CHAPTER ONE
INTRODUCTION

1.1 PREAMBLE

The Middle Proterozoic Mount Isa Inlier in northwestern Queensland (Figure 1.1) is an important source of metals. The most prominent and best-known mine in the region is the Cu-Pb-Zn complex at Mount Isa, in the western part of the inlier, but in the early part of this century most of the mineral wealth, largely copper and gold, came from the eastern part. Kennedy (1979) presents an informative summary of this early mining history. The large mines in this region closed in the 1920s, but smaller deposits have been worked intermittently up to the present time for copper, gold, lead, zinc, silver, cobalt, uranium, and a host of other metals, and exploration never completely ceased. It is only in the last two decades, however, that there has been a major resurgence of interest in finding and exploiting base and precious metal deposits.

Two prominent deposit styles have traditionally been recognized in the eastern Mount Isa Inlier (Figure 1.2). These are copper ± gold ± silver, hosted by discordant, heavily altered breccia bodies (*e.g.* Hampden, Mount Elliott, Mount Dore), and gold + copper (± REE), hosted by stratabound ironstones (*e.g.* Starra, Osborne). A subeconomic lead + zinc ± gold association also occurs in banded iron-formations (*e.g.* Pegmont, Fairmile), and the major uranium deposit of the area (Mary Kathleen) is also hosted by skarn. Cobalt (± tungsten) mineralization is developed in narrow shear zones (*e.g.* Mount Cobalt). The recent discovery of the zinc-lead-silver Cannington deposit (Gomez, 1991) suggests other important styles await revelation.

FIGURE 1.1: Location of the Mount Isa Inlier, and past and present population centres. The site of the Mount Dore breccia-hosted copper deposit is also indicated.

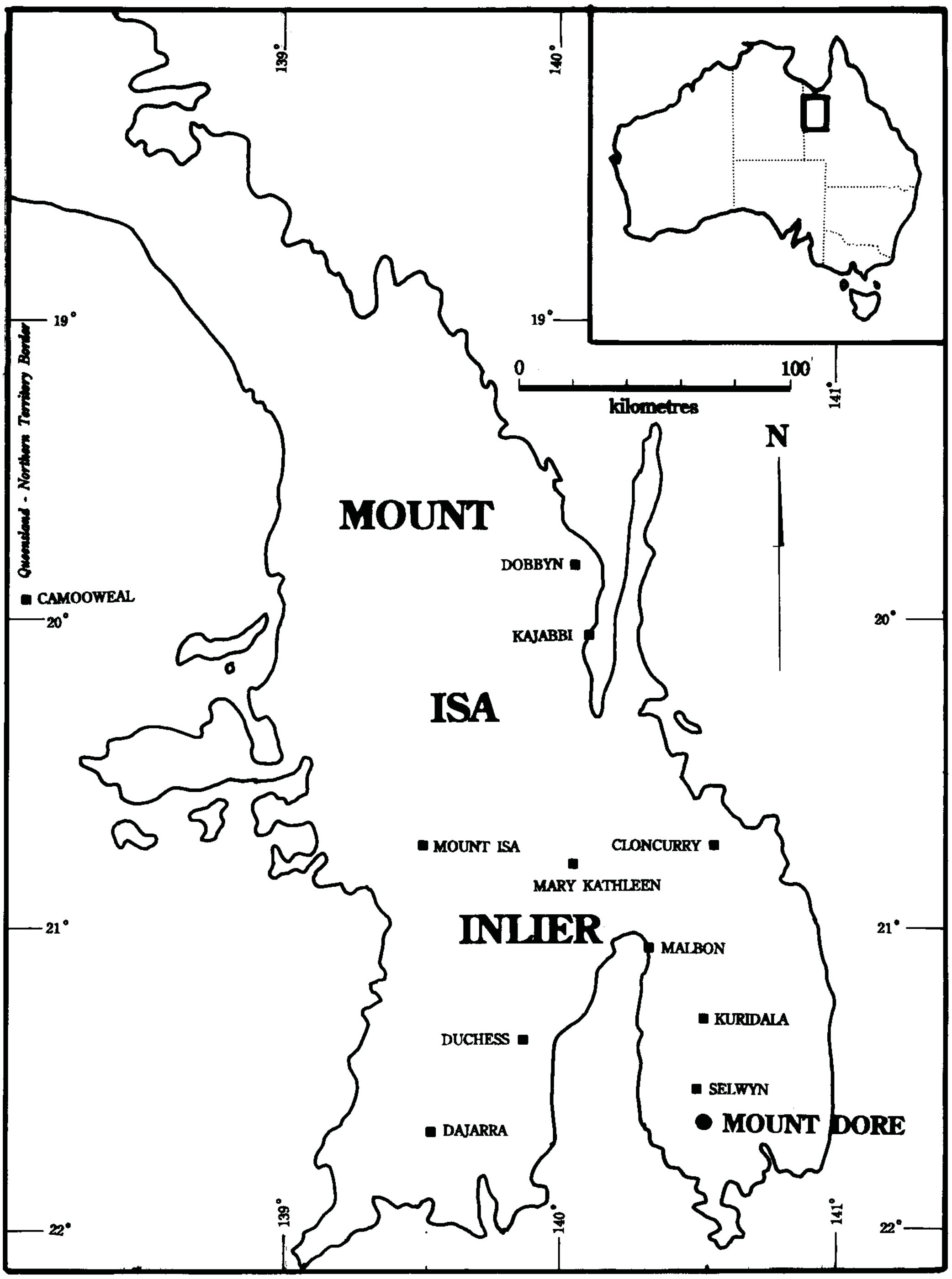
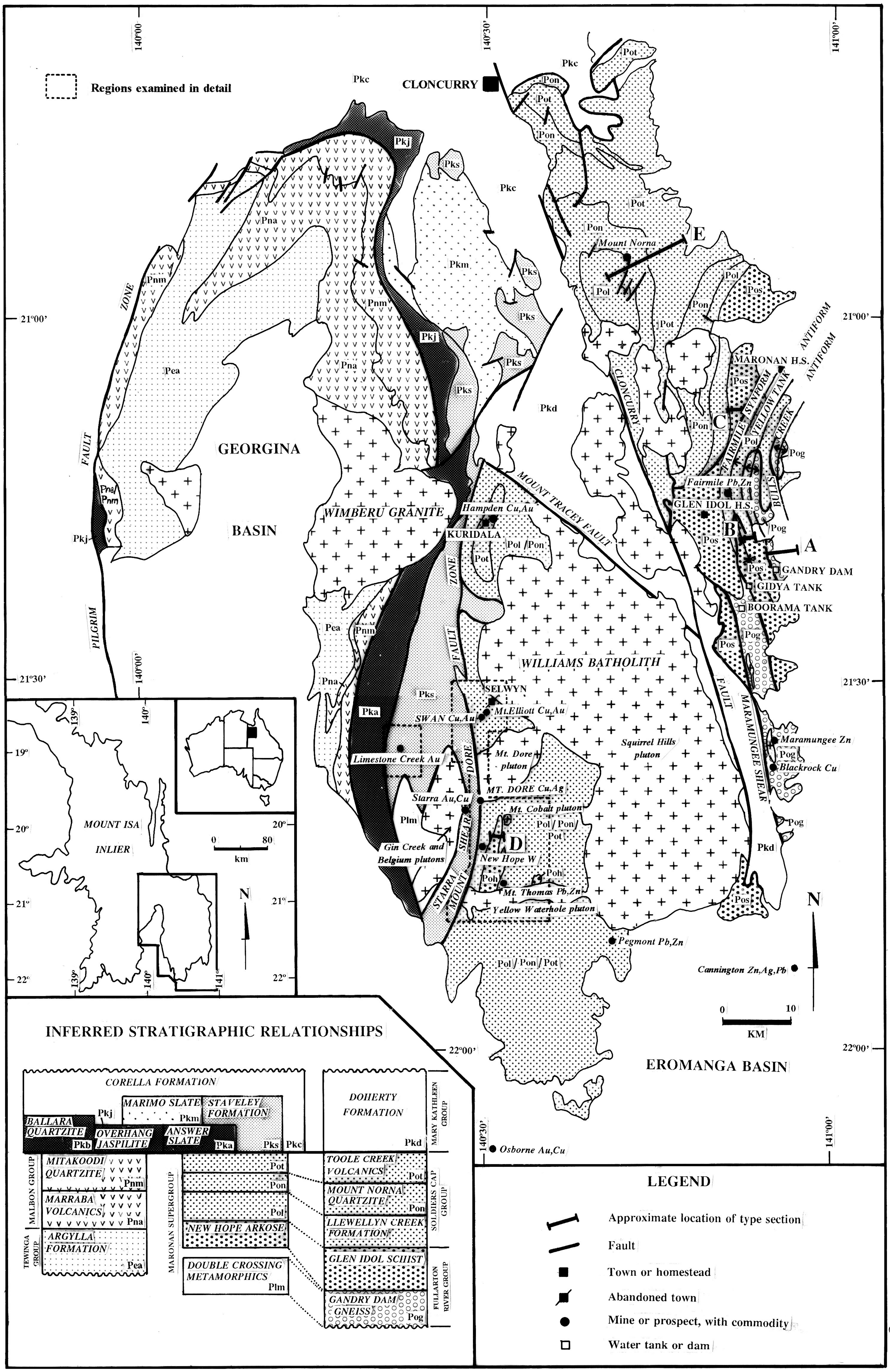


