queensland as CR 13148.

McCONNELL, W.D. & CARVER, R.N., 1985: Authority to Prospect 2181M, Cannibal Creek, north Queensland — report for six months ending 9 September, 1984. Western Mining Corporation. Held by the Department of Mines and Energy, Queensland as CR 13966.

McELROY, C.J. & BRYANT, J.H., 1981: Results of drilling programme at Mt Mulligan, Authority to Prospect 272C. International Mining Corporation N.L. Held by the Department of Mines and Energy, Queensland as CR 8372.

McGAIN, A., 1981: Report on Authority to Prospect 2181M. Fourth six monthly report. R.B. Mining Pty

Ltd. Held by the Department of Mines and Energy, Queensland as CR 9537.

McKAY, G., 1983: A-P 3454M, Featherbed area, report for six months ended 17/10/83. PNC Exploration (Australia) Pty Ltd. Held by the Department of Mines and Energy, Queensland as CR 12979.

McLEAN, D., 1980: Geology of the Mt Carbine deposit. *In Recent Developments in Far North Queensland.* Australasian Institute of Mining and Metallurgy, Far North Queensland Branch, Townsville, 38–40.

McLEAN, D., 1982: Cannibal Creek Authority to Prospect 2181M — half yearly report — 10 September, 1981–10 March, 1982. Newmont Holdings Pty Ltd. Held by the Department of Mines and Energy, Queensland as CR 10499.

MEINERT, L.D., 1983, Variability of skarn deposits Guides to exploration. *In* Boardman, S.J. (Editor): *Revolution in the Earth Sciences.* Kendall-Hunt Publishing Co., 301–316.

MEINERT, L.D., 1987a: Gold in skarn deposits — a preliminary overview. Proceedings of the 7th Quadrennial IAGOD Symposium.

MEINERT, L. D., 1987b: Skarn zonation and fluid evolution in the Groundhog Mine, Central Mining District, New Mexico: *Economic Geology*, **82**, 523–545.

MEINERT, L.D.,1993: Skarns and skarn deposits. *In* Sheaham, P.A. & Cherry, M.E. (Editors): Ore Deposit Models, Volume 2 . *Geoscience Canada Reprint Series* **6**, 117–134.

MERTIE Jr, J.B., 1940: Placer gold in Alaska. *Washington Academy of Science Journal*, **30**, 114–124.

MIEZITIS, Y. & BAIN, J.H.C., 1991: Cape York Peninsula: comments on mineral potential and availability of data as at January 1990. Bureau of Mineral Resources, Australia Record, 1991/74.

MIEZITIS, Y., & MCNAUGHT, I.S., 1987: Mineral resources and prospectiveness of the proposed world heritage listing of wet tropical rainforests area. Bureau of Mineral Resources, Australia, Record 1987/53.

MILLER, C.F. & MITTLEFEHLDT, D.W., 1982: Depletion of light rare-earth elements in felsic magmas. *Geology*, **10**, 129–133.

MOCK, C., LORENZ, R.P. & ELLIOT, B.G., 1988: Gold deposits of Queensland. BMR datafile (MINDEP). *Bureau of Mineral Resources, Australia, Resource Report*, **4**.

MONTEL, J.M., 1986: Experimental determination of the solubility of Ce–monazite in SiO_2– Al_2O_3–K_2O–Na_2O melts at 800°C, 2 kilobars, under H_2O-saturated conditions. *Geology*, **14**, 659–662.

MONTEL, J.M., MOUCHEL, R. & PICHAVANT, M., 1988: High apatite solubilities in peraluminous melts. *Terra Cognita*, **8**, 71.

MORGAN, W.R., 1961: The Carboniferous and Permo–Triassic igneous rocks of the Mossman Four-Mile Sheet area, north Queensland. Bureau of Mineral Resources, Australia, Record, 1961/125.

MORGAN, W.R., 1964a: The igneous geology of the Mossman 1:250 000 Sheet area, north Queensland. Bureau of Mineral Resources, Australia, Record, 1964/75.

MORGAN, W.R., 1964b: The petrography of specimens collected by the 1962 Cape Melville Field Party, north Queensland. Bureau of Mineral Resources, Australia, Record, 1964/1.

MORGAN, W.R., 1965: The igneous geology of the Cooktown 1:250 000 Sheet area, north Queensland. Bureau of Mineral Resources, Australia, Record, 1965/118.

MORGAN, W.R., 1968a: The Ticklehim Creek Dyke Swarm: a proposed new stratigraphical name. *Queensland Government Mining Journal*, **69**(805), 505.

MORGAN, W.R., 1968b: The petrology of some Cainozoic basaltic rocks from the Atherton Tableland and Einasleigh–Mount Garnet areas, north Queensland. *Proceedings of the Royal Society of Queensland*, **80**(1), 1–12.

MORGAN, W.R., 1974: A Carboniferous continental andesite–rhyolite association from the 'Nychum' area, north Queensland, Australia. *Journal of Petrology*, **15**, 97–112.

MORRIS, G., 1991: *Looking Back The Way I Came*. Pinevale Publications, Home Hill (north Queensland).

MORRISON, G.W., 1988: Palaeozoic gold deposits of northeast Queensland. *In* Morrison, G.W. (Editor): Epithermal and porphyry style gold deposits in north Queensland. *EGRU Contribution* **29**, 11–21.

MORRISON, G.W. & BEAMS, S.D., 1995: Geological setting and mineralisation style of ore deposits of northeast Queensland. *In* Beams, S.D. (Editor): 17th International Geochemical Exploration Symposium "Exploring the Tropics". *EGRU Contribution*, **52**, 1–32.

MORTON, C.C., 1938: Mount Perseverance wolfram field. *Queensland Government Mining Journal*, **39**, 188–192.

MORWOOD, D.A. & DASH, P.H., 1996: Mineral occurrences of the Ingham 1:250 000 Sheet area. *Queensland Geological Record,* **1996/5**.

MULLER, P.J. & HENRY, J.L., 1982: Barron River groundwater investigations. Groundwater resources of the Barron River coastal plain. Geological Survey of Queensland Record, 1982/23.

MURRAY, C.G., 1990: Tasman Fold Belt in Queensland. *In* Hughes, F.E. (Editor): Geology of the Mineral Deposits of Australia and Papua New Guinea. *Australasian Institute of Mining and Metallurgy, Monograph* **14**(2), 1431–1450.

MUTTI, E. & RICCI LUCCHI, F., 1972: Turbidites of the northern Appennines: introduction to facies analysis. English translation by T.H. Nilsen. *International Geology Review*, **20**, 125–146.

NESBITT, H.W. & YOUNG, G.M., 1982: Prediction of some weathering trends of plutonic and volcanic rocks based on thermodynamic and kinetic considerations. *Journal of Geology*, **48**, 1528–1534.

NETHERY, J. & BARR, M., 1996: Mungana — Perennial Wallflower of the Chillagoe District. *In Recent Gold Discoveries in North Queensland*. Australasian Institute of Mining and Metallurgy, North Queensland Branch One-Day Seminar, 11 October 1996, 10–13.

NETHERY, J., BARR, M. & WOODBURY, M., 1994: Chillagoe district gold, silver, base metal deposits — hypothermal to epithermal overprinting. *In* Henderson, R.A. & Davis, B.K. (Editors): Extended Conference Abstracts, New Developments in Geology and Metallogeny: Northern Tasman Orogenic Zone. *EGRU Contribution* **50**, 71–74.

NEWBERRY, R.J. & EINAUDI, M.T, 1981: Tectonic and geochemical setting of tungsten skarn mineralization in the Cordillera. *Arizona Geological Society Digest*, **14**, 99–112.

NEWBERRY, R.J. & SWANSON, S. E., 1986: Scheelite skarn granitoids: an evaluation of the roles of magmatic source and process. *Ore Geology Reviews*, **1**, 57–81.

NEWBERRY, R.J., 1982: Tungsten-bearing skarns of the Sierra Nevada. 1. The Pine Creek Mine, California. *Economic Geology*, **7Z**, 823–828.

NEWBERRY, R.J., 1983: The formation of subcalcic garnet in scheelite-bearing skarns. *Canadian Mineralogist*, **21**, 529–544.

NICOLL, R.S., 1988: Preliminary analysis of conodonts from the Mulgrave Formation (Upper Ordovician), north Queensland. Bureau of Mineral Resources, Australia, Professional Opinions, 1988/2.

O'NEILL, M.K., 1988: The origin of chert and the geology of the Chillagoe Formation in the Mungana area. B.Sc. (Honours) Thesis, La Trobe University, Bundoora, Department of Geology.

O'REILLY, S.Y. & ZHANG, M., 1995: Geochemical characteristics of lava-field basalts from eastern Australia and inferred sources: connections with the subcontinental lithospheric mantle? *Contributions to Mineralogy and Petrology*, **121**, 148–170.

OSBORNE, A. & MURDOCK, R., 1981: An evaluation of West Orient leases for Great Northern Mining. Great Northern Mining Corp NL. Held by the Department of Mines and Energy, Queensland as CR 14290.

OSBORNE, J.P., 1988: The geology and sedimentology of part of the Chillagoe Formation, Mungana, northeastern Queensland. B.Sc. (Honours) Thesis, La Trobe University, Bundoora, Department of Geology.

OVERSBY, B.S., 1985: Northern subprovince. *In* Diaz, C.M., Wagner, R.H., Prins, C.F.W. & Granados, L.F. (Editors): The Carboniferous of the World. II. Australia, Indian Subcontinent, South Africa, South America, & North Africa. *IUGS Publication* **20**, 71–76.

OVERSBY, B.S., BLACK, L.P. & SHERATON, J.W., 1980: Late Palaeozoic continental volcanism in northeastern Queensland. *In* Henderson, R.A. & Stephenson, P.J. (Editors): *The geology and geophysics of northeastern Australia*. Geological Society of Australia, Queensland Division, Brisbane, 247–268.

OVERSBY, B.S., RIENKS, I.P. & MACKENZIE, D.E., 1997: Geology of the Timber Top Volcanic Subgroup (Featherbed Volcanic Group) and associated rocks, Mount Mulligan area, north Queensland. *Australian Geological Survey Organisation Record*, **1997/53**.

PAINE, A.G.L., HARDING, R.R. & CLARKE, D.E., 1971: Geology of the northeastern part of the Hughenden 1:250 000 Sheet area, Queensland (with additions to the geology of the southern half). *Bureau of Mineral Resources, Australia, Report*, **126**.

PALMIERI, V., 1978: Late Ordovician conodonts from the Fork Lagoons beds, Emerald area, central Queensland. *Geological Survey of Queensland Publication*, **369**.

PALMIERI, V., 1984: Conodont analysis of limestone samples from the Broken River embayment, north Queensland. Geological Survey of Queensland Record, 1984/38.

PARKINSON, G. (Editor), 1988: *Atlas of Australian Resources. Third Series. Volume 5. Geology and Minerals*. Australian Surveying and Land Information Group, Department of Administrative Services, Canberra.

PAVERD, A.L., 1971: Contact metamorphism and mineralisation at Mt Redcap, Chillagoe, north Queensland. Ph.D. Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

PECCERILLO, A. & TAYLOR, S.R., 1976: Geochemistry of Eocene calc-alkaline volcanic rocks from the Kastamonu area, northern Turkey. *Contributions to Mineralogy and Petrology*, **58**, 63–81.

PERKINS, C. & KENNEDY, A.K., 1998: Permo-Carboniferous gold epoch of north-east Queensland. *Australian Journal of Earth Sciences*, **45**, 185–200.

PETERS, S.G., 1987: Geology, lode descriptions and mineralisation of the Hodgkinson Goldfield, northeastern Queensland. *EGRU Contribution* **20**.

PETERS, S.G., GOLDING, S.D. & DOWLING, K., 1990: Melange and sediment-hosted gold-bearing quartz veins, Hodgkinson goldfield, Queensland, Australia. *Economic Geology*, **85**, 312–327.

PETTIJOHN, F.J., 1957: *Sedimentology*. Second edition. Harper & Brothers, New York.

PHAN, K.D., 1969, Skarns et minéralisations associés. *Chronique Mines Recherches Miniére*, **37**, 292–311, 339–362.

PHILIP, G.M., 1966: The occurrence and palaeographic significance of Ordovician strata in northern New South Wales. *Australian Journal of Science*, **29**, 112–113.

PHILLIPS, G.N. & POWELL, R., 1992: Gold only provinces and their common features. *EGRU Contribution*, **43**.

PICHAVANT, M., KONTAK, D.J., BRIQUEU, L., VALENCIA HERRERA, J. & CLARK, A.H., 1988a: The Miocene–Pliocene Macusani Volcanics, SE Peru. II. Geochemistry and origin of a felsic peraluminous magma. *Contributions to Mineralogy and Petrology*, **100**, 325–338.

PICHAVANT, M., KONTAK, D.J., VALENCIA HERRERA, J. & CLARK, A.H., 1988b: The Miocene–Pliocene Macusani Volcanics, SE Peru. 1. Mineralogy and magmatic evolution of a two-mica aluminosilicate-bearing ignimbrite suite. *Contributions to Mineralogy and Petrology*, **100**, 300–324.

PICHAVANT, M., VALENCIA HERRERA, J., BOULMIER, S., BRIQUEU, L., JORON, J.L., JUTEAU, M., MARIN, L., MICHARD, A., SHEPPARD, S.M.F., TREUIL, M. & VERNET, M., 1987: The Macusani glasses, SE Peru: evidence of chemical fractionation in peraluminous magmas. *In* Mysen, B.O. (Editor): Magmatic processes: physicochemical principles. *Geochemical Society Special Publication*, **1**, 359–373.

PLIMER, I.R., 1997: *A Journey Through Stone: The Chillagoe Story — The Extraordinary History and Geology of One of the Richest Mineral Deposits in the World*. Reed Books, Kew, Victoria.

POLLARD, P.J., 1984: Granites and associated tin–tungsten mineralisation in the Emuford district, northeast Queensland, Australia. Ph.D. Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

POLLARD, P.J., 1988: Petrogenesis of tin-bearing granites of the Emuford district, Herberton Tinfield, Australia. *Australian Journal of Earth Sciences*, **35**, 39–57.

POWELL, C. McA., 1984: Ordovician to earliest Silurian: marginal sea and island arc. *In* Veevers, J.J. (Editor): Phanerozoic earth history of Australia. *Oxford Monographs on Geology and Geophysics* **No. 2**, Clarendon Press, Oxford, 290–309.

POWELL, C. McA., COLE, J.P. & CUDAHY, T.J., 1985: Megakinking in the Lachlan Fold Belt, Australia. *Journal of Structural Geology*, **7**, 281–300.

PRICE, P.L., 1983: A Permian Palynostratigraphy in Queensland. *In* Proceedings of the Symposium on the Permian Geology of Queensland. Geological Society of Australia Inc. (Queensland Division), 155–211.

PRICE, C.D., 1990: AP 4896M, Galli farm out. Exploration report for first year of tenure 26/8/89 to 19/7/90 and final report. CRA Exploration Pty Ltd. Held by the Department of Mines and Energy, Queensland as CR 21891.

PYPER, R., 1989: AP 5466M, Stewart northwest, partial relinquishment report for the period 29th June 1988 to 29th June 1989. Held by the Department of Mines and Energy, Queensland as CR 22199.

RAGGATT, H.G., 1968: *Mountains of Ore*. Lansdowne Press, Melbourne.

RAMSAY, J.G., 1980: The crack seal mechanism of rock deformation. *Nature*, **284**, 135–139.

RANDS, W.H., 1893: Geological observations in the Cooktown district. *Geological Survey of Queensland, Publication,* **91**, 1–5.

RAPP, R.P., RYERSON, F.J. & MILLERE, C.F., 1987: Experimental evidence bearing on the stability of monazite during crustal anatexis. *Geophysical Resources Letters*, **14**, 307–310.

RAPP, R.P. & WATSON, E.B., 1986: Monazite solubility and dissolution kinetics: implications for the thorium and light rare earth chemistry of felsic magmas. *Contributions to Mineralogy and Petrology*, **93**, 304–316.

RAY, G.E. & WEBSTER, I.C.L., 1991: An overview of skarn deposits. *In* Ore deposits, tectonics and metallogeny in the Canadian cordillera. B*ritish Columbia Ministry of Energy, Mines and Petroleum Resources, Paper* **1991–4**, 213–252.

REID, J.E., 1978: Skarn alteration of the Commercial Limestone, Carr Fork Area, Bingham, Utah. *Economic Geology*, **73**, 1315–1325.

REISGYS, L., 1986: Tregoora gold project, north Queensland. *In Extended Abstracts: Gold Exploration and Development, North Queensland Conference, Charters Towers*. Australasian Institute of Mining and Metallurgy, North Queensland Branch, Townsville, 78–81.

RICHARDS, D.N.G., 1980: Palaeozoic granitoids of northeastern Australia. *In* Henderson, R.A. & Stephenson, P.J. (Editors): *The geology and geophysics of northeastern Australia*. Geological Society of Australia, Queensland Division, Brisbane, 229–246.

RICHARDS, D.N.G., 1981: Granitoids of the northern Tate Batholith, Chillagoe, north Queensland. Ph.D. Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

RICHARDS, J.R., WHITE, D.A., WEBB, A.W. & BRANCH, C.D., 1966: Isotopic ages of acid igneous rocks in the Cairns hinterland, north Queensland. *Bureau of Mineral Resources, Australia, Bulletin*, **88**.

RICHARDS, T.H., 1977: The geological history of the Frankland Islands region, coastal north Queensland. B.Sc. Honours Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

RIENKS, I.P., 1991: New plutonic rock units in the northeastern portion of the Ravenswood Batholith. *Queensland Government Mining Journal*, **92**(1070), 30–42.

RIGBY, J.F., 1973: *Gondwanidium* and other similar Upper Palaeozoic genera, and their stratigraphic significance. *Geological Survey of Queensland Publication*, **350**.

RIGBY, J.F., 1993: Review of the Early Permian flora of the Nychum Volcanics north of Chillagoe, north Queensland. *In* Findlay, R.H., Unrug, R., Banks, M.R. & Veevers, J.J. (Editors): *Gondwana Eight. Assembly, evolution and dispersal*. A. A. Balkema, Rotterdam, 241–247.

RIGBY, J.F., in press: The Permian flora of the Mount Mulligan Coal Measures. *Geophytology*.

ROBERTSON, A.D.C., 1993: Cainozoic volcanism in the Butchers Hill 1:100 000 Sheet area. *Queensland Geological Record*, **1993/12**.

ROBINSON, C., 1980: Alluvial tin deposits in the Mount Garnet area. *In Recent Developments in Far North Queensland*. Australasian Institute of Mining and Metallurgy, Far North Queensland Branch, 17th–19th October 1980, 126–136.

ROMBERGER, S.B., 1988: Geochemistry of gold in hydrothermal deposits. *U.S. Geological Survey Bulletin*, **1857-A**, A9–A25.

ROSER, B.P. & KORSCH, R.J., 1986: Determination of tectonic setting of sandstone–mudstone suites using SiO_2 content and K_2O/Na_2O ratio. *Journal of Geology*, **92**, 635–650.

ROSER, B.P. & KORSCH, R.J., 1988: Provenance signatures of sandstone–mudstone suites determined using discriminant function analysis of major-element data. *Chemical Geology,* **67**, 119–139.