FIGURE 1.2: Summary geological map of the Cloncurry Fold Belt showing the locations of the deposits mentioned in this chapter, and also depicting the distribution of major stratigraphic units, including newly-defined units (Beardsmore *et al.*, 1988; Appendix A). Lithostratigraphic unit abbreviations: **Pea** - Argylla Formation; **Pka** - Answer Slate; **Pkc** - Corella Formation; **Pkd** - Doherty Formation; **Pkj** - Overhand Jaspilite; **Pkm** - Marimo Slate; **Pks** - Staveley Formation; **Plm** - Double Crossing Metamorphics; **Pna** - Marraba Volcanics; **Pnm** - Mitakoodi Quartzite; **Pog** - Gandry Dam Gneiss; **Poh** - New Hope Arkose; **Pol** - Llewellyn Creek Formation; **Pon** - Mount Norna Quartzite; **Pos** - Glen Idol Schist; **Pot** - Toole Creek Volcanics. Granitoids, most of which are late to post-tectonic, are indicated by the "cross" symbols. The Double Crossing Metamorphics (Plm) and spatially associated granitoids collectively comprise the Gin Creek Block, which is entirely fault bounded, and of uncertain stratigraphic position.


Regions examined in detail
CLONCURRY
140°00'
140°30'
141°00'
21°00'
21°30'
22°00'
GEORGINA
BASIN
WIMBERU GRANITE
PILGRIM
FAULT
ZONE
CLONCURRY
FAULT
MOUNT TRACEY FAULT
WILLIAMS BATHOLITH
Squirrel Hills pluton
Mt. Dore pluton
Mt. Cobalt pluton
Gin Creek and Belgium plutons
Yellow Waterhole pluton
STARRA
MOUNT
SHEAR
DORE
FAULT
ZONE
MARAMUNGEE SHEAR
FAIRMILE SYNFORM
YELLOW TANK ANTIFORM
BULLS CREEK ANTIFORM
MARONAN H.S.
GLEN IDOL H.S.
GANDRY DAM
GIDYA TANK
BOORAMA TANK
KURIDALA
SELWYN
Mount Norna
Fairmile Pb,Zn
Hampden Cu,Au
Mt.Elliott Cu,Au
SWAN Cu,Au
Limestone Creek Au
MT. DORE Cu,Ag
Starra Au,Cu
New Hope W
Mt. Thomas Pb,Zn
Pegmont Pb,Zn
Maramungee Zn
Blackrock Cu
Cannington Zn,Ag,Pb
Osborne Au,Cu
A
B
C
D
E
EROMANGA BASIN
Pkc
Pkj
Pks
Pkm
Pkd
Pka
Pna
Pnm
Pna/Pnm
Pea
Plm
Pot
Pon
Pol
Pos
Pog
Poh
Pol / Pon
Pol / Pon / Pot
0 10
KM
N
MOUNT ISA
INLIER
0 80
km
139°
140°
141°
19°
20°
21°
22°
INFERRED STRATIGRAPHIC RELATIONSHIPS
CORELLA FORMATION
MARIMO SLATE
STAVELEY FORMATION
BALLARA QUARTZITE
OVERHANG JASPILITE
ANSWER SLATE
Pkb
DOHERTY FORMATION
MARY KATHLEEN GROUP
MITAKOODI QUARTZITE
MARRABA VOLCANICS
MALBON GROUP
ARGYLLA FORMATION
TEWINGA GROUP
MARONAN SUPERGROUP
NEW HOPE ARKOSE
DOUBLE CROSSING METAMORPHICS
TOOLE CREEK VOLCANICS
MOUNT NORNA QUARTZITE
LLEWELLYN CREEK FORMATION
SOLDIERS CAP GROUP
GLEN IDOL SCHIST
GANDRY DAM GNEISS
FULLARTON RIVER GROUP
LEGEND
Approximate location of type section
Fault
Town or homestead
Abandoned town
Mine or prospect, with commodity
Water tank or dam

The discordant, breccia-hosted orebodies have historically been the major sources of metals in the Mount Isa Inlier. The Kuridala-Selwyn region boasts a group of comparatively small breccia-hosted copper orebodies, all having an apparently similar style, and all lying along a 65-kilometre, north-trending linear belt (Figure 1.2). Gold is a significant accessory metal in many instances. For example, the Mount Elliott and Hampden mines produced more than 1055 and 375 kilograms of gold, respectively (Nye and Rayner, 1940; Carter *et al.*, 1961). There are also similarities to the breccia-hosted copper-gold deposits in the Cloncurry district. Much recent exploration in the region has involved re-evaluation of several of the old deposits, with encouraging results. Despite extensive mining in the past, and the current feverish exploration activity, there have been no detailed studies of any of the breccia deposits. A metallogenic study of the eastern Mount Isa Inlier is now well overdue.

1.2 THE MOUNT DORE COPPER DEPOSIT

The Mount Dore copper deposit is a typical example of the breccia-hosted style of mineralization, and lies about 110 kilometres south of Cloncurry (Figure 1.2). Past production from this body, probably dating to the time that the Mount Elliott Mine was at its peak of activity (1908-1920; Kennedy, 1979), has been a mere 15.74 tonnes of oxide ore for a total of 5.81 tonnes of copper (Nye and Rayner, 1940). The Mount Dore deposit therefore historically received far less attention that its more profitable cousins to the north, and remained comparatively little known geologically until recently. Reassessment of the prospect in the late 1970s launched the prospect into prominence, however, when a resource of 40 million tonnes of copper ore, grading 1.08 percent Cu and 6.5 g/t Ag to a depth of 300 metres was defined (Nisbet, 1980). No lower limit to mineralization was defined. The drillcore and detailed mapping obtained during this exploration were readily available on-site, providing one of the most substantial databases for any of the deposits in this part of the Mount Isa Inlier, and an opportunity to study in detail a representative of a major style of mineralization.

Earlier workers have looked at some aspects of the petrogenesis of the Mount Dore deposit, but there has been no detailed treatise. White (1957) and Brooks (1960) noted that the lode was hosted in a shear zone sub-parallel with bedding, indicating the possibility of structural control of the mineralization. The most extensive study prior to the one before you is the Honours dissertation by Ophel (1980). He described the general characteristics of the breccias associated with mineralization, proposing sedimentary, tectonic and volcanic origins for them. He also documented the broad style of alteration and mineralisation, and suggested that mineralisation was originally syn-sedimentary, but was remobilised and concentrated in the breccias during a hydrothermal alteration event related to intrusion of the adjacent Mount Dore Granite. A comprehensive petrogenetic study of the deposit was beyond the scope of his work, but Ophel (1980) did provide a good preliminary geochemical database of electron microprobe analyses of alteration phases. Nisbet (1983) examined the deposit briefly, concluding that breccias are fracture- and solution-related, and that mineralization is epigenetic. He could not deduce, however, whether hydrothermal fluids were of magmatic or metamorphic derivation. Laing (1983) observed the spatial association of brecciation, alteration and mineralisation with upright, north-trending, open folds, which he ascribed to the D_3 deformation event (terminology after Bell and Duncan, 1978). He noted similarities with the Mount Isa copper deposit, and suggested that folding and brecciation at Mount Dore provided open space for precipitation of metamorphically remobilised sulphides, in a manner analogous to that proposed by Swager (1983) and Perkins (1984a,b) for the Mount Isa orebody.

1.3 AIMS AND STRUCTURE OF THE THESIS

The way is opened then for the present study, which is concerned with a detailed study of the petrogenesis of the Mount Dore deposit, as part of a regional programme investigating the metallogeny of the Mount Isa Inlier, being undertaken by the Geology Department at the James Cook University of North Queensland. The overall aim of this work may therefore be stated as:

To determine the geologic setting and origin of the Mount Dore breccia-hosted copper deposit, and suggest a regionally applicable metallogenic model for this style of mineralization.

More specifically, the study has the following aims:

(i) Determine the regional geological setting of the Mount Dore and similar deposits. The regional stratigraphy, and structural and metamorphic histories of this part of the Mount Isa Inlier were previously poorly understood;

(ii) Characterize the controls on localization of the Mount Dore deposit in terms of regional geological processes;

(iii) Analyse the alteration and mineralization parageneses, and using this information draw conclusions regarding the provenance of the hydrothermal fluid, and its subsequent geochemical evolution as it passed through the Mount Dore region;

(iv) Compare the results of the foregoing studies with known geological features of other deposits in the region, and make an assessment of the wider applicability of the model deduced for the Mount Dore deposit.

To achieve these aims, a programme of research has been undertaken which included regional and prospect-scale mapping, logging and sampling of diamond drill core, and detailed petrologic examination of the samples using petrographic, mineral chemistry, fluid inclusion and stable isotope techniques.

The investigation reported herein fell naturally into two parts. The first phase involved unravelling the regional stratigraphy and tectonic history, through lithological and structural mapping. The results are presented in Chapters Two and Three, and have contributed to the recent tectonic modelling for the Mount Isa Inlier (see Beardsmore *et al.*, 1988).

Armed with a firm regional geological framework, the second phase of the study examined the Mount Dore deposit in some detail. Chapters Four through Six look at, respectively, the local geology; alteration and mineralization parageneses and geochemistry; and fluid geochemistry and provenance.

The final chapter reviews the known geological characteristics of other, apparently similar copper deposits, compares them with the Mount Dore deposit to test the model derived for this prospect for wider applicability, and draws together the results of the entire study into a regional metallogenic model which can be tested with further research.

CHAPTER TWO
STRATIGRAPHIC DEVELOPMENT OF THE KURIDALA-SELWYN REGION

2.1 INTRODUCTION

2.1.1 Rationale

The Kuridala-Selwyn region is here regarded here as comprising those exposed Proterozoic rocks of the Mount Isa Inlier extending from the abandoned township of Selwyn southwards to the limits of outcrop of these rocks. Metasediments define a broad belt up to 40 km wide and 130 km long, sandwiched between the Cambrian and Mesozoic units of the Georgina Basin in the west, and the Proterozoic Williams Batholith and predominantly Tertiary units of the Eromanga Basin to the east (Figure 1.2).

Knowledge of the stratigraphy of the Mount Isa Inlier has now reached a level where preliminary interpretations of the early tectonic evolution of the inlier can be made. For instance, it is now generally accepted that sedimentation in the western half of the Mount Isa Inlier largely occurred in an active ensialic rifting environment (Glikson *et al.*, 1976; Blake, 1980; Wyborn and Blake, 1982; Derrick, 1982). The tectonic development of the eastern part of the inlier was relatively poorly understood, however, because the lithologic characteristics of, and stratigraphic relationships between the different units were less well known. Better constraints on the tectonic evolution of this part of the inlier were therefore required before reasonable interpretations of regional metallogeny could be made.

The first task of the present study was therefore to examine the stratigraphy and structure of the Kuridala-Selwyn region, and pool the results with those from similar studies to the east (Newbery, 1990) into the regional tectonostratigraphic synthesis (now reported in Beardsmore *et al.*, 1988).

2.1.2 History of previous investigations

The first geological observations in the Mount Isa Inlier were those of the ill-fated Burke and Wills, who in 1860-61 made general notes on the lithologies during their northward traverse across the inlier and along the Cloncurry River. In his search for the lost expedition later in 1861, McKinlay (1863) recorded a specimen of copper. The first major mention of the Mount Isa Inlier in the geological literature was by Daintree (1872) who, by analogy with the metamorphic rocks of Victoria, regarded all the metamorphic rocks in Queensland as Silurian or older.

The discovery of copper and gold in the Cloncurry region by Ernest Henry in 1867 prompted a number of variably-detailed mineralogical surveys, some of which attempted to place parts of the Mount Isa Inlier in stratigraphic context (*e.g.* Jack, 1885; Cameron, 1901; Ball, 1908; Woolnough, 1912; Dunstan, 1913). An event of note was the recognition of the Mount Isa Inlier as Proterozoic in age (Saint-Smith, 1924), but in general geological knowledge of the area advanced slowly until the mid to late 1930's when, spurred on by the discovery of the Mount Isa deposit, the Aerial, Geological and Geophysical Survey of Northern Australia (AGGSNA) undertook major geological and geophysical investigations around the most strongly mineralized areas of the Mount Isa Inlier.