ROWINS, S.R., GROVES, D.I. & McNAUGHTON, N.J., 1997: A Reinterpretation of the role of granitoids in the genesis of Neoproterozoic gold mineralisation in the Telfer Dome, Western Australia. *Economic Geology*, **92**, 133–160.

RUBENACH, M.J., 1978: Northernmost section of the Tasman Orogenic Zone. *In* Rubenach, M.J. (Editor): *Excursions handbook, Third Australian Geological Convention, Townsville, 1978*. Geological Society of Australia, Queensland Division, Brisbane, 43–67.

RUBENACH, M.J., 1994: Skarn deposits of the Chillagoe–Mount Garnet region. *In* Henderson, R.A. & Davis, B.K. (Editors): Extended Conference Abstracts, New Developments in Geology and Metallogeny: Northern Tasman Orogenic Zone. *EGRU Contribution* **50**, 69.

RUBENACH, M.J. & BELL, T.H., 1988: Microstructural controls and the role of graphite in matrix/porphyroblast exchange during synkinematic andalusite growth in a granitoid aureole. *Journal of Metamorphic Geology*, **6**, 651–666.

RUBENACH, M.J. & CARTWRIGHT, I., 1994: Stable isotope fronts in high-temperature skarns at Chillagoe, Queensland: implications regarding fluid flow in skarns. *Geological Society of Australia, Abstracts* **No. 37**, 384.

RUDD, R.E. & PIKE, G., 1978: The veins of Carbine Hill: Mount Carbine 1895 –1978. O'Donnell for Queensland Wolfram, Mareeba, Queensland.

SAINT-SMITH, E.C., 1917a: The Kitchener molybdenite mine, Khartoum. *Queensland Government Mining Journal*, **18**, 226–229.

SAINT-SMITH, E.C., 1917b: New Minnie Moxham mine, Northcote. *Queensland Government Mining Journal*, **18**, 269–272.

SAWKA, W.N., HEIZLER, M.T., KISTLER, R.W. & CHAPPELL, B.W., 1990: Geochemistry of highly fractionated I- and S-type granites from the tin–tungsten province of western Tasmania. *In* Stein, H.J. & Hannah, J.L. (Editors): Ore-bearing granite systems; petrogenesis and mineralizing processes. *Geological Society of America, Special Paper*, **246**, 161–179.

SHANNON, H., 1976: AP 1520M, final relinquishment report. Held by the Department of Mines and Energy, Queensland as CR 5482.

SHAW, R.D., FAWCKNER, J.F. & BULTITUDE, R.J., 1987: The Palmerville fault system: a major imbricate thrust system in the northern Tasmanides, north Queensland. *Australian Journal of Earth Sciences*, **34**, 69–93.

SHELTON, K.L., 1983: Composition and origin of oreforming fluids in a carbonate-hosted porphyry copper and skarn deposit: a fluid inclusion and stable isotope study of Mines, Quebec. *Economic Geology*, **78**, 387–421.

SHEPHERD, S.R.L., 1945: Mount Mulligan coal mine, N.Q. *Queensland Government Mining Journal*, **46**(527), 261–263.

SHERATON, J.W., 1974: Chemical analyses of acid igneous rocks from northeast Queensland. Bureau of Mineral Resources, Australia, Record, 1974/162.

SHERATON, J.W. & LABONNE, B., 1974: Petrography of acid igneous rocks from north-east Queensland. Bureau of Mineral Resources, Australia, Record, 1974/161.

SHERATON, J.W. & LABONNE, B., 1978: Petrology and geochemistry of acid igneous rocks of north-east Queensland. *Bureau of Mineral Resources, Australia, Bulletin*, **169**.

SHIRLEY, J.E., 1979: Crustal structure of north Queensland from gravity anomalies. *BMR Journal of Australian Geology and Geophysics*, **4**, 309–321.

SIEMEN, J.E., 1973: Inspection of St George and Lincoln antimony mines, north Queensland, Memorandum to the Chief Government Geologist, Brisbane. Report, GSQ Commodity File.

SKERTCHLEY, S.B.J., 1897: Report on the tin mines of Watsonville and on various tin, silver, gold and copper mines at Herberton, Mount Albion, Irvinebank, Muldiva, Calcifer, Chillagoe, California Creek and Tate River. *Geological Survey of Queensland Publication,* **119**.

SMART, J., GRIMES, K.G., DOUTCH, H.F. & PINCHIN, J., 1980: The Carpentaria and Karumba Basins, north Queensland. *Bureau of Mineral Resources, Australia, Bulletin*, **202**.

SMIRNOV, VI., 1976, Skarn deposits. *In Geology of Mineral Deposits*, MIR Publication, Moscow, 156–188.

SMITH, R.L. & BAILEY, R.A., 1968: Resurgent cauldrons. *Geological Survey of America Memoir*, **116**, 613–662.

SPRY, A.H., 1986: Australian building stones: Marble. *AMDEL Report* **159**.

STEIGER, R.H. & JAGER, E., 1977: Subcommission on geochronology: convention on the use of decay constants in geo- and cosmochronology. *Earth and Planetary Science Letters*, **36**, 359–362.

STEPHENSON, P.J., 1989: Northern Queensland. *In* Johnston, R.W. (Editor): *Intraplate volcanism in eastern Australia and New Zealand*. Cambridge University Press, Cambridge, 89–97.

STEPHENSON, P.J., 1990: Layering in felsic granites in the main East Pluton, Hinchinbrook Island, north Queensland, Australia. *Geological Journal*, **25**, 325–336.

STEPHENSON, P.J. & CHAPPELL, B.W., 1988: The geology and petrology of the Palm Islands, north Queensland. *Geological Society of Australia, Abstracts*, **21**, 377–378.

STEPHENSON, P.J., CHAPPELL, B.W., McCULLOCH, M., FROST, M.T. & REID E., 1992: The geology of arfvedsonite granites, Hinchinbrook Island, N. Queensland. *In* Brown, P.E. & Chappell, B.W. (Editors): Second Hutton Symposium. The origin of granites and related rocks. *Transactions of the Royal Society of Edinburgh*, **83**(1, 2), 501.

STEPHENSON, P.J. & GRIFFIN, T.J., 1976: Cainozoic volcanicity of north Queensland. *25th International Geological Congress, Australia, 1976. Field Excursion Guidebook*, **7A**.

STEPHENSON, P.J., GRIFFIN, T.J. & SUTHERLAND, F.L., 1980: Cainozoic volcanism in northeastern Australia. *In* Henderson, R.A. & Stephenson, P.J. (Editors): *The geology and geophysics of northeastern Australia*. Geological Society of Australia, Queensland Division, Brisbane, 349–74.

STRICKLAND, C.D., 1982: The Barron River Project A's — P 3171M, 3172M, 3177M, 3178M, 3195M Six Monthly and Final Report for the Period Ending 5.11.82, Report No. CRA Exploration Pty Ltd. Held by the Department of Mines and Energy, Queensland as CR 11623.

SUTHERLAND, F.L., 1977: Cainozoic basalts of the Mt Fox area, north Queensland. *Australian Museum Record*, **30**, 532–543.

TATE, N.M., 1983: The origin of tourmaline nodules in the Finlayson Granite, north Queensland. B.Sc. Honours Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

TAYLOR, R.G., 1971: Mineralogical zoning in the Herberton tinfield, north Queensland, Australia — a discussion. *Economic Geology*, **66**, 813–815.

TAYLOR, S.R. & McLENNAN, S.M., 1985: *The continental crust: its composition and evolution*. Blackwell Scientific Publications, Oxford.

TAYLOR, R.G. & POLLARD, P.J., 1988: Pervasive hydrothermal alteration in tin-bearing granites and implications for the evolution of ore-bearing fluids. *In* Taylor, R.G. & Strong, D.F. (Editors): Recent advances in the geology of granite-related mineral deposits. Proceedings of the CIM conference on granite-related mineral deposits, September 1985. *Canadian Institute of Mining and Metallurgy, Quebec, Special Volume* **39**, 86–95.

TAYLOR, R.G., & POLLARD, P.J., 1990: Exploration for primary deposits of tin and tungsten in north Queensland. *In* Glasson, K.R. & Rattigan, J.H.

(Editors): Geological aspects of the discovery of some important mineral deposits in Australia. *Australasian Institute of Mining and Metallurgy, Monograph Series*, **17**, 253–257.

TAYLOR, R.G., & STEVESON, B.G., 1972: An analysis of metal distribution and zoning in the Herberton Tinfield, north Queensland, Australia. *Economic Geology*, **67**, 1234–1240.

TORREY, C.E., KARJALAINEN, H., JOYCE, P.J., ERCEG, M., & STEVENS, M., 1986: Geology and mineralisation of the Red Dome (Mungana) gold skarn deposit, north Queensland, Australia. *EGRU Contribution*, **21**.

TRAMP, 1937: Bartle Frere goldfield; gold at high altitude. *Cummins & Campbell's Monthly Magazine*, **October 1937**, 14–16.

TREZISE, D.L., 1990: Building Stones. A Review of the Queensland Building Stone Industry. *Queensland Resource Industries Review Series*. Department of Minerals and Energy, Brisbane.

TRUELOVE, A.J., 1982: AP 1995M, Mount Romeo area; report on six months to 13/8/82. Held by the Department of Mines and Energy, Queensland as CR 11225.

TRUELOVE, A.J., 1986: AP 3898M, Six Mile Cooktown; combined final report and report for six months ended 23.11.85. Held by the Department of Mines and Energy, Queensland as CR 15316.

TUCK, R., 1968: Origin of the bedrock values of placer deposits. *Economic Geology*, **63**, 191–193.

TURNER, F.J. & VERHOOGEN, J., 1960: *Igneous and Metamorphic Petrology*. Second edition. McGraw-Hill, New York.

VEEVERS, J. J. (Editor), 1984: Phanerozoic Earth history of Australia. *Oxford Monographs on Geology and Geophysics,* **No. 2**, Clarendon Press, Oxford.

VERWOERD, P. J. & SARGEANT, D. W., 1971: Final report on exploration conducted on APs 203M and 349M, Chillagoe area, north Queensland. Report No. 1971.20. Held by the Department of Mines and Energy, Queensland as CR 3725.

VIDALE, R., 1969, Metasomatism in a chemical gradient and the formation of calc-silicate bands. *American Journal of Science*, **267**, 857–874.

VOKES, F., 1963, Molybdenum deposits of Canada. *Geological Survey of Canada, Economic Geology Report,* **20.**

WALKER, R.G., 1978: Deep water sandstone facies and ancient submarine fans: models for exploration for stratigraphic traps. *American Association of Petroleum Geologists Bulletin*, **62**, 932–966.

WALLIS, D.C., 1993a: Antimony in Queensland. Queensland Minerals and Energy Review Series.

WALLIS, D.S., 1993b: Queensland Mineral Commodity Report — Copper. *Queensland Government Mining Journal*, **94**, 11–26.

WASS, R. & DENNIS, D.M., 1977: Early Palaeozoic faunas from the Warwick–Stanthorpe region, Queensland. *Search*, **8**(6), 207–208.

WATANABE, T., 1960, Characteristic features of ore deposits found in contact metamorphic aureoles in Japan. *International Geology Review*, **2**, 946–966.

WEBB, A.W., 1969: Metallogenic epochs in eastern Queensland. *Proceedings of the Australasian Institute of Mining and Metallurgy*, **230**, 29–37.

WEBB, J.A., BERNECKER, T. & FORDHAM, B.G., 1989: Early Silurian to Early Devonian limestones and cherts of Chillagoe Formation, northeast Australia. *International Geological Congress Abstracts*, **28**(3), 340–341.

WEIL, A.J., 1980: Half-yearly report to 28-10-1980, AP 2403m, Fluorspar. Held by the Department of Mines and Energy, Queensland as CR 8349.

WELLMAN, P., 1997: Geophysical characteristics. *In* Bain, J.H.C. & Draper, J.J. (Compilers & Editors): North Queensland Geology. *Australian Geological Survey Organisation Bulletin* ***240****, and Queensland Department of Mines and Energy Queensland Geology*, **9**(7), 225–226.

WELLMAN, P., MACKENZIE, D.E. & BAIN, J.H.C., 1994: Permian–Carboniferous magmatism in north Queensland, a new perspective. *AGSO Research Newsletter*, **20**, 8–9.

WELLS, A.T., 1989: Permian coal measures in the sub-Laura Basin sequence, Little River–Oakey Creek district, Queensland. *Bureau of Mineral Resources, Australia, Bulletin* **231**, 179–183.

WENTWORTH, C.K., 1922: A scale of grade and class terms for clastic sediments. *Journal of Geology*, **30**, 377–392.

WHALEN, J.B., CURRIE, K.L. & CHAPPELL, B.W., 1987: A-type granites: geochemical characteristics, discrimination and petrogenesis. *Contributions to Mineralogy and Petrology*, **95**, 407–419.

WHITBY, K.J., 1975: Geology and coal resources AP 168C, Mitchell River Area, West. of Cairns, Queensland. Held by the Department of Mines and Energy, Queensland as CR 5444.

WHITE, A.H., 1978: The western margin of the Hodgkinson Basin — a reappraisal. *Queensland Government Mining Journal*, **79**(915), 26–33.

WHITE, A.J.R. & CHAPPELL, B.W., 1983: Granitoid types and their distribution in the Lachlan Fold Belt, southeastern Australia. *In* Roddick, J.A. (Editor): Circum-Pacific Plutonic Terranes. *Geological Society of America Memoir*, **159**, 21–34.

WHITE, A.J.R., CHAPPELL, B.W. & CLEARY, J.R., 1974: Geologic setting and emplacement of some Australian Palaeozoic batholiths and implications for intrusive mechanisms. *Pacific Geology*, **8**, 159–171.

WHITE, M.E., 1961: Fossil plants from the Little River Coal Measures, in the Cooktown region of north Queensland. Bureau of Mineral Resources, Australia, Record, 1961/121.

WHITEHEAD, P. & McDOUGALL, I., 1991: The geomorphological evolution of the Atherton Tableland, north Queensland. *Australian National University, Research School of Earth Sciences, Annual Report for 1991*, 109–110.

WHITTLE, A.W.G., 1968: Summary report to Authority to Prospect 431M, Palmer River area, north Queensland for North Broken Hill Ltd. Mineralogy at the Dianne prospect, Queensland. Held by the Department of Mines and Energy, Queensland as CR 2647B.

WILLMOTT, W.F., TREZISE, D.L., O'FLYNN, M.L., HOLMES, P.R. & HOFMANN, G.W., 1988: *Cairns Region, Sheet 8064, part Sheet 8063, Queensland, 1:100 000 Geological Map Commentary*. Department of Mines, Queensland, Brisbane.

WILLMOTT, W.F., WHITAKER, W.G., PALYREYMAN, W.D. & TRAIL, D.S., 1973: Igneous and metamorphic rocks of Cape York Peninsula and Torres Strait. *Bureau of Mineral Resources, Australia, Bulletin*, **135**.

WILSON, A.F., 1987: Some highlights of the gold deposits of Queensland — past and present, and some future prospects. *Papers of the Department of Geology, University of Queensland*, **12**(1), 1–6.

WITHNALL, I.W., 1997a: Silurian–Early Devonian. *In* BAIN, J.H.C. & DRAPER, J.J. (Compilers & Editors): North Queensland Geology. *Australian Geological Survey Organisation Bulletin* ***240****, and Queensland Department of Mines and Energy Queensland Geology*, **9**(8), 331–333.

WITHNALL, I.W., 1997b: Structure and tectonics. *In* BAIN, J.H.C. & DRAPER, J.J. (Compilers & Editors): North Queensland Geology. *Australian Geological Survey Organisation Bulletin* ***240****, and Queensland Department of Mines and Energy Queensland Geology*, **9**(8), 341–344.

WITHNALL, I.W., 1997c: Carboniferous–Early Permian intrusive rocks. *In* Bain, J.H.C. & Draper, J.J. (Compilers & Editors): North Queensland Geology. *Australian Geological Survey Organisation Bulletin* ***240****, and Queensland Department of Mines and Energy Queensland Geology*, **9**(8), 339–340.

WITHNALL, I.W., GOLDING, S.D., REES, I.D. & DOBOS, S.K., 1996: K–Ar dating of the Anakie Metamorphic Group: evidence for an extension of the Dalamerian Orogeny into central Queensland. *Australian Journal of Earth Sciences*, **43**, 567–572.

WITHNALL, I.W. & GRIMES, K.G., 1995: Einasleigh, second edition. *Queensland 1:250 000 Geological Series — Explanatory Notes*. Department of Minerals & Energy, Queensland.

WITHNALL, I.W. & LANG, S.C., 1990: Tectonic history of the Palaeozoic Broken River Province, north Queensland. *In Proceedings of the Pacific Rim 90 Congress.* Australasian Institute of Mining and Metallurgy, Parkville (Victoria), **II**, 315–324.

WITHNALL, I.W. & LANG, S.C., 1993: Geology of the Broken River Province, north Queensland. *Queensland Geology*, **4**.

WITHNALL, I.W. & McLENNAN, T.P.T., 1991: Geology of the northern part of the Lolworth–Ravenswood Province. *Queensland Resource Industries Record*, **1991/12**.

WITT, W.K., 1985: Diffuse (background), and fracture-controlled feldspathic alteration in tin-mineralised granites of the Irvinebank–Emuford area, northeast Queensland. Ph.D. Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

WITT, W.K., 1987: Fracture-controlled feldspathic alteration associated with tin mineralisation in the Irvinebank–Emuford area, northeast Queensland. *Australian Journal of Earth Sciences*, **34**, 447–462.

WITT, W.K., 1988: Evolution of high-temperature hydrothermal fluids associated with greisenization and feldspathic alteration of a tin-mineralized granite, northeast Queensland. *Economic Geology*, **83**, 310–334.

WOLFF, D., 1980: Operating a large low grade wolfram mine. *In Recent Developments in Far North Queensland*. Australasian Institute of Mining and Metallurgy, Far North Queensland Branch, Townsville, 41–46.

WOODBURY, M.J., 1994: Red Dome and Mungana porphyry Cu–Au and base metal skarns of north-east Queensland. B.Sc. Honours Thesis, Australian National University, Canberra, Department of Geology.

WOODCOCK, J.T., 1958: Treatment of antimony ore from King Pin mine, Mitchell River, north Queensland. CSIRO and the Mining Department, University of Melbourne, Ore Dressing Investigations Report 558.

WOODWARD, A.J., 1976: Paragenesis of the silver–lead mineralisation in the Montalbion–Adventure Creek district, Queensland. M.Sc. Thesis, James Cook University of North Queensland, Townsville, Department of Earth Sciences.

WRONKIEWICZ, D.J. & CONDIE, K.C., 1989. Geochemistry and provenance of sediments from the Pongola Supergroup, South Africa: evidence for a 3.0Ga-old continental craton. *Geochimica et Cosmochimica Acta*, **53**, 1537–1549.

WYATT, D.H., PAINE, A.G.L., CLARKE, D.E., GREGORY, C.M. & HARDING, R.R., 1970: Geology of the Townsville 1:250 000 Sheet area, Queensland. *Bureau of Mineral Resources, Australia, Report*, **127**.

ZARAYSKIY, G.P., ZHARIKOV, V.A., STOYANOVSKAYA, F.M. & BALASHOV, VN., 1987: The experimental study of bimetasomatic skarn formation. *International Geology Review*, **29**, 761–858.

ZHARIKOV, VA., 1970, Skarns. *International Geology Review*, **12**, 541–559, 619–647, 760–775.

ZIMMERMAN, D.O., 1969: Final report, AP 519M, east coast, Cape York, Queensland. Held by the Department of Mines and Energy, Queensland as CR 2887.

ZUCCHETTO, R.G., HENDERSON, R.A., DAVIS, B.K. & WYSOCZANSKI, R., 1998: Age constraints on deformation of the eastern Hodgkinson Province, north Queensland: new perspectives on the evolution of the northern Tasman Orogenic Zone. *Geological Society of Australia, Abstracts* **No. 49**, 498.

APPENDIXES

Appendix 1. List of constituent units, selected granite supersuites, Cairns Region.

SUPERSUITE / BATHOLITH	SUITE	CONSTITUENT UNITS (AREA)	AGE	GEOCHEMISTRY
CENTRAL AND EASTERN HODGKINSON PROVINCE				
Cooktown S-type	Barrow Point	Barrow Point gr.[1] (~4km^2 — Barrow Point Stock)	late Permian	F F–U R H[2]
	Big Tableland relatively high Nb, low Zn	Big Tableland gr.	late Permian	F F R H
	Boolbun	Boolbun Gr. (~41km^2)	late Permian	F F R H
	Collingwood rel. high Na_2O, K_2O, and low ASI, Cr, Zn	Collingwood Gr. (~25km^2)	264–282Ma (est.[3]) (Rb–Sr)	F F R H
	Cooktown rel. high MgO, mg, P_2O_5, Cr, and low Y	Cooktown Gr. (~5km^2)	late Permian	F F R H
		Charlotte Gr. (~3km^2)	275±5Ma (SHRIMP); 262–278Ma (est.) (Rb–Sr)	F F R H
		Finch Bay Gr. (~0.3km^2)	late Permian	F F R H
	Mount Hartley rel. high La, Ce, Th, Zr	Mount Hartley Gr. (~5km^2)	late Permian	F F R H
		Mount Leswell Mgrt. (~2km^2)	late Permian	F F R H
	Mount Poverty rel. high Nb, Zn, Ga	Phoenician Gr. (~7km^2)	late Permian	F F R H
		Finlayson Gr. (~76km^2)	late Permian	F F R H
		Mount Poverty Gr. (~11km^2)	late Permian	F F R H
	Ninian Bay	Ninian Bay mgrt.	late Permian	F F R H
	Roaring Meg rel. high Zn, and low Nb	Bourgamba Mgrt. (~1.5km^2)	late Permian	F F R H
		China Camp Mgrt. (~0.7km^2)	late Permian	F F R H
		Roaring Meg Gr. (~35km^2)	259–266Ma (est.) (Rb–Sr)	F F R H
	Starcke	Starcke gr.	late Permian	F F R H
	Waterfall rel. high ASI[4] , and low Agp[5]	Waterfall Gr. (~5km^2)	247–270Ma (est.) (Rb–Sr)	F F R H

1 all lower case letters for descriptor are used to denote an informal unit
2 classification scheme as used by Champion & Heinemann (1994);
first entry, mafic (M) or felsic (F); second entry, fractionated (F) or unfractionated (U);
third entry, oxidation state (SO = strongly oxidised, O = oxidised, R = reduced, SR = strongly reduced);
fourth entry, K_2O content (UH = ultra-high, H = high, M = medium, L = low)
3 age calculated (estimated) using an assumed initial ratio
4 ASI = Aluminium Saturation Index = Al(molecular)/(Ca + Na + K) (molecular)
5 Agp = Agpaitic Index = Al(molecular)/(Na + K) (molecular)

SUMMARY DESCRIPTION
pale to medium grey, fine to medium-grained, slightly to moderately porphyritic cordierite (altered)–muscovite–biotite granite; accessory garnet, zircon, ilmenite, apatite; contains biotite-rich gneissic enclaves, to ~5cm, as well as sparse inclusions, up to 3m x 2m, of hornfelsed mudstone
medium to coarse-grained, seriate to slightly porphyritic cordierite (altered)–biotite granite; tourmaline locally abundant; numerous microgranite lenses, dykes, sheets, and pods; extensively altered (greisenised) in places; extensively deformed with mylonitic foliation developed locally; associated with significant Sn mineralisation; similar field and petrographic characteristics to the Collingwood Gr. and currently mapped as part of the latter
fine to medium-grained, moderately to highly porphyritic cordierite (altered)–muscovite–biotite granite; accessory zircon, apatite, ilmenite, garnet, tourmaline; intensely deformed in places with a mylonitic fabric developed; minor medium-grained, even-grained to slightly porphyritic biotite–muscovite granite; may contain more than one major pluton
medium to coarse-grained, seriate to moderately porphyritic cordierite (altered)–biotite granite; tourmaline commonly very abundant adjacent to contact with country rocks; miarolitic cavities common locally; scattered pegmatitic patches and lenses; numerous porphyritic microgranite lenses, dykes, sheets and pods; minor aplite; rare topaz; extensively deformed; commonly extensively altered (greisenised); with significant Sn mineralisation in places
white to pale grey, fine to medium-grained, moderately porphyritic to equigranular (garnet–altered cordierite–) tourmaline–muscovite–biotite granite; miarolitic cavities present locally
pale grey to white, moderately to slightly porphyritic, fine to medium-grained (garnet–) cordierite (altered)–tourmaline– muscovite–biotite granite; with scattered enclaves and miarolitic cavities; SHRIMP date may represent a mixed age
pale grey or, locally, white to pale brown, moderately porphyritic, fine to medium-grained, cordierite (altered)–tourmaline–muscovite–biotite granite; miarolitic cavities and enclaves (including biotite-rich metasedimentary gneiss) common; rare fragments of coarse sillimanite present locally
fine-grained, highly to slightly (locally) porphyritic, (altered cordierite–) tourmaline–biotite granite; extensively altered (greisenised) in places, with associated lode, eluvial, colluvial, and alluvial cassiterite deposits; cut by a wolframite-bearing quartz–tourmaline vein; extensively deformed locally
dark grey, fine-grained, slightly to moderately porphyritic biotite granite; accessory ilmenite, apatite, zircon, allanite, tourmaline, muscovite, cassiterite, fluorite; enclaves (up to ~50cm) and miarolitic cavities locally common
medium-grained, even-grained to slightly porphyritic tourmaline–muscovite–biotite granite; tourmaline locally common; extensively altered (greisenised) in places (mainly around margins) with associated cassiterite mineralisation; extensively deformed and recrystallised
white, medium-grained, seriate to moderately porphyritic (altered cordierite?)–tourmaline–biotite granite; accessory muscovite; extensively altered (greisenised) in places; deformed
fine to medium-grained, seriate to moderately porphyritic tourmaline–muscovite–biotite granite; traces of altered cordierite?; small greisen zones (locally with cassiterite) may have been the source of the alluvial cassiterite in the Mount Poverty area
fine to medium-grained, slightly porphyritic to seriate biotite granite; accessory tourmaline, altered cordierite? (rare); tourmaline-rich clots common
mainly fine to medium-grained, even-grained to slightly porphyritic (altered cordierite?–) tourmaline–biotite–muscovite granite; minor greisen
pale brown, fine-grained, slightly porphyritic tourmaline–biotite–muscovite granite; miarolitic cavities and tourmaline-rich aggregates common; associated with tin mineralisation at China Camp
moderately to highly porphyritic, medium to coarse-grained tourmaline–biotite granite; pegmatitic patches common; accessory cordierite (altered), zircon, ilmenite, apatite, monazite?, muscovite; significant Sn mineralisation is associated with this unit and related? microgranites (particularly the latter)
fine to medium-grained, moderately porphyritic biotite granite; traces of altered cordierite?
fine-grained, highly porphyritic (altered cordierite)–muscovite–tourmaline–biotite granite; quartz phenocrysts locally deeply embayed; sparse enclaves (to 10cm) of 'microdiorite' and biotite-rich gneiss; extensively deformed

Appendix 1 (continued)

SUPERSUITE/ BATHOLITH	SUITE	CONSTITUENT UNITS (AREA)	AGE	GEOCHEMISTRY
Cooktown S-type (continued)	unassigned	Mrs Watsons Bay Mgrt. (probably <1km^2)	late Permian	F F R H
		Lizard Island Gr. (~8km^2)	late Permian	F F R H
		Mount Finnigan Gr. (~7km^2)	late Permian	F F R H
Pieter Botte I-type	Nulbullulul	Bunk Creek Gr. (~7km^2)	late Permian	F F R H–UH
		Thornton Gr. (~34km^2)	late Permian	F F R H
		Nulbullulul Gr. (~89km^2)	261±3Ma (SHRIMP)	F F R H
Yates I-type	Bakers Blue rel. high Rb, and low Na_2O, Ba, Sr, Pb, Nb	Bakers Blue Gr. (~18km^2)	280±2Ma (Rb–Sr)	F U R H
	Hope Vale	Hope Vale Gr. (~9km^2)	late? Permian	M–F U R H
	Howick Island	Howick Island Gd. (0.4km^2)	late Permian	F U R H
	Keating; rel. low Na_2O, Ba, Sr, Pb, Nb	Keating Gd. (~12km^2)	late Permian	F U R H
	Puckley rel. high K_2O, Pb, Y, U, and low Na_2O, Sr, V, Cr, N	Leichhardt Pocket Gr. (~37km^2)	early Permian	M–F U R H
		Puckley Gr. (~25km^2)	276±3Ma (Rb–Sr)	F U R H–M
	Talgijah rel. high Nb, and low Na_2O, Ba, Sr, Pb	Talgijah Gd. (5km^2)	early Permian	M–F U R H
	Trevethan rel. high Na_2O, Ba, Sr, and low Pb	Black Mountain gr.	late Permian	F U R H
		Trevethan Gd. (~17km^2)	259±1Ma (Rb–Sr)	M U R H
	Yates rel. high Na_2O, Ba, Sr, Pb	Mount Yates Gd. (~0.5km^2)	late Permian	M U R–O H
Cape Melville I-type	Saint Pauls Hill rel. high TiO_2, Al_2O_3, FeO*, MgO, CaO, P_2O_5, Ba, Nb, Sc, Sr, Zn, Zr, and low Rb	Saint Pauls Hill Mgrt. (~1km^2)	early Permian	F U R H
		Abbey Peak gr.	early Permian	F U R H
	Cape Melville	Cape Melville Gr. (~124km^2)	279±2Ma, 281±2Ma (Rb–Sr)	F U R H
	Altanmoui rel. low Ba, Ce, Cu, Ga, La, Nb, Sc, Zn, Zr, Ga/Al compared to Cape Melville Suite	Altanmoui Gr. (~32km^2)	277Ma (est.) (Rb–Sr)	F U–F R H

SUMMARY DESCRIPTION
white, cream or brown (altered), mainly fine-grained, essentially equigranular to slightly porphyritic tourmaline-biotite-muscovite leucogranite, with irregular pegmatitic zones; forms dykes, lenses, subhorizontal sheets, and pods
medium-grained, slightly porphyritic cordierite (altered)–tourmaline–biotite–muscovite granite and leucogranite, with pegmatitic zones to 30cm and miarolitic cavities to ~2cm; widespread slight to moderate alteration; minor fine-grained, highly porphyritic garnet–bearing granite
pale brown to pale grey, massive, moderately to highly porphyritic, fine-grained cordierite (altered)–tourmaline–muscovite–biotite granite; rare cordierite grains with tiny inclusions of green spinel; sparse enclaves (to ~3cm), some with sillimanite, cordierite (altered), garnet, green spinel
white to pale grey, moderately to highly porphyritic, fine to medium-grained, (clinopyroxene–hornblende–) biotite granite; accessory zircon, apatite, ilmenite, allanite; extensively deformed in places; may be the source of alluvial cassiterite deposits in Slaty and Granite Creeks
pale to medium grey, fine-grained, slightly porphyritic biotite leucogranite; traces of titanite, zircon, allanite, altered hornblende?, cassiterite?; granophyric intergrowths between quartz and K-feldspar common
white to pale grey, fine to medium-grained, slightly to moderately porphyritic hornblende–biotite granite; sparse tourmaline–quartz aggregates (to ~10cm); scattered enclaves (to ~1m) of mainly microgranite; accessory zircon, titanite, apatite, ilmenite, allanite; adjacent country rocks locally contain abundant fine-grained, metasomatic? tourmaline
white to grey, medium to fine-grained, even-grained to slightly porphyritic biotite granite; slightly deformed locally; scattered microgranite inclusions to ~10cm; accessory zircon, ilmenite, apatite, allanite
pale grey, slightly to moderately porphyritic, fine to medium-grained (hornblende–) biotite granite, with accessory allanite, zircon, apatite, ilmenite; scattered mafic enclaves common; minor even-grained to slightly porphyritic, (hornblende–) biotite microgranite
grey, medium-grained biotite granodiorite
white to grey, fine to medium-grained, slightly porphyritic biotite granodiorite to granite?; scattered mafic enclaves to 30cm; accessory apatite, zircon, ilmenite, tourmaline, titanite
pale to medium grey, fine-grained, moderately porphyritic hornblende–biotite granite to granodiorite?; 'dioritic' enclaves common; accessory zircon, apatite, ilmenite, allanite; minor altered cordierite?–muscovite–biotite granite also included in unit
white to pale grey, medium-grained, moderately porphyritic (hornblende?–) biotite granite; minor hornblende–biotite granodiorite; accessory minerals comprise mainly apatite, zircon, allanite, ilmenite, titanite; scattered rounded inclusions up to ~10cm; traces of alluvial cassiterite in places
white to grey, fine to medium-grained, even-grained to slightly porphyritic hornblende?–biotite granodiorite to diorite?, with numerous biotite-rich enclaves to ~10cm (most <3cm) — many appear to be of high-grade metamorphic rocks; rare garnet xenocrysts? and quartz inclusions (to ~4cm); extensively deformed and recrystallised (locally)
white, medium-grained, slightly porphyritic hornblende–biotite granite; with scattered inclusions (to ~5cm) of mainly biotite-rich gneiss and 'microdiorite'; included in Trevethan Granodiorite on current maps
grey, mainly medium-grained, slightly to locally highly porphyritic orthopyroxene–clinopyroxene–hornblende–biotite granodiorite; with inclusions of a variety of rock types up to ~1m; deformed with local subgrain development
white to grey, medium-grained, even-grained hornblende–biotite granodiorite; mafic enclaves (to 30cm — most <10cm); hornblende generally scarce; accessory apatite, zircon, ilmenite, titanite, allanite, rutile?
grey, fine-grained, highly porphyritic (allanite–) hornblende–biotite granite; with sparse inclusions, to ~5cm, of mainly biotite-rich metasediments
coarse-grained hornblende–biotite granite, with accessory allanite; unit of unknown extent in southwestern part of the Melville Range; included in Cape Melville Granite on current maps
medium to coarse-grained, seriate to moderately porphyritic (hornblende–) biotite granite; traces of hornblende and allanite common; enclaves (to ~3m — most <50cm) relatively common; enclaves include metasedimentary gneiss with corundum porphyroblasts and rare quartz fragments
medium-grained, moderately porphyritic biotite granite; accessory zircon, apatite, ilmenite, allanite; with scattered enclaves (to ~1m), biotite-rich schlieren, and pegmatitic patches

Appendix 1 (continued)

SUPERSUITE/ BATHOLITH	SUITE	CONSTITUENT UNITS (AREA)	AGE	GEOCHEMISTRY
Cape Melville I-type (continued)	Cape Bowen rel. low TiO_2, FeO*, MgO, CaO, P_2O_5, Ba, Ce, Cu, La, Nb, Sc, Sr, Zn, Zr, and high Pb, Rb, Y, Ga/Al	Cape Bowen gr.	early Permian	F F R H
Bellenden Ker S-type	Bellenden Ker	Bellenden Ker Gr. (~360km^2)	280±4Ma (SHRIMP)	F–M F–U R H–UH
	unassigned	Bessie Point gr.	early Permian	F F R H
		Clamshell gr.	early Permian	F F R H
		Palmer Point gr.	early Permian	F F R H
		Pugh Creek gr.	early Permian	F F R H
		Walshs Pyramid Gr. (~11km^2)	early Permian	F F R H
		Yarrabah gr.	early Permian	F F R H
Mount Alto S-type	Mount Alto	Mount Alto Gr. (~9km^2)	269±8Ma, 271±5Ma (SHRIMP)	F F R H
Whypalla S-type	Cannibal Creek rel. high P_2O_5, MgO, mg, $(Ce/Y)_N$[6], low Y	Cannibal Creek Gr. (~104km^2)	270Ma, 275Ma (est.) (Rb–Sr)	F F R H
	Curraghmore rel. high Y, La, Ce, $(Ce/Y)_N$	Curraghmore Gr. (~14km^2)	early Permian	F U R H
		Desailly Gr. (~25km^2)	early Permian	F–M U R H
		Kelly St George Gr. (~158km^2)	275–280Ma (est.) (Rb–Sr)	F F R H
		McLeod Gr. (~0.4km^2)	early Permian	F U R H
		Nangee Gr. (~0.7km^2)	early Permian	F F R H
		Northedge Gr. (~15km^2)	277–289Ma (Rb–Sr)	F F R H
	Mareeba rel. high Ni, and low Pb, Zr	Mareeba Gr. (~248km^2)	278Ma, 279Ma (Rb–Sr)	F F–U R H–UH
	Mount Carbine rel. low Zr, Pb, Ga	Spurgeon Gr. (~11km^2)	early Permian	