The first major effort to deduce the regional stratigraphy, and hence geological history for the Mount Isa Inlier was undertaken jointly by the Geological Survey of Queensland (GSQ) and the Bureau of Mineral Resources (now the Australian Geological Survey Organization, and referred to herein as the AGSO) between 1950 and 1960. The results, reported in Carter *et al.* (1961) have formed the basis for all subsequent work in the Inlier. Later revisionary work on the stratigraphy has been most notably that of Derrick *et al.* (1976a-e; 1977a,b; 1978), Bultitude *et al.* (1977), Derrick *et al.* (1980), and lately Blake and Page (1988). Geochronological studies have constrained the ages of many of the units, where relative timing of intrusion of igneous rocks in the region are known (Page, 1978, 1981, 1983), but there remains some disagreement regarding the stratigraphic relationships between major units in the eastern part, and correlation of units from east to west across the inlier.

2.1.3 Statement of the problem

The conventional interpretation of the stratigraphy in the Kuridala-Selwyn region (Figure 2.1a) identifies the Kuridala Formation, Staveley Formation and Answer Slate (formally defined by Carter *et al.*, 1961), the Agate Downs Siltstone and Doherty Formation (originally mapped by these workers as parts of the Staveley and Corella Formations, respectively, but later given formation status by Blake *et al.*, 1981a and Blake, 1982), as the constituent formations of the Mary Kathleen Group (defined by Derrick *et al.*, 1977a). The other main metasedimentary unit is the Double Crossing Metamorphics (first defined by Blake *et al.*, 1981a,b), whose stratigraphic relation to other units remains uncertain, although Blake *et al.* (1983) tentatively correlated them with the Tewinga or Malbon Groups, or older (pre-Tewinga) basement rocks cropping out to the west. All units are intruded by plutons of the late-tectonic Williams Batholith, and the Double Crossing Metamorphics are additionally intruded by bodies of syn-tectonic granite, believed to be derived by partial melting of these metasediments during peak metamorphism (Blake *et al.*, 1983; Switzer, 1987).

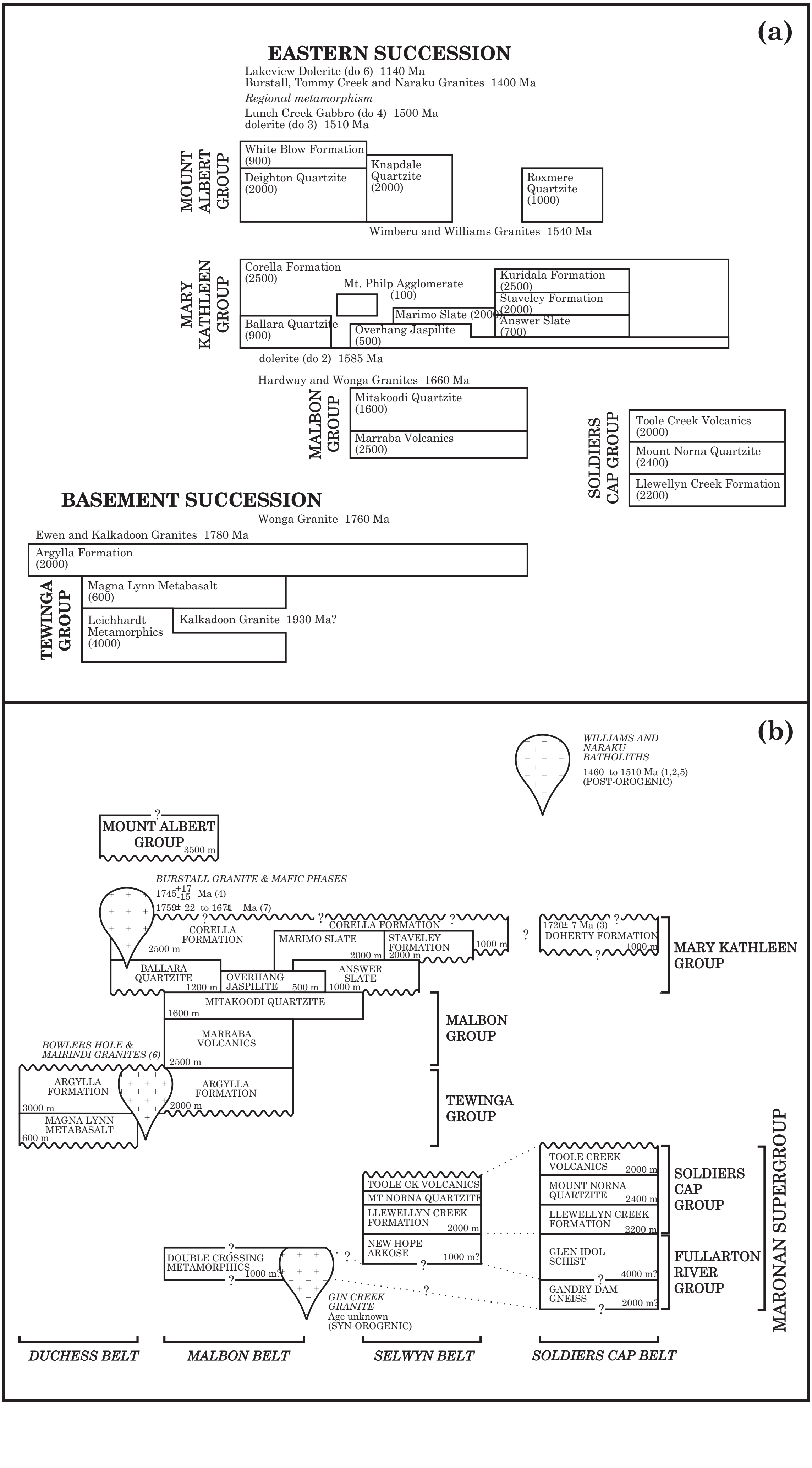
There are (at least) two major problems with the conventional stratigraphic wisdom. The first concerns the uncertain stratigraphic and tectonic relations between the Kuridala Formation and other units in the region, particularly the Staveley Formation. Carter *et al.* (1961) placed the Kuridala Formation conformably ***above*** the Staveley Formation, but Blake *et al.* (1983) interpreted the former to lie conformably or disconformably below the latter. Blake *et al.* (1983) also observed apparent gradation

FIGURE 2.1: Comparison of old and new interpretations of the stratigraphy for the eastern part of the Mount Isa Inlier:

(a) Conventional interpretation, after Wilson (1978). Numbers in parentheses are average thicknesses of stratigraphic units in metres;

(b) Proposed stratigraphy based on the results of this study and that of Newbery (1991). Numbers in parentheses are references from which age data were obtained: (1) Richards *et al.* (1963); (2) Richards (1966); (3) Page (1983a); (4) Page (1983b); (5) Nisbet *et al.* (1983); (6) Blake *et al.* (1984); (7) Pearson *et al.* (1987).

Thickness estimates in this diagram are mainly from Wilson (1978), Blake *et al.* (1984) and Beardsmore *et al.* (1988). The Maronan Supergroup is here maintained as a separate and older entity, but may be stratigraphically equivalent to the Mary Kathleen, Malbon or Tewinga Groups.


(a)
EASTERN SUCCESSION
Lakeview Dolerite (do 6) 1140 Ma
Burstall, Tommy Creek and Naraku Granites 1400 Ma
Regional metamorphism
Lunch Creek Gabbro (do 4) 1500 Ma
dolerite (do 3) 1510 Ma
MOUNT ALBERT GROUP
White Blow Formation (900)
Deighton Quartzite (2000)
Knapdale Quartzite (2000)
Roxmere Quartzite (1000)
Wimberu and Williams Granites 1540 Ma
MARY KATHLEEN GROUP
Corella Formation (2500)
Mt. Philp Agglomerate (100)
Kuridala Formation (2500)
Staveley Formation (2000)
Marimo Slate (2000)
Answer Slate (700)
Ballara Quartzite (900)
Overhang Jaspilite (500)
dolerite (do 2) 1585 Ma
Hardway and Wonga Granites 1660 Ma
MALBON GROUP
Mitakoodi Quartzite (1600)
Marraba Volcanics (2500)
SOLDIERS CAP GROUP
Toole Creek Volcanics (2000)
Mount Norna Quartzite (2400)
Llewellyn Creek Formation (2200)
BASEMENT SUCCESSION
Wonga Granite 1760 Ma
Ewen and Kalkadoon Granites 1780 Ma
Argylla Formation (2000)
TEWINGA GROUP
Magna Lynn Metabasalt (600)
Leichhardt Metamorphics (4000)
Kalkadoon Granite 1930 Ma?
(b)
WILLIAMS AND NARAKU BATHOLITHS
1460 to 1510 Ma (1,2,5)
(POST-OROGENIC)
MOUNT ALBERT GROUP
3500 m
BURSTALL GRANITE & MAFIC PHASES
1745 +17 -15 Ma (4)
1759± 22 to 1671 Ma (7)
CORELLA FORMATION
2500 m
CORELLA FORMATION
MARIMO SLATE
2000 m
STAVELEY FORMATION
2000 m
1000 m
1720± 7 Ma (3)
DOHERTY FORMATION
1000 m
MARY KATHLEEN GROUP
BALLARA QUARTZITE
1200 m
OVERHANG JASPILITE
500 m
ANSWER SLATE
1000 m
MITAKOODI QUARTZITE
1600 m
MALBON GROUP
MARRABA VOLCANICS
2500 m
BOWLERS HOLE & MAIRINDI GRANITES (6)
ARGYLLA FORMATION
3000 m
ARGYLLA FORMATION
2000 m
TEWINGA GROUP
MAGNA LYNN METABASALT
600 m
TOOLE CK VOLCANICS
MT NORNA QUARTZITE
LLEWELLYN CREEK FORMATION
2000 m
NEW HOPE ARKOSE
1000 m?
TOOLE CREEK VOLCANICS
2000 m
MOUNT NORNA QUARTZITE
2400 m
LLEWELLYN CREEK FORMATION
2200 m
SOLDIERS CAP GROUP
GLEN IDOL SCHIST
4000 m?
GANDRY DAM GNEISS
2000 m?
FULLARTON RIVER GROUP
MARONAN SUPERGROUP
DOUBLE CROSSING METAMORPHICS
1000 m?
GIN CREEK GRANITE
Age unknown
(SYN-OROGENIC)
DUCHESS BELT
MALBON BELT
SELWYN BELT
SOLDIERS CAP BELT

of the Kuridala Formation westward into the Answer Slate, and eastward into (undifferentiated) Soldiers Cap Group metasediments, and therefore correlated it with these units. The second problem is that the internal stratigraphy of the Kuridala Formation was poorly understood. White (1957) interpreted carbonaceous slates to occur at both the base and top of the formation (the Mount Elliott and Hampden Slate Members, respectively), whereas Blake *et al.* (1983) were unprepared to define an internal succession, instead choosing to recognize a number of different lithologic subunits, of indeterminate stratigraphic order. These workers did, however, suggest that carbonaceous slates could all occur at a single stratigraphic level, though they did not confirm this.

The major aims of this part of the study were therefore to investigate:

(i) the internal stratigraphy of the Kuridala Formation.
(ii) the stratigraphic and tectonic relationships between the Kuridala Formation and other units.
(iii) the tectonic evolution of the sedimentary basin(s).

To achieve these aims, 18 weeks of airphoto-controlled, 1:25 000 scale field mapping and sampling were undertaken, in the regions designated in Figure 1.2. Interpretations of the stratigraphic and structural relationships outside these regions are based on published AGSO reports and maps (Blake *et al.*, 1983; Donchak *et al.*, 1983; Kuridala and Selwyn 1:100 000 Geological Special Sheets), and on extrapolation of results from this study. The interpretation of regional stratigraphy also depends partly on interpretations of the regional structure (Chapter Three).

A major result of this work is the recognition that the Kuridala Formation is not a valid stratigraphic unit, but a conglomeration of other defined units (Staveley Formation and Soldiers Cap Group), and one newly recognized unit (the New Hope Arkose). The mapping of Newbery (1990) along the far eastern margin of the Mount Isa Inlier also resulted in the recognition and formal definition of new stratigraphic units, and new interpretations early tectonic evolution of the region (Beardsmore *et al.*, 1988; Appendix A). The revised stratigraphy arising from these studies is presented in Figure 2.1b.

The remainder of this chapter will describe the major rock types in the region, discuss the need for revision of the stratigraphy, and present some interpretations of the tectonostratigraphic development of this part of the Mount Isa Inlier.

2.2 STRATIGRAPHY

The units examined in some detail during this study are the Kuridala Formation, Staveley Formation, Double Crossing Metamorphics, Gin Creek Granite, Williams Batholith, and post-metamorphic dolerites. Descriptions and interpreted stratigraphic relations are presented below. The Kuridala Formation is retained at this point in order that its constituent packages may be discussed. Bear in mind, however, that the bulk of this unit belongs to the Soldiers Cap Group (defined by Derrick *et al.*, 1976e) and newly recognized older units (Appendix A). The reasons for its obsolescence are provided in the discussion (Section 2.3).

2.2.1 Kuridala Formation (now obsolete)

Prelude

Rocks assigned by Carter *et al.* (1961) to the Kuridala Formation occupy almost the entire eastern half of the Kuridala-Selwyn belt (Figure 1.2). Four distinct lithological packages are apparent. These are described below in interpreted stratigraphic order, under the general subheadings: (i) meta-arkose, (ii) psammites and psammopelites, (iii) pelites, quartzites and amphibolites, and (iv) carbonaceous slates and amphibolites. The lithologies within each unit are more varied than the names suggest; their lithological characteristics are summarized in Table 2.1.

TABLE 2.1: Comparison of lithological characteristics of the Kuridala Formation (left-hand column) with relevant constituent formations of the Maronan Supergroup (right-hand column). Descriptions of the latter are derived from Derrick *et al.* (1976e) and Newbery (1990).