6 $(Ce/Y)_N$ = Ce/Y with both Ce and Y normalised to chondritic abundances

SUMMARY DESCRIPTION
fine-grained, highly porphyritic biotite granite; with biotite-rich aggregates (to ~1.5cm), pegmatitic patches, sparse, small (to ~10cm) biotite-rich inclusions; unit of unknown extent on northeastern side of the Altanmoui Range; included in Altanmoui Granite on recent maps
mainly white to pale grey or brown (altered), coarsely and highly porphyritic muscovite–biotite granite — biotite>>muscovite; commonly extensively sheared (mylonitised), foliated and recrystallised; inclusions (up to ~25m long — gen. <1m in most places) of biotite-rich gneiss, granite and microgranite locally common; scattered tourmaline-rich aggregates (to ~3cm) in places; locally granophyric; informal units included with Bellenden Ker Granite on recent maps
pale grey, medium-grained, even-grained to slightly porphyritic tourmaline–biotite leucogranite; with numerous tourmaline-rich aggregates up to ~4cm across; granophyric texture present locally; forms pluton of unknown extent in the Bessie Point area
white to pale grey or pink (altered), medium-grained, even-grained to slightly porphyritic (locally) (garnet–altered cordierite?–) tourmaline–biotite–muscovite leucogranite; with scattered tourmaline-rich aggregates (to ~2cm), and extensively altered zones; forms pluton of unknown extent in Clamshell Falls–Behana Creek area
pale brown, medium-grained, even-grained to slightly porphyritic, leucocratic (muscovite–) biotite granite; moderately deformed; forms pluton of unknown extent in Palmer Point area
white, medium to coarse-grained (garnet–altered cordierite?–) muscovite–biotite granite; with biotite-rich clots (to ~3cm) and rare gneiss inclusions (to ~3cm); non-foliated, little deformed; poorly exposed pluton of unknown extent ~1.5km W of Miriwinni
buff to brown or white to pale grey, medium-grained, even-grained to locally slightly porphyritic (tourmaline–muscovite–) biotite leucogranite; with biotite-rich clots, tourmaline-rich aggregates (to 2cm) and granophyric intergrowths in places; extensively deformed; forms stock centred on Walshs Pyramid
white to brown, medium to coarse-grained, mainly even-grained (tourmaline–altered cordierite?–) muscovite–biotite leucogranite; with scattered tourmaline-rich aggregates (to ~10cm); moderately to extensively deformed with a poorly developed foliation; forms pluton of unknown extent in Brown Creek area, west of Yarrabah Beach
cream to white, medium-grained, slightly to moderately porphyritic (biotite–) garnet–tourmaline–muscovite granite; minor fluorite, apatite; miarolitic cavities relatively common; adjacent hornfelses commonly contain abundant cordierite (extensively altered)
pale grey to white, medium to coarse-grained, slightly to highly porphyritic (garnet–) muscovite–biotite granite; extensively deformed and commonly foliated; source of significant eluvial and alluvial cassiterite deposits — mainly in Granite and Cannibal Creeks; surrounded by prominent metamorphic aureole
composite unit consisting of: (1) white to pale grey, medium-grained, highly porphyritic muscovite–garnet–biotite granite, with well-developed, locally gneissic, foliation; and (2) deformed, pale grey, medium-grained, moderately to highly porphyritic muscovite–garnet–biotite granite; (2) intrudes (1)
white to pale grey, medium-grained, slightly to moderately porphyritic (garnet–) muscovite–biotite granite; biotite- rich gneissic inclusions common; minor scheelite present locally in quartz veins and alteration zones within the granite; probable source of small alluvial tin deposits adjacent to SW margin
pale grey, cream or white, medium to coarse-grained, even-grained to slightly porphyritic (garnet–) muscovite–biotite granite; with scattered enclaves of biotite-rich gneiss and quartzite; small irregular pods and lenses of tourmaline–muscovite-bearing pegmatite
pale grey, fine-grained, highly porphyritic (clinopyroxene–) garnet–biotite–orthopyroxene granite; accessory ilmenite, zircon, apatite, sillimanite, muscovite; heterogeneous unit with up to ~50% phenocrysts locally; numerous 'microdioritic' enclaves to ~30cm; presence of rare clinopyroxene may indicate some magma mingling/mixing
grey, fine–medium-grained, even-grained biotite–muscovite granite; extensively deformed
white, medium-grained, moderately to highly porphyritic, (garnet–) tourmaline–muscovite–biotite granite; with scarce enclaves (to ~15cm) of biotite-rich metasedimentary rocks; cut by rare dykes (up to ~15cm thick) of tourmaline-bearing aplite and aplitic microgranite, as well as numerous dykes (up to ~20m thick) of intermediate to basic rocks; formerly included in the Mount Alto Supersuite
white to pale grey, medium to locally coarse-grained, slightly to moderately porphyritic muscovite–biotite granite, with pegmatitic patches and lenses, quartz–tourmaline aggregates, and sparse, small, mafic enclaves; locally foliated
cream to pink (altered), fine to medium-grained, even-grained tourmaline–muscovite–biotite granite; extensively altered; host to extensive alluvial and eluvial cassiterite deposits

Appendix 1 (continued)

SUPERSUITE/ BATHOLITH	SUITE	CONSTITUENT UNITS (AREA)	AGE	GEOCHEMISTRY
Whypalla S-type (continued)	Mount Carbine (continued)	unit $Pgwc_m$, Mossman[7], Rumula		F F R H
		Mount Carbine Gr. (~596km^2)	280±7Ma (Rb–Sr)	F F–U R H
	Mount Pike rel. high Y, and low Pb, Th, La, Ce, $(Ce/Y)_N$	Bullhead Gr. (~1km^2)	early Permian	F F R H
		Mount Pike Gr. (~21km^2)	284±4Ma (SHRIMP)	F U R H
	Whypalla rel. high Y, and low $(Ce/Y)_N$	Koobaba Gr. (~11km^2)	early Permian	F U–F R H
		Lang Creek Gr. (~7km^2)	early Permian	F F R H
		Mount Windsor gr.	early Permian	F F R H
		Whypalla Gr. (~500km^2)	278±4Ma (Rb–Sr)	F U–F R H
CHILLAGOE–MOUNT GARNET–HERBERTON BELT				
Lags A-type	Lags	Lags Mgrt. (17km^2)	279±4Ma (Rb–Sr)	F U O–R H
		unit Pmg (~2km^2)	early Permian	F U–F R–SO H–UH
		Yokas Mgrt. (~16km^2)	early Permian	M U R H
	Maneater rel. low Al_2O_3, Ba, Zr, and high TiO_2, FeO*, P_2O_5	Maneater Gd. (~49km^2)	late Carboniferous? –early Permian	M–F U O(–R) H
	unassigned	Bustlem Mgrt. (~39km^2)	280±4Ma (Rb–Sr)	F U O–R H
		Saint Helena Monzogranite (~23km^2)	early Permian	M U O–R H
Ootann I-type	California Creek	California Gr. (~111km^2)	late Carboniferous	F F O H
		Mount Cardwell Gr. (~333km^2)	late Carboniferous	F F O–R H
	Nymbool	Nymbool Gr. (~10km^2)	~316Ma, 318±43Ma (Rb–Sr)	F U R–SR H
	Ootann	Bamford Gr. (~7km^2)	303±5Ma (Rb–Sr)	F F O–R H
		Billycan Gr. (~6km^2)	300±1Ma (Rb–Sr)	F U O–R H
		Bird Spring Gr. (~2km^2)	late Carboniferous	F ? ? H
		Borneo Gd. (~10km^2)	304±4Ma (Rb–Sr)	M–F U O H
		Bulluburrah Gd. (~4km^2)	late Carboniferous	F U O–R H
		Bungabilly Gr. (~11km^2)	late Carboniferous	F U O H
		Burke Gr. (~3km^2)	late Carboniferous	F U–F R–O H

[7] 1:100 000 sheet area

SUMMARY DESCRIPTION
biotite microgranite; with scattered pegmatitic patches
white, medium to coarse-grained, moderately to highly porphyritic (garnet–tourmaline–) muscovite–biotite granite; tourmaline locally common; extensively deformed in places; cut by dykes and pods of albite-bearing microgranite, some with garnet and/or miarolitic cavities
white to pink (altered), fine to medium-grained, even-grained garnet–biotite–muscovite leucogranite; garnet and muscovite rel. common; aureole foliation and associated folds developed in country rocks adjacent to contact
white to pale grey, fine to coarse-grained, slightly to highly porphyritic muscovite–biotite granite; accessory garnet, zircon, apatite, ilmenite, monazite?, rutile?; enclaves to ~40cm common
white to grey, fine to coarse-grained, moderately to highly porphyritic tourmaline–garnet–muscovite–biotite granite; consists of several, small, scattered plutons; extensively deformed and locally recrystallised; miarolitic cavities present in places; with scattered enclaves of 'microdiorite' and garnet-bearing biotite gneiss
white to cream, medium-grained, even-grained (garnet–) biotite–muscovite granite
medium grey, medium to coarse-grained, even-grained garnet–muscovite–biotite granite; accessory zircon, ilmenite, apatite, monazite?, sillimanite; scattered inclusions of (garnet–) biotite gneiss; mapped as part of the Whypalla Gr. because the whereabouts of the contact between the two units is not known
white, medium to coarse-grained, moderately to highly porphyritic muscovite–biotite granite; accessory garnet, zircon, apatite, monazite?, ilmenite; variations in texture, grainsize, and mineral abundances suggest unit consists of more than one pluton; locally with a well-developed tectonic foliation
pale to medium grey, pink, or brown, highly porphyritic biotite microgranite
pale grey, pink, greenish grey, or brown, highly porphyritic (hornblende–) biotite microgranite; locally flow banded, extensively altered
pale grey to red-brown, very fine-grained, highly porphyritic garnet–hornblende microgranite, with embayed quartz phenocrysts; extensively altered
fine to medium-grained, slightly porphyritic to even-grained, granophyric biotite–hornblende granodiorite — contains hypersthene and/or augite, very rare garnet, and enclaves of arenite and granite; subordinate fine grained, slightly porphyritic two?-pyroxene–biotite–hornblende granodiorite — grades into slightly porphyritic dacite; commonly altered
medium to pale grey, or pinkish grey, highly porphyritic augite?–fayalite–hypersthene microgranite
medium to dark grey, very highly porphyritic garnet–augite–hypersthene–biotite microgranodiorite to microgranite; some hornblende–biotite microgranodiorite to microdiorite
white, medium-grained, slightly porphyritic to even-grained biotite granite, with small quartz aggregates; extends into Georgetown Region
pink to cream, medium-grained, slightly porphyritic biotite granite; extensively altered in places; minor fine-grained granite; probably consists of more than one major intrusion; extends into Georgetown Region
grey, fine to medium-grained, slightly porphyritic biotite granite; small biotite-rich inclusions common; minor aplite, aplitic biotite microgranite
pale to medium grey or pinkish grey, medium to coarse-grained biotite granite; variably and locally extensively altered (greisenised), with patchy W–Mo–Bi mineralisation (concentrated in pipes)
pink, medium-grained, even-grained biotite granite; leucocratic; accessory apatite, zircon, magnetite with ilmenite exsolution lamellae; rare inclusions (most <2cm across)
pale pink to white, medium to coarse-grained, even-grained biotite granite
consists of two subunits: (1) pale grey to pink, highly porphyritic (hornblende–) biotite microgranite, and some grey, fine-grained, biotite granite; and (2) pale grey to pinkish or greenish grey, highly porphyritic hornblende–biotite microgranodiorite
consists of two subunits: (1) greenish grey, very highly porphyritic hornblende–biotite microgranodiorite to microgranite; and (2) very dark grey, medium to coarse-grained pyroxene?–biotite–hornblende gabbro
pale pink, medium to coarse-grained, even-grained to slightly porphyritic, leucocratic (hornblende–) biotite granite, with sparse mafic enclaves to 5cm; minor aplitic biotite microgranite, aplite
pale grey to pink, medium to coarse-grained biotite granite

Appendix 1 (continued)

SUPERSUITE/ BATHOLITH	SUITE	CONSTITUENT UNITS (AREA)	AGE	GEOCHEMISTRY
Ootann I-type (continued)	Ootann (continued)	Carrs Gr. (~104km^2)	late Carboniferous	F U O–R H
		Convict Gr. (~0.7km^2)	late Carboniferous	F F O H
		Cottell Rhyolite (~27km^2)	300±1Ma (Rb–Sr)	F U O–R H
		Deadman Gr. (~0.5km^2)	late Carboniferous	F F O H
		Election Gr. (~2km^2)	late Carboniferous	F U–F O H
		Gibbs Gr. (~17km^2)	late Carboniferous	F U O H
		Halpin Gr. (~105km^2)	late Carboniferous	F U O H
		Indicator Gr. (~28km^2)	late Carboniferous	F F O–R H
		Jacks Gr. (~2km^2)	late Carboniferous	F U O H
		James Creek Gr. (~13km^2)	291±6Ma, 299Ma (Rb–Sr)	F F R–O M–H
		Koorboora Gr. (~15km^2)	late Carboniferous	F U O H
		Little Watson Gr. (~6km^2)	late Carboniferous–early Permian?	F U? R? H?
		Lucy Gr. (~16km^2)	late Carboniferous	F U O–R H
		Ootann Gr. (~146km^2)	~304Ma (Rb–Sr) 301±2Ma, 299±2Ma (K–Ar)	M–F U O–R H
		Pandora Gr. (~11km^2)	late Carboniferous–early Permian?	F U R H
		Petford Gr. (~87km^2)	299±6Ma (Rb–Sr)	F U O–R H
		Pinchgut Gr. (~1km^2)	late Carboniferous	F F O H
		Quaker Gr. (~39km^2)	306±3Ma, 300±2Ma (K–Ar)	F U–F O–R H
		Reddicliffe Gr. (~89km^2)	late Carboniferous	F F O H
		Retchford Gr. (~1.6km^2)	late Carboniferous	F U O–R H
		Sentinel Range Igneous Complex (felsic part) (~2km^2 — total area of unit)	303±2Ma (K–Ar)	M–F U R H
		Stirlington Gr. (~4km^2)	301–302Ma (Rb–Sr)	F U R H
		Sunnymount Gd. (~24km^2)	late Carboniferous	F U–F O H–UH
	Sandy Tate	Sandy Tate Gr. (~220km^2)	late Carboniferous	F U–F O–R H

SUMMARY DESCRIPTION
grey to pale pink (altered), fine to medium-grained, slightly porphyritic hornblende–biotite granite; with scattered enclaves up to ~1m; accessory opaque oxide, zircon, allanite, titanite
very pale grey, cream, or white, medium to coarse-grained biotite leucogranite; with sparse W–Mo mineralisation; cut by aplite dykes, and quartz veins and pipes
(1) fine to medium-grained, variably porphyritic rhyolite (spherulitic in places), and (2) moderately crystal-poor, intrusive rhyolitic ignimbrite; minor rhyolite breccia, polymictic breccia
pale to medium grey or pinkish grey, highly porphyritic biotite microgranite
medium to fine-grained, highly porphyritic biotite granite; and fine-grained (muscovite–) hornblende–biotite leucogranite with miarolitic cavities — with traces of late or post-magmatic fluorite
pale grey to pinkish grey, very highly porphyritic hornblende?–biotite microgranite
pinkish grey to greenish grey, highly porphyritic biotite microgranite
pink, medium-grained, slightly porphyritic biotite–hornblende granite
(1) medium to coarse-grained biotite leucogranite; (2) medium to fine-grained, slightly to moderately porphyritic biotite granite; (3) fine-grained, aplitic biotite leucogranite and aplite; (4) altered, highly porphyritic biotite granite; (5) medium-grained, moderately to highly porphyritic biotite granite; composite unit consisting of several distinct subunits at least some of which may represent discrete plutons
pale to medium grey or pinkish grey, medium to coarse-grained biotite granite; variably altered and extensively mineralised locally (with wolframite, molybdenite, bismuth, scheelite, cassiterite)
pink, coarse-grained biotite granite
pale pink to white, medium to coarse-grained biotite granite
medium to coarse-grained, even-grained (hornblende–) biotite granite; rounded mafic enclaves (most <5cm) common; locally converted to clinopyroxene-bearing endoskarn; minor porphyritic microgranite
medium to coarse-grained, even-grained hornblende–biotite granite and minor granodiorite; rounded mafic enclaves (to ~30cm) common; slightly to moderately altered in places
fine to medium-grained, slightly to moderately porphyritic biotite granite to leucogranite; minor slightly altered, slightly porphyritic biotite leucogranite to aplite, and moderately altered, fine-grained biotite leucogranite
consists of two subunits: (1) highly porphyritic hornblende–biotite granite; and (2) fine to medium-grained, uneven-grained (hornblende–) biotite granite
fine-grained leucogranite and aplitic leucogranite; granophyric in part; commonly altered with sericite and chlorite common; minor U mineralisation, mainly along joints and fractures
pale grey, fine-grained, slightly to moderately porphyritic (hornblende–) biotite granite; scattered mafic enclaves to ~75cm; most samples slightly to moderately altered
consists of three subunits: (1) pink to cream, medium to coarse-grained, mainly even-grained, rarely porphyritic, biotite granite, with rare microgranite; (2) pink to cream, fine to medium-grained, even-grained to slightly porphyritic biotite leucogranite; and (3) pink to cream, fine to medium-grained, even-grained to slightly porphyritic biotite leucogranite with numerous mafic enclaves
pale pink to pinkish grey, fine to medium-grained, even-grained to slightly porphyritic (hornblende–) biotite granite; slightly altered in places; several small Au mines present in or adjacent to unit — in particular, at the contact between the granite and Jamtin Rhyolite
mainly white to pale grey, fine-grained, porphyritic (hornblende–) biotite granite; accessory opaque oxide, allanite, zircon, titanite; minor aplite, pegmatite, medium to coarse-grained, even- grained to slightly porphyritic biotite granite; granitic rocks form net-veined complexes with even-grained to porphyritic quartz diorite; some heterogeneous hybrid? rocks; the felsic rocks show considerable textural and compositional variation; may be responsible for the metasomatic, skarn-type, subeconomic Cu–Sn mineralisation at Red Hill
pink, medium-grained, even-grained hornblende–biotite granite; leucocratic; inclusions rare; allanite a prominent accessory locally
consists of three subunits: (1) cream to pink, medium to coarse-grained leucogranite, with quartz veins and minor tungsten–molybdenum mineralisation; (2) pink, fine to medium-grained biotite granite, with numerous mafic enclaves; and (3) medium to pale grey, hornblende–biotite granodiorite
white to pink, coarse-grained, even-grained to slightly porphyritic hornblende–biotite granite

Appendix 1 (continued)

SUPERSUITE/ BATHOLITH	SUITE	CONSTITUENT UNITS (AREA)	AGE	GEOCHEMISTRY
Ootann I-type (continued)	unassigned	Campbell Creek Gd. (1.5km^2)	late Carboniferous	M? U O? M?
		Flat Rock Gr.	late Carboniferous	
		Hermit gd.	late Carboniferous	M? U R? H?
		Kitchener Gr. (~5km^2)	late Carboniferous	F U ? ?
		Mountain Camp Gr. (~5km^2)	late Carboniferous	F U R H
		Oaky Creek gr. (~7km^2)	late Carboniferous	F F O H
		Martin Creek Mgrt. (~73km^2)	late Carboniferous	F U–F O H
		Parada Gr. (~13km^2)	late Carboniferous	F ? ? H?
		Sheba Gr. (~27km^2)	late Carboniferous	F F R H
		Wabaredory Gr. (~3km^2)	308±4Ma (Rb–Sr)	M U O H
		Worcester Gd. (~21km^2)	late Carboniferous	F U O–R H
		unit Clgn, Bellevue (<0.5km^2)	late Carboniferous	
	Watsonville	Watsonville Gr. (~129km^2)	~281Ma, 289±16Ma (Rb–Sr)	M–F U R H
Ootann? I-type	unassigned	Wurruma Granite (~1.0km^2)	late Carboniferous	F F R H
		Red Dome mgrt. (<0.5km^2)	322±3Ma, SHRIMP (Perkins & Kennedy, 1998)	F U–F SO–R M–UH
Almaden I-type	Airport	Airport Quartz Diorite (~1.6km^2)	late Carboniferous	M U R H
	Almaden	Almac Gd. (~8km^2)	late Carboniferous	M–F U O–R H
		Almaden Gd. (~125km^2)	~301–302Ma, 303±5Ma (Rb–Sr)	M–F U O–R M–UH
		Belgravia Gd. (~6km^2)	late Carboniferous	M U O H
		Big Watson Gd. (~12km^2)	late Carboniferous–early Permian	F U R H
		Bilch Creek Gd. (~2km^2)	late Carboniferous	M U O H
		Bock Gd. (~1km^2)	late Carboniferous	F U R–O H
		Hiker Gd. (~1km^2)	~300Ma	M–F U O–SO M–H
		Prices Dam Igneous Complex — units CPgg, CPgd (~1km^2)	late Carboniferous–early Permian?	M–F U R L–H

SUMMARY DESCRIPTION
grey, fine-grained granodiorite
porphyritic biotite granite
grey, medium-grained hornblende–biotite granodiorite
pink to cream, medium to coarse-grained, even-grained to slightly porphyritic biotite granite; rare hornblende and mafic enclaves; commonly moderately to extensively altered (greisenised); contains significant deposits of molybdenite in quartz veins and stockworks and greisen zones; minor wolframite, cassiterite, chalcopyrite, galena, bismutite, arsenopyrite, silver, and gold have also been reported
pink, fine to coarse-grained biotite granite; minor biotite microgranite
fine to medium-grained biotite granite; leucocratic; associated with Mo mineralisation in the NW; the molybdenite is mainly in quartz veins and adjacent aplitic granite
white, fine to medium-grained, even-grained biotite granite
pink, fine to medium-grained, slightly to highly porphyritic biotite granite; leucocratic; rare hornblende, titanite
medium to dark greenish grey, fine to medium-grained, highly porphyritic hornblende–biotite granite; moderately to extensively altered
consists of two subunits probably representing discrete plutons; (1) pale grey, medium-grained hornblende–biotite granite, and (2) pale to medium grey, medium-grained, slightly porphyritic two pyroxene–hornblende–biotite granodiorite to granite
white, cream or pale pink, fine to medium-grained, even-grained to moderately porphyritic (chilled margin) tourmaline–biotite leucogranite; extensively altered
pale grey, grey, cream, or pink, fine to coarse-grained, mainly even-grained biotite granite; locally porphyritic; composite unit consisting of two main plutons
porphyritic biotite granite; previously informally referred to as Airport granite porphyry
white to pink, very fine-grained, porphyritic (3–5% quartz and feldspar phenocrysts) rhyolite to microgranite, and fine-grained sparsely porphyritic (<3% phenocrysts) aplitic microgranite with scattered quartz and feldspar phenocrysts; extensive potassic, sericitic, and argillic alteration; with crenulate microcrystalline quartz veins and quartz-vein stockworks
dark green, fine-grained quartz diorite; mafic inclusions common; very similar to mafic units of the Almaden Suite
fine-grained, moderately to highly porphyritic (augite–) biotite–hornblende granodiorite to quartz monzodiorite or quartz monzonite; minor clinopyroxene–plagioclase-rich rocks (endoskarn); mafic enclaves to 2m common
fine to medium-grained, variably porphyritic hornblende–biotite granodiorite and biotite–hornblende granodiorite; minor hornblende–biotite granite, tonalite, and quartz monzodiorite?; accessory clinopyroxene (rare), titanite, opaque oxide; mafic inclusions common; moderately to extensively altered in places; hosts fissure-vein fluorite deposits, and gold-bearing vein and fissure-fill lodes
medium-grained, porphyritic biotite–hornblende granodiorite; clinopyroxene present locally; mafic enclaves to ~15cm common; locally forms net-veined complexes with gabbro and dolerite (forming mainly irregular dykes)
fine to medium-grained, moderately to highly porphyritic hornblende–biotite granodiorite to granite, with mafic enclaves to 15cm common; minor medium to fine-grained, slightly porphyritic (hornblende–) biotite granodiorite to granite, and highly porphyritic (hornblende–) biotite microgranite or microgranodiorite
pale to medium grey, fine to medium-grained, highly porphyritic biotite–hornblende granodiorite to granite; commonly altered
dark grey, fine to medium-grained, slightly porphyritic augite–biotite–hornblende granodiorite
fine to medium-grained, variably porphyritic and heterogenous (augite–) biotite–hornblende granodiorite and biotite–hornblende granodiorite; numerous mafic enclaves to ~10cm; contains narrow, gold-bearing vein and fissure- fill lodes near contact with the Almaden Granodiorite
consists of several small intrusions; (1) fine-grained, highly porphyritic biotite?–clinopyroxene?–hornblende granodiorite to tonalite? — extensively altered, with scattered mafic inclusions to 15cm; (2) altered, fine to medium-grained, slightly porphyritic hornblende–biotite granodiorite, with mafic enclaves (to 15cm) common; (3) extensively altered, fine-grained, highly porphyritic biotite–hornblende granodiorite, with scattered mafic enclaves to 15cm; well-defined geophysical and geochemical anomalies associated with zones of breccia and pervasive alteration — traces of scorodite and cassiterite

Appendix 1 (continued)

SUPERSUITE/ BATHOLITH	SUITE	CONSTITUENT UNITS (AREA)	AGE	GEOCHEMISTRY
Almaden I-type (continued)	Almaden (continued)	Ruddygore Gd. (~248km^2)	~300Ma (Rb–Sr)	M–F U O–R M–H
		Silver Pot Gd. (~10km^2)	282±15Ma, 276Ma, 280Ma (Rb–Sr)	M–F U R–O H
		Solanum Gd.(~1km^2)	late Carboniferous	M U O H
		Subkin Gd. (~5km^2)	late Carboniferous	F U R H
		Wotan Gd. (~15km^2)	late Carboniferous	M U O H
	Kalunga	Bakerville Gd. (~6km^2)	301±5Ma, 298Ma (Rb–Sr)	M U R–O M
		Kalunga Gd. (~38km^2)	292–299Ma, 295±16Ma (Rb–Sr)	M–F U R–O H
		Poona Creek Gd. (~0.8km^2)	late Carboniferous?	F U O–R H
	Long Gully	Long Gully Gr. (~8km^2)	late Carboniferous	F U O–R H
	Retire	Retire Monzodiorite (~16km^2)	~301–302Ma (Rb–Sr)	M U O–R M–H
		Muldiva Quartz Monzodiorite (~5km^2)	late Carboniferous	M U O–R H
		Prices Dam Igneous Complex — unit CPgp (~1km^2)	late Carboniferous–early Permian?	M U SR–R L–M
	unassigned	Clotten Granodiorite (~1km^2)	early Permian?	M U R? H?
		Catherine Creek Granodiorite (~5km^2)	late Carboniferous–early Permian	M? U R? H?
		Mount Masterson Granodiorite (~1km^2)	late Carboniferous–early Permian	M U R? H?
		Hammonds Creek Gd. (part) (~30km^2, total area)	~293Ma (Rb–Sr)	M U O M–H
Claret Creek I-type	Claret Creek	Ballast Creek Dacite (~8km^2)	300±5Ma (Rb–Sr)	M–F U R–O M
		Munderra Gd. (~22km^2)	≥290Ma (Rb–Sr)	M U O M–H
		Three Mile Mgrt. (~10km^2)	300±5Ma (Rb–Sr)	F U R H
Claret Creek? I-type	unassigned	Hammonds Creek Gd. (part)	~293Ma (Rb–Sr)	M U O M–H
O'Briens Creek I-type	Go Sam	Askins Mgrt. (~2km^2)	late Carboniferous	F F R–O H
		Go Sam Gr. (~44km^2)	315Ma (Rb–Sr)	F F R–SO H
		Junction Mgrt. (~0.5km^2)	late Carboniferous	F F R H
		Mount Gibson Mgrt. (~3km^2)	310Ma, 310±13Ma, 312±4Ma (Rb–Sr)	F F SR–R H
		Parker Mgrt. (~0.3km^2)	late Carboniferous	F F SR H
		Percy Granophyre (~35km^2)	314Ma, 313±13Ma, 314±3Ma, 315±10Ma (Rb–Sr)	F F SR–SO H

SUMMARY DESCRIPTION
medium-grained, slightly to moderately porphyritic hornblende–biotite granodiorite; mafic enclaves to 2m common; rare ortho- and clino-pyroxene; minor highly porphyritic clinopyroxene–biotite–hornblende granodiorite to tonalite?, and fine-grained, highly porphyritic biotite granodiorite with rare hornblende; also minor titanite–diopside 'granodiorite' (endoskarn); miarolitic cavities present locally; widespread variable hydrothermal alteration; contains porphyry copper-type mineralisation at the Ruddygore mine and Metal Creek prospect
mainly grey, fine to medium-grained, slightly porphyritic hornblende–biotite granodiorite; mafic enclaves to ~10cm common; previously mapped as part of the Kalunga Granite
medium to dark grey, medium to fine-grained, highly porphyritic biotite–hornblende granodiorite
grey, fine-grained, moderately to highly porphyritic (hornblende–) biotite granodiorite; mafic enclaves to 1m common
grey to pale pink (altered), fine-grained, moderately to highly porphyritic hornblende–biotite granodiorite; mafic enclaves to 15cm common
medium to dark grey, medium to fine-grained, even-grained to slightly porphyritic biotite–hornblende (minor) and hornblende–biotite granodiorite; rare aplite, aplitic biotite microgranite
medium-grained, even-grained biotite–hornblende to hornblende–biotite granodiorite, with rare augite and hypersthene; minor (hornblende–) biotite granite; microdioritic enclaves (most <10cm) common; rare aplite
pale grey, fine to coarse-grained (mainly medium-grained) hornblende–biotite granodiorite; minor microgranite; delineated as a discrete unit by Clarke (1990, 1995); included in Saint Patrick Hill Granite by Donchak & Bultitude (1998)
medium-grained, slightly to moderately porphyritic hornblende–biotite granite, with mafic enclaves (to 30cm) common; commonly slightly altered; forms net-veined complexes with 'diorite' in several places; minor associated Cu mineralisation;very similar chemically to Kalunga Suite granites
fine to medium-grained, slightly porphyritic quartz monzodiorite, with various combinations of hypersthene, augite, biotite, and hornblende
grey to dark grey, fine to medium-grained, even-grained to slightly porphyritic biotite–hornblende quartz monzodiorite; forms extensive net-veined complex with the Quaker Granite
grey, fine to medium-grained, highly porphyritic, biotite?–clinopyroxene?–horneblende? granodiorite to tonalite?, with scattered mafic enclaves to 15cm; extensively altered
medium to dark grey, fine to medium-grained granodiorite
grey, medium-grained, even-grained biotite–hornblende granodiorite to monzogranite
grey, fine to medium-grained hornblende granodiorite
medium-grained, even-grained to slightly porphyritic hornblende–biotite and biotite–hornblende granodiorite; numerous enclaves; rare augite and hypersthene; minor biotite granite, biotite–hornblende quartz diorite, aplite, and altered mineralised aplite?
pale grey intrusive dacite, rhyodacite, and breccia
medium-grained, even-grained to locally porphyritic biotite–hornblende granodiorite and tonalite; minor leucocratic granodiorite
porphyritic biotite microgranite
medium-grained, even-grained to slightly porphyritic hornblende–biotite and biotite–hornblende granodiorite; numerous enclaves; rare augite and hypersthene; minor biotite granite, biotite–hornblende quartz diorite, aplite, and altered mineralised aplite?
slightly porphyritic biotite microgranite; included in Pinnacles Granite on most recent maps
pink to yellow, medium-grained, porphyritic biotite granite; with associated Sn mineralisation
topaz-bearing aplite; with associated Sn mineralisation
pink to grey, fine-grained, slightly porphyritic biotite granite
topaz-bearing microgranite; included in Go Sam Granite on most recent maps
pink to cream or pale yellow, fine-grained, granophyric biotite granite

Appendix 1 (continued)

SUPERSUITE/ BATHOLITH	SUITE	CONSTITUENT UNITS (AREA)	AGE	GEOCHEMISTRY
O'Briens Creek I-type (continued)	Go Sam (continued)	Pinnacles Gr. (~12km^2)	311±5Ma (Rb–Sr)	F F R–O H
		Top Nettle Mgrt. (~3km^2)	late Carboniferous	F F R H
	Herberton	Atlanta Gr.	~303Ma (Rb–Sr)	F F SR–O H
		Hales Siding Gr. (6km^2)	late Carboniferous	F F R–O H
		Jumna Gr. (~44km^2)	~314Ma (Rb–Sr)	F F SR H
		Lass O'Gowrie Gr. (~27km^2)	~314Ma (Rb–Sr)	F F? R? H?
	Cherry Tree	unit Pgzm (~15km^2)	early Permian?	F F R–O H
		Cherry Tree Gr. (~6km^2)	early Permian?	F F O? H
		Specimen Hill Gr. (~1km^2)	early Permian?	F F O H–UH
		Kauri Gr. (~25km^2)	early Permian?	F F R–O H
		Cattle Camp Gr. (~20km^2)	late Carboniferous	F F R–O H–UH
		Herberton Hill Gr. (~27km^2)	late Carboniferous	F F O H
	Lappa	The Gorge Rhyolite (~13km^2)	~302Ma (Rb–Sr)	F U(–F?) O(–R?) H
		Opah Gr. (~50km^2)	late Carboniferous	F F R H
	Nettle (Emu Suite of Pollard, 1984, 1988; Witt, 1985)	Billings Gr. (~13km^2)		F F R–SO H
		Black Diamond Gr. (~0.1km^2)	<313–315Ma	F F SR H
		Black Prince Gr. (~35km^2)	late Carboniferous	F F R–O H
		Boot Gr. (~6km^2)	late Carboniferous	F F R H
		Brownville Gr. (~0.2km^2)	late Carboniferous	F F? R? H
		Brumby Gr. (~0.6km^2)	late Carboniferous	F F? R? H?
		Cigarette Gr. (~0.6km^2)	~313–315Ma	F F R–SO H
		Confluence Gr. (~0.8km^2)	late Carboniferous	F F? R? H
		Denford Gr. (~0.4km^2)	~313–315Ma	F F SR–O H
		Devon Mgrt. (~2.5km^2)	late Carboniferous	F F O H
		Disaster Gr. (~0.2km^2)	late Carboniferous	F F? R H
		Emuford Gr. (also referred to as Emu Gr.) (~217km^2)	313–315Ma	F F R H

SUMMARY DESCRIPTION
pink to yellow, medium-grained, porphyritic biotite granite
porphyritic biotite microgranite; informally referred to as the Top Nettle porphyry
very highly porphyritic to even-grained, medium to coarse-grained biotite granite; minor aplite, pegmatite; rare small mafic enclaves
pale pink, fine to coarse-grained, even-grained biotite granite and leucogranite; minor slightly porphyritic hornblende–biotite granite; rare aplitic microgranite
pink to cream, coarse to medium-grained biotite granite; subordinate aplitic microgranite; cassiterite-bearing greisen zones common
pink to pale grey, fine to coarse-grained, even-grained to locally porphyritic biotite granite; subordinate aplitic biotite microgranite, aplite: numerous dyke-like greisen zones with associated Sn mineralisation
pale pink to pale grey, or pale brown, fine to medium-grained, porphyritic biotite syenogranite; leucocratic, with miarolitic cavities, pegmatitic pods, and traces of fluorite; commonly granophyric; delineated as a discrete unit by Clarke (1990, 1995); included in Saint Patrick Hill Granite by Donchak & Bultitude (1998)
pale pink to pale grey, fine to coarse-grained, porphyritic to even-grained biotite granite; generally extensively altered; minor microgranite; delineated as a discrete unit by Clarke (1990, 1995); included in Saint Patrick Hill Granite by Donchak & Bultitude (1998)
pale pink to pale grey, fine to coarse-grained, porphyritic to even-grained biotite granite; generally altered; minor microgranite; delineated as a discrete unit by Clarke (1990, 1995); included in Saint Patrick Hill Granite by Donchak & Bultitude (1998)
pale pink to pale grey, fine to coarse-grained, porphyritic to even-grained (muscovite–) biotite granite; extensively altered; minor microgranite, granophyre; delineated as a discrete unit (Niger Creek granite) by Clarke (1990, 1995); included in Saint Patrick Hill Granite by Donchak & Bultitude (1998)
pale pink to pale grey, fine to coarse-grained, porphyritic to even-grained biotite monzogranite to syenogranite; extensively altered; minor microgranite, greisen; delineated as a discrete unit (Wild River granite) by Clarke (1990, 1995); included in Saint Patrick Hill Granite by Donchak & Bultitude (1998)
pale pink to pale grey, or cream, fine to coarse-grained, porphyritic to even-grained biotite monzogranite to syenogranite; with traces of topaz, fluorite; minor microgranite, granophyre; delineated as a discrete unit by Clarke (1990, 1995); included in Saint Patrick Hill Granite by Donchak & Bultitude (1998)
undivided porphyritic microgranite, intrusive flow-banded rhyolite, dacite?, intrusive rhyolitic to dacitic? breccia
pink to cream, fine to medium-grained, even-grained to porphyritic leucocratic biotite granite; some porphyritic biotite microgranite
pale grey to pink, fine to coarse-grained, even-grained to variably porphyritic, biotite granite to microgranite; with sheet-like distribution; with associated Sn mineralisation
pale pink, fine-grained to pegmatitic, slightly porphyritic to seriate, granophyric (topaz–fluorite–) biotite granite; with associated Sn mineralisation; included in Emuford Granite on most recent maps
pale pink, medium to coarse-grained, porphyritic biotite granite; commonly extensively altered; also includes Brownville Gr., Disaster Gr., Glenlinedale Gr., Stingo Gr., Wilderness Gr. on most recent maps
fine-grained, granophyric biotite granite; also includes Boulder Peak Gr. (Sandy gr.) on most recent maps
fine-grained, porphyritic granite; included in Black Prince Gr. on most recent maps
medium to coarse-grained, porphyritic biotite granite; also includes Hayes Granite (Nanyeta gr.) on most recent maps
pale pink, fine-grained, porphyritic (topaz–) biotite granite; with associated Sn mineralisation
medium to coarse-grained, porphyritic biotite granite
pale pink, fine-grained, slightly porphyritic to seriate or pegmatitic, granophyric (tourmaline–topaz–) biotite granite; with associated Sn mineralisation
slightly porphyritic biotite microgranite; included in Nettle Gr. on most recent maps
fine-grained, porphyritic biotite granite; included in Black Prince Gr. on most recent maps
mainly pink to cream, coarse-grained, seriate, fluorite-bearing biotite granite; subordinate fine-grained biotite granite; extensively altered in places; hosts numerous albite-rich and greisen alteration zones with cassiterite and/or wolframite; may consist of more than one major pluton

Appendix 1 (continued)