CARBONACEOUS SLATES AND AMPHIBOLITES Pale grey to black, variably silicified (± mylonitized) carbonaceous slate, quartz-mica schists and phyllites, quartzite, and amphibolite (meta-dolerite). Less than 200 m thick in the Selwyn to Stuart section; up to 1000 m thick around Kuridala.	***TOOLE CREEK VOLCANICS*** Amphibolites, carbonaceous slates, blue quartzites, laminated scapolitic siltstones, in a sequence up to 2000 m thick.
PELITES, QUARTZITES AND AMPHIBOLITES Clean, even-grained meta-arenites, variably carbonaceous pelitic schists, and amphibolite; meta-arenites are laterally continuous, internally massive, and occur in packages up to 80 m thick or as isolated beds a few metres thick; amphibolite most abundant interbedded with meta-arenite, as lenses (sills?) less than 150 m wide and thousands of metres long; minor banded iron-formation (e.g. Mount Thomas); carbonaceous schists are increasingly abundant up-sequence, and are commonly staurolite-bearing. Sedimentary structures are rare. Sequence is less than 400 m thick in the Selwyn-Stuart section, but up to 1500 m thick around Kuridala.	***MOUNT NORNA QUARTZITE*** Thick-bedded, feldspathic meta-arenites, quartzites, poorly-bedded meta-lutites, and amphibolite; minor marble, calcsilicates, and banded iron-formation. Sequence is up to 2000 m thick.
PSAMMITES AND PSAMMOPELITES Well-bedded, siliciclastic meta-greywackes, meta-arenites and meta-argillites in varying relative proportions; thin- to thick-bedded; good sedimentary structures (e.g. graded bedding, partial to complete Bouma sequences) indicating mass flow transport and deposition. Sequence is up to 2000 m thick throughout the Kuridala-Selwyn-Stuart region.	***LLEWELLYN CREEK FORMATION*** Medium- to thick-bedded, quartz-mica meta-arenites; subordinate argillaceous schists; locally abundant graded bedding, scour-and-fill structures, load-casting, ripple cross-lamination, and partial to complete Bouma sequences. Sequence is up to 2000 m thick.
META-ARKOSE Thick-bedded (up to 2 m), massive, medium- to coarse-grained quartz-rich meta-arkose; minor interbeds of staurolitic schist. Sequence is at least 1000 m thick.	***GLEN IDOL SCHIST*** Thick-bedded quartzofeldspathic meta-arenites, and minor biotite-rich metalutites; abundant quartzofeldspathic segregations and late pegmatite swarms. Sequence is up to 1500 m thick.

Note on terminology

The terms ***psammite***, ***pelite*** and ***psammopelite*** used herein are defined on compositional and textural basis. All refer to metamorphosed sedimentary rocks. Psammites are metamorphosed arenites, which may be quartzofeldspathic, and which generally have high SiO_2 and low FeO and MgO contents. Metamorphism produces little change in the mineralogy and grainsize, although any primary clay matrix component is converted to micas. Pelites are derived from argillaceous sediments, and have high Al_2O_3, K_2O, FeO and MgO contents. Metamorphism produces abundant micas, and other minerals which may develop include andalusite, kyanite, sillimanite, almandine garnet, staurolite and cordierite. Grainsize is determined largely by the grade of metamorphism, and may range from slaty to gneissose. Psammopelites fall into two categories. The first comprises metasediments in which individual beds grade texturally and compositionally from psammitic to pelitic. The most diverse mineral assemblages occur in the pelitic portions, and if porphyroblastic phases have developed, there may be a grainsize inversion from psammitic to pelitic parts of beds. The second category comprises lithologies which are truly mid-way compositionally between psammites and pelites. Compositional grading may or may not be evident.

Meta-arkose *(or New Hope Arkose)*

This crops out in two near-elliptical, relatively high relief pods in fold cores to the south and southeast of Mount Dore (**Poh** - Figure 1.2). It has not been recognized anywhere north of these exposures. The largest pod is about 10 km long and 3 km wide, and the smaller pod, lying 5 km further east, about 1000 by 800 m in size. The unit is mostly a monotonous sequence at least 1000 m thick of pale orange-pink (in freshly-broken sections), thick-bedded (1 to 2 m), internally structureless, medium- to coarse-grained quartzofeldspathic psammite (metamorphosed quartz-rich arkose), with dispersed minor interbeds up to 20 cm thick of strongly foliated staurolite-bearing schist.

Both bodies of meta-arkose pass abruptly, though apparently conformably to the north, east and west into finer-grained, thinner bedded (30 cm or less) more siliciclastic psammites and psammopelites. Faulting along both eastern and western margins is likely. The southern margins of both bodies are truncated by the Yellow Waterhole Granite, and the large pod is intruded on its northeast margin by the Mount Cobalt Granite. Thermal metamorphic assemblages have developed along all contacts with granite. The outcrop patterns suggest the lithology occupies the cores of antiforms, and is therefore older than surrounding units. The stratigraphic base is not exposed.

Psammites and psammopelites *(or Llewellyn Creek Formation)*

These comprise the most voluminous package in the Kuridala Formation, occupying a band up to 16 km wide along the eastern margin of the Kuridala-Selwyn belt, and having a total thickness probably exceeding 2000 m (taking into account tectonic thickening of the sequence). Outcrop tapers towards and beyond Selwyn but expands again in the vicinity of Kuridala (**Pol** - Figure 1.2). Outcrop is generally as low hills and undulating terrain, becoming progressively sparser and lower to the south as it passes beneath Recent alluvial sand, silt and gravel.

Lithologies are predominantly siliciclastic, consisting of psammites, pelites and psammopelites, which vary in their relative proportions in different places. Much of the unit consists of monotonously interbedded fine- to coarse-grained psammite and psammopelite, with lesser pelite, in beds averaging 3 to 30 cm thick. Sedimentary structures are common, including graded bedding, and planar and cross-laminations. Some beds show a range of features interpreted to be the B to D subdivisions of a standard Bouma sequence. Some parts comprise greater than 80 percent thickly bedded (1 to 10 m, averaging about 2 m), commonly amalgamated, internally massive to crudely graded psammites. The (inferred) tops of these beds are laminated in rare instances. All beds are laterally continuous at greater than outcrop scale.

Psammites are moderately to poorly sorted and rounded, and consist mainly of medium- to coarse-grained (occasionally gritty) quartz, with minor feldspar (orthoclase and plagioclase) and rare micaceous lithic fragments. Minor intergranular material is predominantly muscovite and biotite. Textural and compositional maturity is poorest in the coarsest units. Psammopelites and pelites have successively increasing proportions of micas, and are consequently more schistose. True pelites are muscovite-biotite schists, which may contain ellipsoidal porphyroblasts of andalusite up to 10 cm long, and of almandine garnet up to 1 mm in diameter. Donchak *et al.* (1983) sketchily describe this unit in the Kuridala area as a sequence of largely massive metagreywacke, well-bedded meta-arenite and schist, of undisclosed thickness. The essential mineralogy is quartz + muscovite, and other minerals which may be present are biotite, chlorite, microcline, albite, hornblende, opaques, porphyroblastic garnet and poikiloblastic andalusite. The overall sedimentological characteristics of this unit imply mass-flow transport and deposition.