SUPERSUITE/ BATHOLITH	SUITE	CONSTITUENT UNITS (AREA)	AGE	GEOCHEMISTRY
O'Briens Creek I-type (continued)	Nettle (continued)	Excelsior Gr. (~4km^2)	late Carboniferous	F F SR–R H
		Geebung Gr. (3km^2)	late Carboniferous	F F? R? H?
		Glen Gr. (~0.5km^2)	late Carboniferous	F F? R? H?
		Glenlinedale Gr. (~0.3km^2)	late Carboniferous	F F O H
		Hayes Gr. (~0.3km^2)	late Carboniferous	F F? R? H?
		Nettle Gr. (~87km^2)	303Ma, 308±4Ma, 311±4Ma, 313±4Ma, 315Ma (Rb–Sr)	F F R–SR H
		Rock of Ages Gr. (~0.8km^2)	late Carboniferous	F F? R? H?
		Boulder Peak Gr. (~0.3km^2)	late Carboniferous	F F? R? H
		Shady Mgrt. (~0.4km^2)	late Carboniferous	F F SR H
		Stinking Cornishman Mgrt. (~0.1km^2)	late Carboniferous	F F R H
		Stingo Gr. (~0.2km^2)	late Carboniferous	F F? R? H
		Whelan Creek Gr. (~1.5km^2)	late Carboniferous	F F R–O H
		Wild Gr. (~4km^2)	308±4Ma, 311Ma, 313Ma, 315±8Ma (Rb–Sr)	F F–U R–O H–UH
		Wilderness Gr. (~1km^2)	late Carboniferous	F F? R? H
	Ravenshoe	Neds Gully Gr. (~0.6km^2)	late Carboniferous	F F R–O H
		Ravenshoe Gr. (~66km^2)	307±4Ma, 309Ma (Rb–Sr)	F F O H
	unassigned	Bloodwood Gr. (~0.2km^2)	late Carboniferous	F F R? H
		Butterfly Gr. (~0.6km^2)	late Carboniferous	F F? R? H?
		Croissant Gr. (~0.4km^2)	late Carboniferous	F F R? H
		Gibsons Gully Aplite	308Ma, 311±4Ma (Rb–Sr)	F F SR–R M–UH
		Giblets Gr. (~1km^2)	late Carboniferous	F F? R? H?
		Lime Gr. (~0.5km^2)	late Carboniferous	F F? R? H?
		Madjack Creek Gr. (~1km^2)	late Carboniferous	F F O H
		No Hays Minas Gr.	late Carboniferous	F F R? H
		Oaky Gr. (~0.3km^2)	late Carboniferous	F F R H
		Panorama Gr. (0.5km^2)	late Carboniferous	F F R? H
		Parker Mgrt. (0.3km^2)	late Carboniferous	F F R? H?
		Python Gr. (0.3km^2)	late Carboniferous	F F? R? H?
		Reids Gr. (0.2km^2)	late Carboniferous	F F R? H

SUMMARY DESCRIPTION
medium to coarse-grained, porphyritic biotite granite
fine-grained, granophyric biotite granite
medium to coarse-grained, porphyritic biotite granite
fine-grained, granophyric biotite granite; included in Black Prince Gr. on most maps
fine-grained, granophyric biotite granite; included in Brumby Gr. on most maps; informally referred to as Nanyeta granite
grey or white, medium-grained, slightly to highly porphyritic biotite granite; four phases recognised; with associated Sn mineralisation; also includes Devon and Shady Microgranites on most recent maps
fine-grained, granophyric biotite granite
medium to coarse-grained, porphyritic biotite granite; included in Boot Gr. on most recent maps; informally referred to as Sandy granite
topaz-bearing microgranite; included in Nettle Gr. on most recent maps
topaz-bearing microgranite; included in Wild Gr. on most recent maps
fine-grained, porphyritic biotite granite; included in Black Prince Gr. on most recent maps
grey biotite granite; originally referred to as Deadman gr., but name subsequently used by Mackenzie & others (1993) for another unit
white, coarse-grained biotite granite
fine-grained, granophyric biotite granite; included in Black Prince Gr. on most recent maps
porphyritic biotite granite; informally referred to as Pinnacles porphyry
pink, medium-grained biotite granite
pale pink, fine to medium-grained biotite granite; included in Sugar Bag Gr. on most recent maps
pale pink, fine-grained, porphyritic biotite granite
pale pink, fine to medium-grained and pegmatitic, granophyric biotite granite
white to cream, topaz-bearing aplite
pale pink, medium-grained, porphyritic biotite granite
pink to cream, fine to medium-grained biotite granite
pink, medium to coarse-grained biotite granite; minor biotite microgranite
pink, coarse-grained, seriate biotite granite; included in Oaky Gr. on most recent maps
pink to cream, fine-grained, porphyritic biotite granite
pale pink, fine to medium-grained (tourmaline–) biotite granite
fine-grained, topaz-bearing granite
pale pink, medium-grained, porphyritic biotite granite; alteration zones common
pale pink, fine-grained, porphyritic biotite granite; included in Emuford Gr. on most recent maps

Appendix 1 (continued)

SUPERSUITE/ BATHOLITH	SUITE	CONSTITUENT UNITS (AREA)	AGE	GEOCHEMISTRY
O'Briens Creek I-type (continued)	unassigned (continued)	Starlight Gr. (~0.2km^2)	late Carboniferous	F F R–O H
		Sugar Bag Gr. (~1.5km^2)	late Carboniferous	F F O–SO H
		Titania Gr. (~0.2km^2)	late Carboniferous	F F R H
BEDARRA GRANITE BELT				
Dunk Island I-type? (rel. high SiO_2 and ASI)	Dunk Island rel. high CaO, Pb, and low TiO_2, FeO*, MgO, ASI, Ba, Cu, Ni, Rb, Sc, V, Zn	Dunk Island Gr. (~3km^2)	early Carboniferous	F U R(–SR) M
	Woin-Garin rel. high TiO_2, FeO*, MgO, P_2O_5, ASI, Ba, Cu, Ni, Nb, Rb, Sc, Zn, Zr, and low CaO, Na_2O, Sr	Woin-Garin gr.	336±5Ma (SHRIMP)	F U R H(–M)
Bedarra I-type	Coolah rel. low K_2O, P_2O_5, ASI, Ba, Ce, La, Nb, Pb, Th, Zr, and high TiO_2, FeO*, MgO, Na_2O, Sc, Sr, V, Zn	Coolah gr.	early Carboniferous	F U O M
	Bedarra	Bedarra gr.	early Carboniferous	F U R H
		Brook gr.	early Carboniferous	F F O–R H
		Coombe gr.	early Carboniferous	F F R H
		Hudson gr.	early Carboniferous	F U R H
		Smith gr.	early Carboniferous	F U R H
		Stingaree gr.	early Carboniferous	F U? O H
		Toolgbar gr.	early Carboniferous	F U–F R H
		Bowden gr.	early Carboniferous	F U R–O H
unassigned I-type?	unassigned anomalously high TiO_2, FeO*, Na_2O, Ga, Nb, U, Y, Zn, Zr, Ga/Al, and low SiO_2, K_2O, Pb	North Island gr.	335±6Ma (SHRIMP)	F U O M
Wheeler A-type	Wheeler rel. low SiO_2, FeO*, Ba, Pb, Sr, and high TiO_2, Al_2O_3, P_2O_5, Ce, Ga, La, Nb, Rb, Sc, Th, V, Y, Zn, Zr, Ga/Al	Wheeler gr.	early Carboniferous	M U R H
Tapp-Ana S-type?	Tapp-Ana (rel. high K_2O, P_2O_5, ASI, Ba, Pb, Zn, and low TiO_2, MgO, Ga, Nb, Ni, Rb, Th, U, V	Tapp-Ana gr.	early Carboniferous	F U R(–SR) H

SUMMARY DESCRIPTION
pale pink, fine-grained to pegmatitic, slightly porphyritic to seriate, granophyric (topaz–fluorite–) biotite granite; included in Emuford Gr. on most recent maps
pale pink to cream, medium-grained, porphyritic (topaz–) biotite granite; includes Bloodwood Gr. on most recent maps
pale pink, fine-grained to pegmatitic, porphyritic, granophyric (topaz–) biotite granite; included in Emuford Gr. on most recent maps
pale grey, medium-grained, even-grained to slightly porphyritic biotite granite; with bluish grey quartz grains and scattered lenticular inclusions (to ~10cm) of biotite gneiss; samples from GR 4106 80165 (northeastern side of Dunk Island)
white to brown (altered), medium to coarse-grained, moderately porphyritic biotite granite; with a well-developed tectonic foliation and numerous enclaves (to ~2m) of mainly microdiorite?, and biotite gneiss; samples from GR 4123 80132 (northern end of small beach, southwestern side of Dunk Island); included in Dunk Island Granite on recent maps
pale brown to orangey pink, medium-grained, slightly porphyritic biotite granite; intrudes coarser grained biotite granite; samples from GR 4152 80040 (Hudson Island); relatively mafic unit, similar to Dunk Island Supersuite granites
white to pale grey, medium to coarse-grained, moderately to highly porphyritic biotite granite; with enclaves of fine to medium-grained, slightly to moderately porphyritic biotite granite (to ~1m), biotite-rich metasedimentary rocks (to ~10cm), and biotite-rich clots (to ~4cm); cut by dykes (up to ~30cm thick) of fine-grained, even-grained biotite granite; samples from GR 4099 80100, GR 4093 80090 (Bedarra Island)
cream or pale grey to pale brown (iron stained), medium-grained, even-grained to slightly porphyritic biotite granite; with biotite-rich schlieren; cut by dykes of more mafic granite (North Island granite) in places; samples from GR 4240 79935 (large boulders on southwestern side of North Island), GR 4245 79931 and GR 4245 79933 (on southwestern and northern sides of Tween Island, Brook Islands group, respectively)
mainly grey to pale brown (iron stained), medium to coarse-grained, slightly to moderately porphyritic biotite granite; cut by pale grey to pale brown, fine to medium-grained, highly porphyritic biotite granite with biotite-rich clots (to ~3cm) and schlieren/zones; numerous dykes of pale brown to brown, fine to medium-grained biotite granite in places; samples from GR 4150 80049, GR 4124 80051, GR 4122 80052, GR 4124 80053 (Coombe Island)
cream to buff, coarse-grained, highly porphyritic biotite granite; with rare inclusions (to ~10cm)
pale grey to pale brown (iron stained), medium-grained, slightly to moderately porphyritic biotite granite; samples from GR 4151 80053, GR 4153 80052 (Karramban Island)
white, medium to coarse-grained biotite granite
pale grey, medium-grained, moderately porphyritic biotite granite; with scattered biotite-rich clots (to ~3cm); samples from GR 4116 80064 (bouldery rubble on the southern side of Wheeler Island), where unit cuts Wheeler granite
mainly pale grey to pale brown, medium-grained, moderately porphyritic biotite granite; with biotite-rich schlieren/zones; cut by microgranite dykes (<1m) and quartz veins (<5cm); commonly slightly to extensively altered; samples from GR 4148 80050 (bouldery outcrops at northwestern end of Bowden Island)
pale grey to pale brown (altered), medium-grained, slightly porphyritic biotite granite; with sparse feldspar phenocrysts up to ~1.5cm long; unit forms dykes (up to ~70cm thick), which cut more felsic Brook granite; possibly a mafic member of the Bedarra Supersuite, but rel. high Zr, Ga/Al, in particular, imply possible A-type affinities; samples from GR 4240 79935 (large boulders on southwestern side of North Island, Brook Islands)
white and black, medium-grained, slightly porphyritic biotite granite; with scattered feldspar phenocrysts to ~2cm; heterogeneous with biotite-rich zones interspersed with relatively biotite-poor zones; cut by more felsic, more highly porphyritic biotite granite; samples from GR 4116 80064 (bouldery rubble on the southern side of Wheeler Island)
white to brown (altered), medium to coarse-grained, moderately porphyritic, biotite granite; with rare, ovoid pegmatitic zones (to 30cm in length), a well-developed tectonic foliation and numerous enclaves (to ~2m) of mainly microdiorite? and biotite granite; cut by thin (<15cm) pegmatite dykes; samples from GR 4123 80132 (boulder on small beach, southwestern side of Dunk Island); included in Dunk Island Granite on recent maps

Appendix 2. Production Table for Cairns Region.

Gold

Location	Production period	Ore (t)
Kraft Creek (Bartle Frere Gold Field)	1937–1942	
Clohesy River area	1894–98, 1905–06, 1934–36, 1938, 1951	2 453
Hodgkinson Gold Field	1876–1897	~300 000
Jordan Gold Field Group	1898–1981	
Kamerunga	1932–1935, 1984–85	>3 800
Maytown and Groganville	1872–1897	?
Mount Peter Gold Field	1899–1951	
Mulgrave Gold Field	1879–1942	
Munburra Alluvials Group		
Northcote	1991–92	75 145
Old Starcke Group (Diggings Creek)		
Palmer Gold Field (including West Normanby Gold Field)	1874–1990	
Red Dome	1924–25, 1987–97	~12 200 000
Russell River Gold Field (Russell Extended Gold Field, Russell Terraces, The Terraces, Boonjie)	1887–1959	
Six Mile Creek	1921, 1939–1948	111
Starcke No. 1 Gold Field (Cocoa Creek)	1892–1896	1 157
Starcke No. 2 Gold Field	1890–1913	5 964
Towalla Group	1889–1907	

Tin

Location	Production period
Barrow Point	1939
Cannibal Creek & Granite Creeks	1969 1876–1884
China Camp	1910–1920
Cooktown Tinfield (including Annan River Tinfield)	1885–1992
Dolly Grant	
Gilmore	1906–1975, 1932–1937
Herberton Tin Field	1883–1930, 1938–1990
Herberton Deep Leads	1883–1895, 1946–1966, 1983, 1985–1988
Howick Island	?1921
Koorboora	
Leichhardt Creek	1996
Mount Spurgeon	1887–1909, 1957–66
Mount Windsor Tableland	1909–1932
Palmer Gold Field	1880–1884, 1900–1937, 1948, 1958, 1969, 1970
Pandora	1924–28, 1962
Russell Gold Field (Russell Extended Gold Field, Russell Terraces, The Terraces, Boonjie)	
Stannary Hills Group	

Tailings (t)	Lode gold (kg bullion)	Alluvial gold (kg)	Reference
	14.052		Garrad & Rees (1995)
	40.242		Dash & Morwood (1994)
	9 700 9 820	~1 300	Wallis (1993), Garrad (1993) Dash & Cranfield (1993)
	158.5	242.547	Garrad & Rees (1995)
	9.442		Dash & Morwood (1994)
	4 274		Lam & others (1991)
	314		Garrad & Rees (1995)
	76	130	Garrad & Rees (1995)
	46		Denmead (1932)
	383		Dash & Cranfield (1993)
	71.5		Ball (1909)
	4 340.5	>33 210 46 093(lode & alluvial)	Denaro & Ewers (1995) Dugdale (1991)
	22 717kg Au, 105 855kg Ag, 36 059.9t Cu		The Australian General Mining Year Book 6th Edition for years 1989-91 and Minmet 6/11/1998 for years 1992–98
		680.4 3 000 833	Garrad & Rees (1995) Dempsey (1980) de Keyser (1964)
	2.7		Denaro & Ewers (1995)
	34.5		Denaro & Ewers (1995)
457	314 2.2	117.5	Denaro & Ewers (1995)
	137	18	Garrad & Rees (1995)

Lode tin (t cassiterite conc)	Alluvial tin (t cassiterite conc)	Reference
	0.25	Denaro & Ewers (1995)
34.1 3.5	>2 260	Lam & others (1991)
	~1 000	Lam (1993)
272.0	12 578 14 000 (combined alluvial & lode)	Denaro & Ewers (1995) Morrison & Beams (1995)
	5.6	
~153		
>150 000 (combined alluvial & lode) ~140 000 (combined alluvial & lode to 1987) 85 385 (lode) and 58 709 (alluvial)		Pollard (1984) Taylor & Pollard (1990) Garrad (1991)
	4 000	Cuttler (1972)
	0.50	Denaro & Ewers (1995)
14 600t Sn conc		Morrison & Beams (1995)
	5.08t Sn conc	MINMET 7/11/97
	~300	Derived from Lam (1993)
	90	Lam & Genn (1993)
	455	Derived from Dugdale (1991), Lam & Genn (1993), Denaro & Ewers (1995)
9.5		Garrad (1993)
	~100t CST conc.	Garrad & Rees (1995)
	~5 000t CST conc	Blake (1972)

Appendix 2 (continued)

Tungsten

Location	Production period
Bamford Hill	1893–1950, 1970–74, 1978–81
Cooktown Tinfield	1899–1902, 1919, 1921, 1955–1957
Hodgkinson Gold Field	
Howick Island	?1921
Koorboora	?1900–1905 (main period)
Lode Hill (Petersen's Scheelite Workings)	1917–1920, 1931, 1942–1952, 1985
Mount Carbine	1894–1987
Mount Perseverance	1917–1920, 1928–1950–1974
Noble Island	1904–1912, 1916
Palmer Gold Field (Spring Creek/ Keddies Lode)	1907 1969–1970
Wolfram Camp	1893–1980

Base Metals

Location	Production period	Ore (t)	Copper conc. (t)
Calcifer group	~1888–1937	~26 450	~1 555
Chillagoe Consols	~1903–26	~30 500 (incomplete ore figure)	400
Christmas Gift	1911–27	8 500	85
Consolation (Devonean West)	1911–1930, 1960s	41 799	694.2
Copper Firing Line	1909–1943	~3000 >530	
Dianne Copper Mine	1980–1983	70 000	>18 000 12 567–18 153
King Vol (Tartana area)	1922–25	2 200	0.3
Maniopota	1905–26, 1929–1930	790	
Montalbion group	~1885-1895, 1900-1910 ~1885-1895	39 170 39799	100.6
Mount Garnet	1898–04	~100 000	~4 415
Mount Molloy	1905-1910	>43 600	>3 900t of ~90% pure Cu
Muldiva group	~1890–1927	19 000	270
Mungana area	1888–1927	328 320	7 782
Mungana Group	1888–97, 1901–14, 1921–27	367 000	8 700
Nightflower	1923-1930	1 234	
O.K. mine (and surrounds)	1902–1910, 1937–43	81 544	7 808
Orient Camp West group	1886–1924	~6600	
Ruddygore	1896–1909, 1916, 1920, 1930	32 750	1 450
Siberia Lode Group			>366
Silver Valley area			>780
St George Copper Mines	1905–1907	~8t of ~30% Cu	
United North Australian (UNA) group	1883-1958	>10 372	>2 480

Lode tungsten (t wolframite conc)	Lode tungsten (t scheelite conc)	References
~2 000		Dash & others (1988)
8.30 30.87		Denaro & Ewers (1995) Dugdale (1991)
	0.4t	Dash & Cranfield (1993)
0.25		Denaro & Ewers (1995)
>750		Kerr (1991)
53.2		Dash & Cranfield (1993)
16 400 (combined wolframite & scheelite) (7.8t cst) from ~19 000 000t ore		Dash & Cranfield (1993)
172 (1.75t cassiterite conc.)		Dash & Cranfield (1993)
18.70		Denaro & Ewers (1995)
0.20	5 966.7	Denaro & Ewers (1995)
5 400t W, 1 455t W/Bi		Dash & others (1988)

Lead (t)	Silver (kg)	Other / comments	References
400	744		Dash & others (1988)
6 500	13 950		Dash & others (1988)
500	858.7		Dash & others (1988)
	1 809.1	134.7t cassiterite conc	Dash & others (1991)
			Blake (1972) Dash & others (1991)
	1 000 25 000		Lam & Genn (1993) Calculated from Wallis (1993b)
369	257		Culpeper & others (1990)
150	1 340		Dash & others (1988)
1 038	47 492 49 258	1.1kg Au	Dash & others (1991)
	~29 500		Bruvel & others (1991)
			Dash & Cranfield (1993)
1 150	9 800		Dash & others (1988)
31 328	100 000		Broadhurst (1952)
35 000	100 400		Ishaq & others (1987)
305	1 123	0.624kg Au	Garrad (1993)
	102	12kg Au	Culpeper & others (1990)
~2 640	9 100	(incomplete figures)	Dash & others (1991)
	1 865		Dash & others (1988)
~28	~117.5	~21g Au	Dash & others (1991)
118	3 948		Dash & others (1991)
			Denaro & others (1994b)
	23 485	>1 543.9t CST conc	Dash & others (1991)

Appendix 2 (continued)

Antimony

Location	Production period	Production	References
Cocoa Creek (Starke No. 1 Gold Field)	1891	168t ore	Wallis (1993a)
Northcote area	1877–1884, 1890–1960s intermittently, 1991–1992	2 362t metal and conc	Wallis (1993a)
Retina (Mitchell River area)	1905–1907, 1940–1952, 1960s	389t ore/conc	Wallis (1993)
Six Mile Creek	1944–1945	7t of ~58% Sb ore	Denaro & Ewers (1995)
Uncle Sandy (Starcke No. 2 Gold Field)	1906 1989	9t of 9% Sb ore 40.6	Wallis (1993a)
Woodville area	1884–1907	1 266t of ~50% Sb ore	Garrad (1993)
Zig Zag (south-west of Herberton)	1987/88	40t of 33% Sb	Wallis (1993a)

Coal

Location	Production Period	Coal (t)	Reference
Mount Mulligan	1907–1957	1 000 000t 981 007t	Garrad (1993) Hawthorne (1975)

Limestone

Location	Period	Production	Reference
Fairchance		60 800t	
Ootann (Crotty Lime)	1972–75	32575t BLIME, 470t PLIME	Dash & other (1988)
Little Mulgrave River area	1926, 1961–73	3979t Early Lime	Garrad & Rees (1995)
White Gem		2 160t	

Molybdenum

	Period	Molybdenum Concentrate (t)	References
Bamford Hill	1893–1950, 1970–74, 1978–81	170	Dash & others (1988)
Wolfram Camp	1893–1980	135	Dash & others (1988)

Fluorite

	Production Period	Fluorite (t)	References
Mistake	1915–1921, 1937–38, 1958, 1972	1 140	Dash & others (1988)
Perseverance (Fluorspar)	1912-28, 1944-45, 1972	9 272	Dash & others (1988)

Silica Sand

Location	Production period	Silica sand (Mt)	References
Cape Flattery Silica Mine	1968–1993 1994–1998	14.8 9.79	Denaro & Ewers (1995) DME production statistics

Other Commodities

Locality	Production Period	Commodity & Amount Produced	Reference
Mount Lucy	1903–14, 1926–42	45 344t ironstone flux	Dash & other (1988)
Wolfram Camp	1893–1980	80t Bismuthinite conc	Dash & other (1988)
Bamford Hill	1893–1950, 1970–74, 1978–81	~20t Bismuthinite conc	Dash & other (1988)
Alhambra (Coolgarra area)	1908	304.8kg bismuthinite conc	Blake (1972)
Mount Martin	1900s–1940s	1 117t 40–50% Mn ore	Garrad & Rees (1995)

Appendix 3. Resources table for Cairns Region (sorted by commodity).