Well-preserved sedimentary structures indicate that this unit youngs predominantly westward for at least 3 km east of the Mort River. Younging evidence is sparse west of the Mort River, but the unit is folded around the F_2 Mort River Synform, and must young eastward away from the New Hope Arkose, which occupies the core of the F_2 New Hope Antiform. Limited data from psammopelites north and west of the meta-arkose suggest westward younging. The psammite-psammopelite sequence is much reduced in apparent thickness west of the meta-arkose, and thick quartz veins are common, suggesting a faulted western boundary with the pelite-quartzite-amphibolite sequence. A similar conclusion was reached by Nisbet *et al.* (1983) on the basis of their observations of a steep magnetic gradient along the contact. No younging information is recorded by Donchak *et al.* (1983) for this unit in the Kuridala region. However, from their regional distribution, and stratigraphic relationships determined from other units, younging can be interpreted to be westward overall, with the unit passing conformably into the younger pelite-quartzite-amphibolite unit (**Pon**).

Pelites, quartzites and amphibolites *(or Mount Norna Quartzite)*

The main mapped exposures of this unit occur in a 400 m wide, north-trending band passing to the west of the meta-arkose, and more extensively in the Kuridala area (**Pon** - Figure 1.2). A small wedge abuts the Yellow Waterhole Granite at Mount Thomas. Here the unit is dominated by a prominent ridge-forming quartzite, which can be traced on the 1:100 000 Selwyn Special Sheet southwards and then eastwards into the eastern part of the Kuridala Formation. Staurolite-bearing rocks and an increase in abundance and thickness of amphibolite bodies were noted in brief traverses across this region, but mapping is currently inadequate to prove the extension of this unit these parts. Lithologies assigned to the same unit have been mapped around Pegmont by Newbery (1990).

This unit is thicker around Kuridala than it is near Selwyn. Donchak *et al.* (1983) do not cite a thickness, but outcrop depicted on the 1:100 000 Kuridala Special Sheet suggests at least 1500 m. In the Selwyn region recognized parcels of this unit rarely exceed 400 m in thickness. Suspected portions towards the eastern side of the Kuridala Formation in the Selwyn area may be thicker.

Constituent lithologies are clean, even grained quartzites, variably carbonaceous pelitic schists, and amphibolite. Quartzites occur as thick, laterally continuous beds, in packages up to 80 m thick, or as isolated lenses a few metres in width and several tens of metres in length within pelitic rocks. Some quartzites to the east of Kuridala contain small amounts of pyrite (Searl, 1952). Amphibolite is so common as to be regarded part of the sequence, and appears to be spatially association with quartzite. It occurs in lenses up to 150 m wide (but generally less) and several kilometres in strike length, and is generally believed to have been intruded as sills (Carter *et al.*, 1961; Donchak *et al.*, 1983; Nisbet *et al.*, 1983; this work). Pelitic schists are generally separated from amphibolites by bands of quartzite (Searl, 1952; Nisbet *et al.*, 1983), and become more carbonaceous approaching the carbonaceous slate-dominated unit. Throughout the Kuridala-Selwyn region the unit is characteristically comparatively iron-rich, with local development of (chemogenic?) banded iron-formation (BIF)(*e.g.* Pegmont, Mount Thomas), and abundant staurolite and garnet in chemically favourable pelitic rocks. These are regarded as diagnostic features of the unit.

Sedimentary structures are generally poorly developed, and younging data consequently rare. Nisbet *et al.* (1983) used a pegmatitic phase along the western margin of the major amphibolite body at Mount Cobalt to interpret concentration of volatiles in the roof zone of the original sill, and hence westward younging. This is consistent with the younging evidence from the psammite-psammopelite sequence to the east. In the Kuridala area, the unit is folded around a major F_2 fold interpreted to be a syncline, the core of which is occupied by carbonaceous slates and amphibolites (Broadhurst, 1936; Honman, 1938; Searl, 1952; Donhchak *et al.*, 1983). This package therefore appears to be conformable both on the psammite-psammopelite units and beneath the carbonaceous slate-amphibolite unit in all areas where contacts are discernible, although in the Mount Cobalt region south of Selwyn faulting parallel to these contacts is prevalent. Quartzites and amphibolites appear to be more common towards the upper contact with carbonaceous slates.

Carbonaceous slates and amphibolites *(or Toole Creek Volcanics)*

The bulk of this unit occupies a narrow band along the western boundary of the Kuridala Formation. AGSO mapping shows it extending to the far southern extremity of Proterozoic outcrop, then northwards again around the eastern boundary of Kuridala Formation, adjacent to the Squirrel Hills Granite. Immediately around Kuridala it occupies the core of a major F_2 syncline, flanked to both sides by the pelite-quartzite-amphibolite unit (**Pot** - Figure 1.2). Relief is generally low, but silicified or otherwise altered rocks form strike ridges with up to 35 m relief. The unit forms distinctively dark toned bands on aerial photographs. The unit is up to 1000 m thick around Kuridala, but around and to the south of Selwyn as far as the Yellow Waterhole Granite this unit is rarely wider than 200 m. Tectonic attenuation is suspected here (Chapter 3). Extensions mapped by the AGSO south and east are probably thicker.

This unit is characterized by pale grey to black, variably silicified carbonaceous slates, quartz-mica schists and phyllites, quartzite and amphibolite. Unequivocal bedding, as laminations generally less than 5 mm thick, is rare in the slaty lithologies, and is not evident in either the phyllites or the quartzite. Quartzite rarely exceeds 10 m in width, and forms a series of prominent, discontinuous, north-south striking ridges in the Selwyn region, invariably along the boundary with the Staveley Formation. It is very fine-grained, probably recrystallized, grey to pale pink-orange, and is generally strongly foliated, parallel to the gross layering. The foliation is defined by pronounced alternating paler and darker layers, each less than 1 millimetre thick, which consist of layers of coarser (0.3 mm) and finer (<0.03 mm), polygonal quartz and intergranular muscovite. Rootless isoclinal folds are commonly developed parallel to this layering, and a strong, down-dip mineral streaking is developed where foliation is most intense (*e.g.* JCU-26856, 29864, 29866). The foliation and lineation are not always well developed, and in places the quartzite can resemble a large vein of massive buck quartz. The quartzite grades into both the quartz-muscovite schists and carbonaceous slates, both of which are also mylonitic, and commonly strongly silicified adjacent to it (*e.g.* JCU-29859). There are no unequivocal sedimentary structures, and the features of the package here are probably largely tectonic. The implications of this are discussed in Chapter 3. Porphyroblastic metamorphic minerals are rarely developed, but chiastolitic andalusite and sericitic spots to 1 mm interpreted to be (retrogressed) cordierite are common in the slates where they abut late tectonic granitoids (Blake *et al.*, 1983; this work).

Thick (tens to hundreds of metres), concordant bodies of amphibolite and metadolerite are abundant around Kuridala, intercalated with the slates, but are only rarely present and much thinner (less than 10 m) to the south of Mount Dore. Early workers interpreted those around Kuridala as basalt flows based on their concordance with bedding, vesicularity on interpreted stratigraphic tops, and apparent soft-sediment deformation in sediments stratigraphically underlying them (Broadhurst, 1938; Searl, 1952). Later workers preferred an intrusive origin, as dolerite sills (Carter *et al.*, 1961; Donchak *et al.*, 1983).