Name	Commodity	Type and age of deposit	Resources and reserves	Reference
Antimony Reward (Waterhole)	Antimony	Epigenetic (CR14793)	Unknown category, 96 200t @ 3–10% Sb. Unknown category, 16 500t @ 29–65% Sb, 9.14t Sb	Atherton Antimony N.L., Southern Miner, 1971
Saint George	Antimony		Closely spaced, vertical percussion drilling indicated a reserve of 258 000t @ 3.5% Sb; a reinterpretation gave reserve of 1 035t @ 3.1% Sb with a cutoff of 0.5% Sb	CR 13423, 1971 Taylor(1971)
Aspiring Nos.1 & 2	Base Metals	Chalcopyrite, molybdenum and pyrite occur as structurally controlled veins and disseminated mineralisation	Inferred resource: 50Mt @ 0.1% Cu, 200ppm Mo, trace Au, Ag to a vertical depth of 100m	Climie, 1974
Baal Gammon	Base Metals		Open Pit resource: 3Mt @ 1.2% Cu, 46g/t Ag and 0.3% Sn 11Mt @ 0.25% Sn Indicated/measured resource: 2.1Mt @ 1.2% Cu, 52g/t Ag and 0.3% Sn	Reg of Aust Mining 1996/97; Morrison & Beams (1995) MINMET 7/11/97
Comeno	Base metals	Epithermal deposit formed in a high level crustal environment. Open space fracture infill. Several episodes of fracturing and multiple reopening. Mineralisation fluids had a common source (Woodward,1976)	Indicated resource: 23 400t @ 0.45% Cu, 1.9% Pb, 6.95% Zn, 136.5ppm Ag, 0.37% Sn, 0.54% As Inferred resource: 18 000t	CR22145, 1981
Federation	Base metals	Magmatic hydrothermal, related to post-tectonic granites	Inferred resource: 350 000t @ 1.5% Cu, 0.5% Sn, 60ppm Ag Crater anomaly: Inferred resource: 150 000t @ 2.5% Cu, 0.5% Sn, 90ppm Ag	Great Northern Mining Corporation NL, Annual Report, 1981
Isabel	Base metals		Proven-Probable reserves: 52 000t @ 2.5% Pb, 120g/t Ag, and 13.5% Zn	MINMET 7/3/97
King Vol (Walsh River)	Base metals		undiluted Inferred resource: 350 000t @ 25% Zn, 1% Cu and 25g/t Ag	Register of Australian Mining 1997/98, page 330
Mount Garnet	Base metals		2Mt @ 0.5% Cu, 25g/t Ag, 9% Zn undiluted Indicated/Measured resource: 2.33Mt @ 0.5% Cu, 25g/t Ag and 9% Zn	Morrison & Beams (1995) Register of Australian Mining 1997/98, page 329
Mungana	Base metals	Cu-Au base metal skarn & breccia hosted mineralisation	unknown resource category: 1.6Mt @ 2.1g/t Au, 106g/t Ag, 1% Cu, 2.3% Pb, and 2.3% Zn between the surface and 240m depth (This include the Mungana deep resource) Inferred Resource of 2.7Mt @ 2.48g/t Au, 76g/t Ag, 1.43% Cu, 1.21% Pb, and 5% Zn (Total resource for the Mungana and Mungana Deep prospects)	Nethery & Barr (1996) MINMET 6/11/1998

Appendix 3 (continued)

Name	Commodity	Type and age of deposit	Resources and reserves	Reference
Mungana Deep Prospect	Base metals	Gold and base metal mineralisation associated with rhyolite porphyries within the Early Silurian–Early Devonian Chillagoe Formation	Indicated resource for: 0.4Mt @ 1.8g/t Au, 84g/t Ag, 0.8% Cu, 2.2% Pb, 3.0% Zn (190–240m depth)	Nethery & Barr (1996)
Nightflower (Don Lease, Argentum mines)	Base metals	Fault controlled hydrothermal vein related to the Late Carboniferous to Early Permian Featherbed Volcanic Group A combination of hydrothermal vein and volcanic exhalative (CR 21702)	Indicated resource: 40 000t @ 14% Pb, 7% Zn, 30g/t Ag Inferred resource: 80 000–210 000t @ a average grade of 2.5 % Cu	CR 4983 CR 21702
OK Mine	Base metals	Besshi-Kieslager type volcanic-hosted massive sulphide within the OK Member of the Devonian Hodgkinson Formation	1Mt @ 3% Cu equivalent Estimated resource of 400 000t @ 2–3% copper down to 140m	?? Register of Australian Mining 1997/98, page 281
Orient Camp West	Base metals		Indicated Resource: 229 000t @ 2.9% Pb, 5.1% Zn, 180g/t Ag, 190g/t (Resource figures are selected blocks)	CR 21971
Ruddygore	Base metals	Mesothermal porphyry copper and weak porphyry tin	Inferred resource: 10Mt @ 0.4% Cu	Lacy (1980)
Shannon	Base metals	Skarn?	Inferred resource: 1.01Mt @ 1.23% Cu, 0.96g/t Au, 20.2g/t Ag, 0.53%Zn, 0.07%Sn, and 0.08%Bi	CR 3725
Tartana area	Base metals	Skarn/siliceous breccia mineralisation developed within the Early Silurian–Early Devonian Chillagoe Formation	Inferred resource: 927 000t of oxide ore at an average grade of 0.83% Cu at a cut off of 0.25% Cu	Register of Australian Mining 1996/97, page 234
Titree (Chillagoe area)	Base metals	Skarn	Inferred Resource: 350 000t of flux ore @ 1% Copper	De Keyser and Wolff (1964)
West Orient	Base metals		Proven-Probable reserves: 182 000t @ 3.36% Pb, 213g/t Ag, and 9.36% Zn	MINMET 7/11/97
Zillmanton	Base metals	Contact-pyrometasomatism (Broken Hill South Ltd., 1947–CR 99)	Inferred resource: 260 000t @ 2.7% Cu	CR 3725
Bathurst Range	Coal	Coal seam hosted by the Dalrymple Sandstone	Indicated resource: 45Mt coking coal from underground operations	Coxhead (1997)
Ironstone Leases (Razed, Highway)	Fluorite	Pyrometasomatic contact skarn	7 300t at 10–11% F Total indicated and inferred resource: 2.496Mt @ 0.32% Sn, 11% F	CR 14896 CR 14897
Mistake	Fluorite	Fissure vein within granitoid	Unknown resource category: 50 800t @ 25% fluorite to 76m depth.	Comalco Ltd., ARDM,1972
Perseverance Lode (Fluorspar Group)	Fluorite	Fissure vein	Inferred resource: 30 500t of fluorite to 80m depth	Levingston (1970)

Name	Commodity	Type and age of deposit	Resources and reserves	Reference
Atric (Bellevue East)	Gold		Total Inferred mineral resource of 860 000 tonnes grading 2.22g/t Au (cut-off grade of 0.5g/t Au to a depth of 170 m) 523 000t @ 3.08g/t Au (cut-off grade 1g/t Au to 50m) Jenny Birch personal communication	Birch, 1998
Belfast Hill (Disraeli)	Gold	Mineralisation is localised in structural zones which are considered to be hydrothermal feeders for chlorite or thiosulphate-bearing fluids, high in an epithermal system(Mock and others, 1988)	Inferred resource: 244 000t @ 1.5g/t Au *In situ* Revised to a resource of 700 000t @ 1.9g/t Au (average grade) in an area of quartz-stibnite veining Again revised to an *in situ* Measured resource of 278 000t @ 1.9g/t Au and inferred resource of 420 000t @ 1.9g/t Au.	Mock and others, 1988 Register of Australian Mining 1990/91, page 150 Register of Australian Mining 1991/92, page 109 & MINMET (7/11/97)
Black Bess (Springs)	Gold	Epithermal fissure lodes (Jensen, 1941). Mesothermal veins probably sourced from upwardly migrating metamorphic fluids (Golding and others, 1990)	Measured reserves: Sulphide ore–80100t @ 4.71g/t Au (all oxide ore was mined).,>8.4t Sb, >126.558kg Au (125.748kg 1991–1992)	Nittoc International Co Ltd, Annual Report, 1992
East Leadingham (Emily Extended)	Gold	Epithermal fissure lodes (Jensen,1941). Mesothermal veins probably sourced from upwardly migrating metamorphic fluids (Golding and others, 1990)	Measured resource: 37 800t @ 11.55ppm Au	Dash & Cranfield, 1993
Emily	Gold	Epithermal fissure lodes (Jensen,1941). Mesothermal veins probably sourced from upwardly migrating metamorphic fluids (Golding and others, 1990)	Measured resource: 42 000t @ 4.9ppm Au Measured resource: 53 400t @ 3.7ppm Au Indicated resource: 49 000t @ 3.3ppm Au (some of which has been mined). Proven remaining reserves: 21 500t @ 5.11ppm Au	McConnell, 1992
Emily South (South Emily)	Gold	Epithermal fissure lodes (Jensen,1941). Mesothermal veins probably sourced from upwardly migrating metamorphic fluids (Golding and others, 1990)	Indicated resources: Main–45 000t @ 6.4ppm Au Indicated resources: East–66 472t @ 3.3ppm Au (some of which has been mined) Remaining proven reserves: 18 800t @ 5.61ppm Au	McConnell, 1992
Ethel	Gold	Epithermal fissure lodes (Jensen, 1941). Mesothermal veins probably sourced from upwardly migrating metamorphic fluids (Golding and others, 1990)	Measured reserves: Oxide ore–~3 100t @ 3.81g/t Au; Sulphide ore–40 200t @ 3.81g/t Au	Nittoc International Co Ltd, Annual Report, 1992
Ethel Extended (East Ethel, Jessie)	Gold	Epithermal fissure lodes (Jensen, 1941). Mesothermal veins probably sourced from upwardly migrating metamorphic fluids (Golding and others,1990)	Proved reserves: 116 000t @ 6.24ppm Au Probable reserves, 114 000t @ 6.24ppmAu Inferred resource, 68 000t @ 5–6g/t Au	Cambrian Resources NL, 1986, Register of Australian Mining 1992/93, page 107
Fine Gold Creek	Gold	Alluvial gold	Proven resource: 4.6 Mlcm @ 0.6g/t Au	Register of Australian Mining 1989/90

Appendix 3 (continued)

Name	Commodity	Type and age of deposit	Resources and reserves	Reference
General Grant	Gold	Mesothermal veins(285–335°C)(Peters, 1987). Probably sourced from upwardly migrating metamorphic fluids(Golding and others, 1990)	Inferred resource: 7 260t @ 12.4ppm Au	Peters, 1987
Harpers (Chillagoe area)	Gold	Skarn	unknown resource category: 830 000t @ 1.9g/t Au to 100m depth	Elders Resources (1987), EPM 3383
Hilltop	Gold		Inferred resource: 20 050t @ 1.78g/t Au	CR 20255
Hodgkinson River	Gold	Placer deposit derived from erosion of the Hodgkinson Gold Field	Inferred resource: 6Mm^3 @ 0.2–0.5g/cubic metre Au	Garrad, 1993
Hurricane, Hurricane North, Main, and Poseidon Gold Prospects	Gold		Total resource figure is 97 000t @ 1.1g/t Au (for Hurricane main lode only) which includes a Measured resource of 68 000t, Indicated resource of 25 000t and Inferred resource of 4 000t; September 1995 a total inferred resource of 400 000t @ 1g/t is reported Total inferred resource of 230 000t @ 0.9g/t Au obtained for the Hurricanne North, Main and Poseidon deposits to a depth of 30m	Register of Australian Mining 1996/97, page 165 MINMET 7/11/97
Lost Mine (Lost Mine Extended)	Gold		Inferred resource: 125 000t @ 3.0 g/t Au for the Lost mine. Lost mine Extended has a Inferred resource: 375 000t @ 3.0g/t Au	CR 20970
Maid of the Forest (Mount Trial) Union Group	Gold		Inferred resource: 17 490t @ 1.97g/t Au	CR 20270
Midway (Honey)	Gold		Indicated resource: 78 000t @ 3.0g/t Au to 30 m depth	CR 20970
Minnie Moxham (Lizzie Moxham)	Gold		Indicated resource: 630 000t @ 8–9.6g/t Au. This resource has been partly mined by Mount Arthur Molybdenum N.L. for 56.8kg Au Indicated resource: 58 000t @ 2.93g/t Au with a further 15 000t @ 3g/t Au (mineable grade) and inferred resource: 12 000t @ 5g/t Au (underground)	Register of Australian Mining 1990/91, page 158 MINMET
Mosman River	Gold		Indicated resource: 232 000m^3 @ 0.19 g/m^3 Au using a cutoff of 0.1 g/m^3 Au; Platinum (385.5–840.5ppm) and palladium (2.2–6.1ppm) content is high	Denaro & Ewers, 1995
Northcote	Gold	Late Carboniferous–Early Permian? mesothermal stibnite–gold–quartz veins hosted by Devonian metasediments	Aggregate Measured/ Indicated/ Inferred resource: 870 725t @ 4.16g/t Au using a 1.8g/t Au cutoff	Register of Australian Mining 1997/98, page 193

Name	Commodity	Type and age of deposit	Resources and reserves	Reference
Northcote/ Minnie Moxham	Gold	Late Carboniferous–Early Permian? mesothermal stibnite–gold–quartz veins hosted by Devonian metasediments	244 000t @ 5.76g/t Au (7 separate Sb–quartz vein systems) 164 000t @ 1.9g/t Au (Oxide ore); 399 000t @ 4g/t Au (Sulphide ore); 272 000t @ 4.7g/t Au	Australian Gold Annual 1996
Nymbool Porphyry prospect (Blacks Creek)	Gold		Open pit indicated resource: 1.175Mt @ 0.79g/t Au and Inferred resource of 180 000t @ 0.8g/t Au (oxide and transitional ore, strip ratio 3.2:1). Also a primary sulphide Indicated resource: 560 000t @ 0.51g/t Au	Register of Australian Mining 1997/98, page 184
Pillidge	Gold		Indicated resource: 47 000t @ 1.9g/t Au to 20m depth	CR 20970, 1987
Pinnacle Creek	Gold		Inferred Resource: 420 000t @ 1.87g/t Au 871 000t @ 4.16g/t Au using a 1.8g/t Au cutoff	Register of Australian Mining 1996/97, page 171 MINMET 7/11/97
Quartz Top Ridge	Gold		Inferred resource: 12 000t @ 1.75g/t Au to 30m depth.	CR 19780
Red Dome	Gold		Measured & indicated resource: 1.604Mt @ 2.1g/t Au, 112g/t Ag, 1% Cu, 2.3% Pb, and 2.3% Zn	Register of Australasian Mining 1998/99, page 164
Reedy (formerly called Cardia)	Gold		Inferred resource: 680 000t @ 1.4g/t Au	Register of Australian Mining 1997/98, page 192
Saint George River	Gold		Probable Reserves of 372 000 lcm @ 0.26g/t Au. These resources were mined for a short period under tribute but the operations were on care and maintenance in early 1991	Register of Australian Mining 1988/89, page 161
Sandy Creek (Palmer River Gold Field)	Gold	Syntectonic/synmetamorphic Au–quartz and Au–Sb–quartz veins in Devonian metasediments; gold-bearing chert-quartzite units.	Measured–Indicated geological resource of 1.5 Mlm^3 grading ~0.4g/t Au remained in the unworked leases held along Sandy Creek	Register of Australian Mining 1993/94, page 133
Tregoora renamed to Big A (Sleeping Giant, Black Knight, Rim Fire, Black Bishop, Rainbird)	Gold	Late Carboniferous–Early Permian? mesothermal stibnite–gold-quartz veins hosted by Devonian metasediments	Indicated resource: 846 082t @ 2.2g/t Au (0.5g/t cut-off); or 529 942t @ 3.1g/t Au (1.0g/t Au cut-off) Sleeping Giant–460 000t @ 3.28g/t Au to 60 m depth	(BHP Gold 1989) Register of Australian Mining 1988/89, page 163
Triple Crown	Gold		Inferred, Indicated & Measured resource: 0.652Mt @ 1.42g/t Au; *In situ* resource of 117 000t @ 2.14g/t Au (1g/t cut-off) within a pit design of 6.3:1 (waste:ore) strip ratio Inferred, Indicated & Measured resource: 0.117Mt @ 2.14g/t Au	Register of Australian Mining 1997/98, page 197 MINMET 7/11/97

Appendix 3 (continued)

Name	Commodity	Type and age of deposit	Resources and reserves	Reference
Unnamed	Gold		Inferred resource: 420 000t @ 1.9ppm Au, using 1.0ppm cutoff	Central Mining Corp. N.L., 1988, CR 19759
Victory	Gold		Inferred Resource: <10 000t @ 6.67g/t Au	CR 21794
Waitemata (Wattamatta, Jannie Jan, Janny Jan, Clohesy, Rising Sun) (Clohesy River Gold Mines)	Gold	Hydrothermal quartz vein	Inferred resource: 25 000t @ 15g/t Au Dumps: Inferred resource: 6 000t @ >2g/t Au	Loloma Mining Co. Ltd, 1975 Personal communication V. Nettle, 1993
Walter Hodgson & Occident	Gold		Indicated resource: 10 000t @ 11.5g/t Au	CR 5251
West Normanby River	Gold	Alluvial and eluvial placer gold deposit	Inferred resource: 596 000 lcm @ 0.4g/lcm Au Indicated and Inferred resource: 867 000 lcm @ 0.37g/lcm Au Indicated resource: 600 000bcm @ 0.4g/bcm Au and an Inferred resource: 267 000 lcm @ 0.3g/lcm Au	Register of Australian Mining 1994/95, page 147 Register of Australian Mining 1990/91, page 164 MINMET 7/11/97
Woodville	Gold	Late Carboniferous–Early Permian? mesothermal stibnite–gold-quartz veins hosted by Devonian metasediments	Inferred/indicated Resource: 0.4Mt @ 1.25g/t Au for ML 20009 & MLA 20118	MINMET 7/11/97
Retina (Peter Pan, Mitchell River Antimony Mine)	Gold, Antimony		Inferred resource: 45 000t @ 5% Sb, (Aminco) Indicated resource: 33 000t @ 8% Sb Inferred resource: 165 000t @ 6% Sb grading ~6–7g/t Au downgraded by a factor of at least 3 by Johannesburg Consolidated Investment Ltd	Garrad (1993) Johannesburg Consolidated Investment Ltd
Tunnel (Craig's Tunnel, Wingfields Tunnel)	Gold, Antimony	Epithermal fissure lodes (Jensen,1941). Mesothermal veins probably sourced from upwardly migrating metamorphic fluids (Golding and others, 1990)	Indicated resource: 8 100t @ 8.0 % Sb Measured resource: Oxide ore–6 900t @ 4.70ppm Au; sulphide ore–29 000t @ 4.70ppm Au (Oxide ore probably mined out)	CR 3830 Dash & Cranfield, 1993
Griffiths Hill (Mungana area)	Gold, Copper		Combined Measured–Indicated and Inferred Resource: 753 500t @ 2g/t Au, 1% Cu using a 0.84% Cu and/or Cu equivalent cutoff (Cu equiv.(%) = Au(g/t)x0.5) has been calculated	Barr, 1994
Mount Lucy	Iron	Skarn developed with Chillagoe Formation at the contact of the Carboniferous Lucy Adamellite	unknown resource category: 250 000t of 68.5% Iron, 0.57% Ag	Dash & others, 1988
Mount Ruby	Iron	Skarn	70–80 000t @ 54.1% Fe and 6.7% Si	Connah (1954)
Western	Iron	Skarn	70–80 000t @ 54.6% Fe and 6.1% Si	Connah (1954)
Fairchance quarry	Limestone	Limestone	Measured reserves: 39 000t of high quality limestone	Recalculated from Connah (1958)

Name	Commodity	Type and age of deposit	Resources and reserves	Reference
Melody Rocks	Limestone	Limestone in Devonian metasedimentary sequence	>100Mt of high to chemical grade limestone Indicated resource: 100Mt of limestone to a depth of 120m analysing 55% CaO, 1% SiO_2, 0.4% MgO, 0.2% Fe_2O_3 and 0.4% Al_2O_3	CR 15622 MINMET 7/11/97
White Gem	Limestone	Limestone	Estimated resource: 17 800t above the quarry floor and 35 600t to 30m below the quarry floor	Denmead (1949), only a very small part of this has been mined
Nychum (Wrotham)	Perlite	Volcanic glass	~700Mt perlite	Jones, 1995
Cape Flattery dunefield	Silica sand	Cainozoic silica sand dunes.	Proven reserves: 200Mt silica sand	Cooper, 1993
Mourilyan silica sand deposit	Silica sand	Pleistocene–Holocene age inner and outer beachridge barrier complex	Indicated reserves: 10 739 500 tonnes of >99% silica to 0.5m depth	Cooper, 1993
Adventure (Great Adventure)	Tin	Magmatic hydrothermal, related to post-tectonic granites	Measured+Indicated resource, 34500t @ 2.63% Sn (Metals Exploration NL,1963, CR7983); Indicated resource, 29 000t @ 2.6% Sn, 11 000t @3.3% Sn (1%Sn cutoff), ~2 100t cassiterite conc	Metals Exploration NL, 1970, CR15228
Black Adder Flats	Tin		Inferred Resource: $6.1Mm^3$ @ 0.039kg Sn/m^3	(CR 1745)
Cassowary Creek deep lead	Tin		Indicated resource containing 513t of tin metal	Register of Australian Mining 1996/97, page 301
Collingwood Prospect	Tin	Cassiterite-bearing sheeted quartz-tourmaline and greisen vein system in a late Palaeozoic granitoid	Indicated resource: 4.035Mt @ 0.73 % Sn. Probable reserves: 2.027Mt @ 1.0 % Sn. Probable reserves: 3.106Mt @ 0.90 % Sn Indicated resource: 2.2Mt @ 1% Sn which includes a Probable resource: 0.91Mt @ 1.01% Sn	Miezitis & Bain, 1991; Miezitis & McNaught, 1987 Register of Australian Mining 1997/98, page 385
Con Goo	Tin	Magmatic hydrothermal, related to post-tectonic granites	Proven reserve: 1 200t @ 1.1%Sn; Inferred resource: 7 000t @ 0.9%Sn	CR14483, 1982
Confederation	Tin	Magmatic hydrothermal, related to post-tectonic granites	Inferred resource: 100 000t @ ~1.0% cassiterite	Great Northern Mining Corporation NL, Annual Report, 1985
Daisy Bell (Chief's lode, Biddell's lode)	Tin	a siliceous end phase expelled from the cooling of the Elizabeth Creek granite. This material was injected in one instance along a major greisen dyke(CR13812)	Inferred resource: 10 000t @ 0.5% Sn & W (A) Inferred resource: 5 000–10 000t @ >0.5% Sn & W combined (B) Inferred resource: 30 000t @ 1.5–2% Sn, 70000t @ 0.5–0.8% Sn (C)	A. Gold Copper Exploration Ltd, Southern Miner,1971 B. Gold Copper, CR13812 C. R.B. Mining Pty Ltd, 1970, CR5378
General Gordon (Glenlinedale)	Tin	Magmatic hydrothermal related to post-tectonic granites	unknown resource category: 7–10 000 tonnes orebody grading 1–1.5% cassiterite conc	CR 13808

Appendix 3 (continued)

Name	Commodity	Type and age of deposit	Resources and reserves	Reference
Gillian Prospect (Pinnacle, Nymbool)	Tin	Wrigglite skarn related to the O'Brien Creek Supersuite and hosted by Devonian metasedimentary rocks of the Hodgkinson Formation Pyrometasomatic contact skarn	Indicated resource: 1.3Mt @ 0.54–0.69% tin and an Inferred resource: 500 000t @ 0.54–0.69% tin (0.54% assumed dilution through core loss, 0.69% non-dilution) 1.8Mt @ 0.69% cassiterite 4Mt @ 11% fluorine 20–22.5Mt @ 0.7–0.9% Sn	Register of Australian Mining 1997/98, page 385 MINMET 7/11/97 Register of Australian Mining (1994/95, page 147) Bruvel & others (1991)
Governor Norman(Kelly Norman) Kelly Norman orebody	Tin	Magmatic hydrothermal, related to post-tectonic granites	Indicated resource: 17 000t @ 1.7% Sn	A. Great Northern Mining Corporation NL, Annual Report, 1984
Grasstree United (Never Say Die) (Grasstree Pocket)	Tin	Cassiterite-bearing quartz veins and alteration zones in a late Palaeozoic granitoid. Alluvial placer tin deposit	Inferred resource: 1Mt @ 138g/t cassiterite	CR 5054
Great Southern (part of Jumna Tin Project)	Tin	Magmatic hydrothermal, related to post-tectonic granites	Indicated resource: 20 000t @ 1.3% Sn	Register of Australian Mining 1997/98, page 385
Horse Creek	Tin		Inferred resource: 750 000m^3 @ 350g cassiterite/m^3 (±250 000m^3)	CR 12563
Jack Johnson	Tin	Magmatic hydrothermal, related to post-tectonic granites	Inferred resource: 8 000t @ 0.9% Sn	CR14337,1984
Jeannie River Prospect	Tin	Complex cassiterite-sulphide lodes in Devonian metasediments intruded by Permian granite	6.7Mt @ ~0.8% Sn	Lord & Fabray (1990)
Jumna Tailings dam (part of Jumna Tin Project)	Tin	Tailings dams from the Jumna plant which ceased operations in 1987	Indicated resource: 150 000t @ 0.35% Sn	Register of Australian Mining 1997/98, page 385
Just In Time claim (Mount Hartley)	Tin		Inferred resource: 96 449 m^3 of eluvium @ 0.55kg/m^3 cassiterite (0.2kg/m^3 cutoff)	CR 10851
Kings Plains Prospect	Tin	Cainozoic alluvial placer tin deposit	Inferred resource: 87Mm^3 of alluvium @ 130g/m^3 cassiterite, with 77g/m^3 cutoff (including 42Mm^3 @ 160g/m^3 cassiterite) Inferred resource: 128Mm^3 at 119g/m^3 cassiterite (dredge to a depth of 42.7m)	M.H. Wood CR 2434 ?
Lamb	Tin	Magmatic hydrothermal, related to post-tectonic granites	Indicated resource: 1 620t @ 0.65% Sn	CR14452, 1982
Lee Creek	Tin		unknown resource category: 2.1Mm^3 of alluvium @ 383g/m^3 cassiterite; or 0.9 Mm^3 of wash @ 759 g/m^3 cassiterite	CR 2434

Name	Commodity	Type and age of deposit	Resources and reserves	Reference
Leichhardt Creek	Tin	Recent alluvial placer tin deposit	Proven/probable resource: 7.536Mbcm grading 408g/bcm Indicated & Inferred resource: 73.818Mbcm grading 249g/bcm Total resource of ~200Mt of alluvium grading 100–500g/bcm, proven reserves of 1.14Mbcm @ 404g/bcm and probable reserves of 478 000bcm @ 411g/bcm Measured reserves: 1.7Mlcm @ 369g/lcm	MINMET (7/11/97) MINMET (7/11/97) Register of Australian Mining 1996/97, page 301 Register of Australian Mining 1997/98, page 385
Little Plum Tree Creek (Skull Creek, Skull Lagoons)	Tin	Recent alluvial placer tin deposit	Inferred resource: 191 000m^3 @ 273g Sn/m^3 (100g/m^3 cutoff); including 48 000m^3 @ 470g Sn/m^3, (400g/m^3 cutoff)	CR 8528
Mount Hartley Creek (below Mount Hartley)	Tin		Indicated resources: 381 440m^3 @ 0.18kg/m^3 in the lower terraces and 453 125m^3 at an unknown grade in the upper terraces	Denaro & Ewers, 1995
Mount Holmes	Tin	Greisenised roof zone above a shallowly buried granitic intrusive	Inferred potential resource: 7Mt –10Mt @ 0.055% Sn (0.07% cassiterite) and 0.01% WO_3	Gold Mines N.L./Poseidon Expln. Ltd, 1989, CR 22194
Mount Lewis	Tin	Magmatic hydrothermal greisen and quartz veins, related to the Mount Carbine granite	Inferred resource: 144 630m^3 @ 0.46kg cassiterite/m^3	personal communication C.J.Robinson, 1992
Mount Ormonde	Tin	Magmatic hydrothermal, related to post-tectonic granites	Proven reserves: 11 500t @ 0.59% Sn	CR 14483, 1982
Mount Poverty	Tin		Inferred resource: 20 000m^3 of erratic tin mineralisation	Denaro & Ewers, 1995
Mountaineer lease, (located at the junction of Flaggy Creek and the West Normanby River)	Tin		unknown resource category: 54 000m^3 of stanniferous wash @ <0.75kg/m^3 cassiterite	McGain, 1981
Mungumby Creek (located at the base of the Big Tableland, Cooktown Tinfield)	Tin		Indicated resource: 595 125m^3 @ 0.20kg/m^3 cassiterite; or 434 760m^3 @ 0.43kg/m^3	CR 10851
Never Can Tell	Tin	Magmatic hydrothermal related to post-tectonic granites	Probable resource: 15Mt @ 0.2% Sn	Noranda, 1968
Nine Mile Creek (Cannibal Creek area)	Tin	Alluvial tin	unknown resource category: 76 500m^3 grading 683g/m^3 cassiterite	Northern Mining Syndicate in 1974
Nymbool	Tin	Alluvial tin	200 000 lcm @ 500g/lcm cassiterite	Register of Australian Mining 1997/98, page 385

Appendix 3 (continued)

Name	Commodity	Type and age of deposit	Resources and reserves	Reference
Palmer River	Tin		Resources remaining in the Palmer River include 139 000m^3 @ 0.41g/m^3 (Spear Creek), 254 000m^3 @ 0.20g/m^3 (Blackfellow Creek), 1 400 000m^3 @ 0.26g/m^3 along the Palmer River, 850 000m^3 at 0.8g/m^3 in the upper reaches of Doughboy Creek, and 70 000m^3 at 0.26g/m^3 in the Little Palmer River	Denaro & Ewers, (1995)
Patrick (Patrick Day	Tin	Magmatic hydrothermal, related to post-tectonic granites	Inferred resource: 4 851t @ 0.7% Sn	Loloma Minerals,1982, CR15109
Peacemaker (part of Jumna Tin Project)	Tin	Magmatic hydrothermal, related to post-tectonic granites	Indicated resource: 20 000t @ 1.3% Sn	Register of Australian Mining 1997/98, page 385
Sailor	Tin		Estimate Resource: >12Mt averaging 0.1% tin 13.5Mt @ 0.1% Sn	CR 14265; Morrison & Beams (1995)
Sand Hills (2km south-west of Mount Hartley)	Tin		Indicated resource of 14 963 lcm at 0.74kg/m^3 cassiterite and 28 416 lcm at 0.66kg/m^3	Dominion (ML 968)
Smiths Creek Tin Prospect	Tin		Measured/Indicated/ Inferred Resource: 250 000t @ 1.75% cassiterite	MINMET (7/11/97)
Stannum Ace	Tin	Magmatic hydrothermal, related to post-tectonic granites	Indicated resource: 17 700t @ 0.75% cassiterite. Plus an additional Inferred resource: 5 600t @ 0.75% cassiterite. (incorporates the ore between the Referendum and Stannum-Ace mines)	CR14454,1982
Station Creek (Mulligan Highway)	Tin	Alluvial placer tin-tungsten deposit	Inferred resource: 46Mm^3 @ ~180g Sn/m^3 Probable resource: 30Mm^3 @ 120g Sn/m^3	Mineral Deposits Ltd, AP 1211M, 1973 Ravenshoe Tin Dredging Ltd, AP 1699M, 1976–1979
Tin Creek (Cannibal Creek area)	Tin		Resource of 383 000m^3 of stanniferous wash grading 694g/m^3 cassiterite	Northern Mining Syndicate, 1974
Two Jacks	Tin		Inferred resource: 30 000t (cut off grade 0.6% Sn)	R.B. Mining, 1970, CR 5378
Upper Mossman River	Tin		Potential resource: 250 000m^3 to >3 m depth in places averaging 3.5kg/m^3 cassiterite	Zarda Alluvial Tin Ltd
Waterfall Creek to Trevethan Creek	Tin		Inferred resource: 0.95Mm^3 of alluvium at an average grade of 482g/m^3 cassiterite. In 1978, Serem Australia Pty Ltd reassessed the deposits and calculated overall indicated resources as 2.1Mm^3 at an average grade of 383g/m^3, comprising 0.9Mm^3 of wash at an average grade of 759g/m^3 cassiterite and 1.2Mm^3 of overburden	Denaro & others, 1994

Name	Commodity	Type and age of deposit	Resources and reserves	Reference
Windermere	Tin	Wrigglite skarn related to the O'Brien Creek Supersuite and hosted by Devonian metasedimentary rocks of the Hodgkinson Formation. Pyrometasomatic contact skarn	Inferred resource: 650 000t @ 0.56% tin	Register of Australian Mining 1997/98, page 385
World's Fair	Tin	Magmatic hydrothermal, related to post-tectonic granites	Inferred resource: 53 600t @ 0.6–2.0% cassiterite (incorporates all ore between Ibis and World's Fair to 73m below surface)	CR14454, 1982
You & Me (Stannary Hills Group)	Tin	Magmatic hydrothermal, related to post-tectonic granites	unknown resource category: 10 000t @ 1.2% Sn	personal communication A.Walter, Great Northern Mining Corporation NL,1989
Clearwater (Bonny Boy, Bonnie Boy) (Romeo Group)	Tungsten	Cassiterite and wolframite-bearing sheeted vein system in a late Palaeozoic granitoid	Inferred resource: 2Mt @ 0.1 % Wolframite	CR 11225
Mount Carbine	Tungsten	Hydrothermal sheeted vein system, genetically related to adjacent granitic intrusions (Murray, 1990; McLean, 1980). Fluids were a mixture of magmatic and that derived from metasediments (Higgins & others, 1987)	Inferred resource: 28Mt @ 0.1% WO_3, using 0.03% cutoff	de Roo, 1988
Mount Perseverance Group	Tungsten	Hydrothermal vein swarm similar to the Mount Carbine	Inferred resource: 13Mt @ 0.025–0.038% WO_3	A. R.B. Mining Pty Ltd, 1971, CR 6886
Zarda (Mount Spurgeon)	Tungsten	Alluvial and eluvial deposits derived from the Permian Spurgeon Granite	Potential resource: 250 000m^3 averaging 3.5kg/m^3 cassiterite	Zarda Alluvial Tin Ltd (1935)
Pom Pom	Tungsten	Magmatic hydrothermal vein	Indicated resource: 2 756t @ 2.0% WOLF; Inferred resource: 23 750t @ 1.0% WOLF; Indicated resource: 5 700t @ 1.0 % WOLF	Greaves, 1980 Taylor, 1971
Watershed Prospect	Tungsten	Quartz-scheelite veins and disseminated scheelite in Devonian Calcsilicate rocks and Permian granite	14Mt @ 0.3% WO_3	Miezitis & McNaught, 1987
Wolfram Camp	Tungsten	Greisen zones and pipes along the contact of Carboniferous James Creek Granite with Devonian Hodgkinson Formation	Inferred resource: 2Mt @ 1.0% WO_3, 0.5% Mo and 0.1% Bi Estimated resource: >1Mt @ 1.5% combined WO_3, Mo and Bi	MINMET 6/12/96 Register of Australian Mining 1997/98, page 313
Wolfram Line	Tungsten		Inferred resource: 1.016Mt @ 2% W	R.B. Mining, CR5378, 1970