Limited younging evidence in the Kuridala region indicates this unit occupies the core of a synformal syncline (Donchak *et al.*, 1983), and is therefore conformable above the pelite-quartzite-amphibolite unit (**Pon**). No younging evidence was found around or south of Selwyn, but other units to the east young westwards overall, suggesting this unit is younger, and probably conformable. The body of evidence therefore implies this unit is at the top of the Kuridala Formation. Its contact with the adjacent Staveley Formation is tectonic along the entire length (see Chapter Three), and its northern extremities are juxtaposed against the Doherty Formation along the Mount Tracey Fault (Figure 1.2). The consequence of this is that the stratigraphic relationship between the Kuridala Formation and the Mary Kathleen Group is unknown.

2.2.2 Staveley Formation

The Staveley Formation crops out over almost the full length of the Kuridala-Selwyn belt, and its overall distribution is largely as depicted in the 1:100 000 Selwyn and Kuridala Special Sheets. The main revision is the extension of the unit in a strip between the Mount Dore Fault Zone and the Gin Creek Block (Figure 1.2). This area was originally mapped as Staveley Formation unit by Carter *et al.* (1961), but Blake *et al.* (1983) regarded it as Kuridala Formation. Recent mapping supports the former conclusion.

A variety of lithologies comprise the Staveley Formation. Three distinct packages are recognized - (i) metabasalts, (ii) ironstones, and (iii) variably calcareous metaclastic sediments. These may eventually warrant member status.

Metabasalt

A small body of metabasalt was observed by Blake *et al.* (1983). Recent mapping has revealed intense deformation and metasomatism in the lower part of the Staveley Formation, and led to the recognition of extensive belts of metabasalt up to 1000 metres thick immediately to the east of the Gin Creek Block (Switzer, 1987), and in the vicinity of the Limestone Creek prospect (this study; Figure 1.2). In the vicinity of Selwyn, metabasalt crops out as pods up to 6 km long and 1.5 km wide. Patches of actinolite + magnetite rock occur along the eastern margin of the Staveley Formation, adjacent to the Mount Dore Granite. Many pods of amphibolite plotted on the 1:100 000 Kuridala Special Sheet may be prove to be metabasalt. Significant areas of metabasalt may wait unrecognized between Selwyn and Kuridala.

All material interpreted as metabasalt in the Staveley Formation is fine-grained generally dark green, massive amphibolite. Other textural evidence for an extrusive rather than intrusive character includes diffuse, contorted compositional layering (possibly representing original flow features), interbedded sedimentary material in amphibolites in the Selwyn and Limestone Creek areas (Dimo, 1975; this study), and amygdaloidal textures in fine-grained amphibolites to the north and south of Starra (Davidson *et al.*, 1989). In addition, less altered material in the Starra Shear has a major and trace element geochemistry consistent with an Fe-rich tholeiitic basaltic progenitor (Davidson *et al.*, 1989).

In the Starra and Limestone Creek areas, lenticular pods up to tens of metres in size of massive, fine-grained amphibolite are surrounded by anastomosing bands of strongly foliated, but mineralogically similar material. An earlier breccia texture is sometimes observed in these bands, where lenticular fragments up to several centimetres long are flattened parallel to the foliation. The amphibolite in these areas is interpreted to be variably mylonitized metabasalt (Switzer, 1987; this work), and tectonic attenuation may be significant. The peak metamorphic mineral assemblage consists mainly of fine, interlocking actinolite and plagioclase, with minor interstitial quartz, carbonate, sphene and opaques, indicating upper greenschist facies grade. Relatively undeformed metabasalt is coarser (0.2 to 0.3 mm) than highly deformed material (less than 0.05 mm). This prograde metamorphic assemblage is commonly extensively retrogressed to K-feldspar+epidote+biotite+chlorite±tourmaline. This is more prevalent in strongly foliated metabasalt, and is metasomatic in character (see Chapter 3).

Metabasalts in the Starra area are tectonically juxtaposed against, and structurally overlie the higher-grade metamorphic schists and gneisses of the Double Crossing Metamorphics. In the Limestone Creek area they occupy the cores of antiformal structures. In both areas, they are overlain by the fine-grained calcareous metaclastite sequence of the Staveley Formation, within which limited younging evidence suggests it is younger than the metabasalts, which are thus inferred to lie at the base of the Staveley Formation, conformably beneath the clastic sequence.

Ironstones

This unit is sandwiched between the metabasaltic and variably calcareous metasedimentary units of the Staveley Formation. Much of it crops out in two north-south trending ridges greater than 6 km long and up to 40 m high, in the corridor of Staveley Formation between the Gin Creek Block and the Mount Dore Fault Zone. Lithologies of similar character also crop out at Limestone Creek and at SWAN (Figure 1.2).

The sequence varies in thickness up to 100 metres, and is characterized by a series of discontinuous lenticular and sheet-like horizons of massive to schistose quartz-magnetite ± haematite rock, hosted by fine- to medium-grained (≤1 millimetre), variably magnetitic quartz-feldspar- muscovite-biotite-chlorite schists, which also contain narrow bands and lenses of variably magnetic quartz-feldspar- chlorite schist. Fierce debate persists over the origin of this unit, with both synsedimentary (Davidson *et al.*, 1989) and syndeformational (Laing *et al.*, 1988; White, 1989) models proposed. The unit may not deserve stratigraphic status, but is included here for completeness.

Variably-calcareous meta-arenites and meta-lutites

These lithologies comprise the bulk of the Staveley Formation. The southern extremities of this unit crop out in a north-trending band up to 2 km wide, between the

Gin Creek Block and the Kuridala Formation. They expand northwards into a basin up to 12 km wide, then taper to about 2 km width near Kuridala. Relatively minor outliers up to 4 km long and 1 km wide occur east of the main bodies, as outliers folded and faulted into the Kuridala Formation. The stratigraphic thickness probably does not exceed 1500 metres in both the Selwyn and Kuridala areas (Donchak *et al.*, 1983; this work).

The bulk of the unit consists of a sequence of pale yellow-brown, dark grey-green, and dark green-brown, variably calcareous and ferruginous grey siltstone and phyllite, with numerous interbeds of brown siliceous arenite, and minor pyritic siltstone (Donchak *et al.*, 1983; Blake *et al.*, 1983; this work). Bedding is generally well-developed, averaging 1 to 15 mm thick in the lutites, and 10 to 20 cm thick in the arenites. Sedimentary structures are common, and particularly well-developed in arenaceous units. Syndepositional structures include graded beds, low-angle cross-laminations, symmetrical ripples with wavelengths averaging 20 to 30 mm. Many such structures are defined by very thin (<0.1 mm), haematite-rich lamellae. Post-depositional structures include convolute bedding (slump folding), ball-and-pillow structures, and occasional layers containing cubic holes up to 2 mm in diameter, with "hopper" textures, interpreted to have contained halite.

Minor quartz pebble-to-cobble conglomerate crops out as a series of small ridges (up to 150 m long and 15 m wide) about 22 km south of Selwyn (around Grid Ref. 54K VA457965), within 20 metres of the eastern margin of the Staveley Formation. Bedding is generally poorly developed and internally massive, but is occasionally defined by variations in clast abundance, or by lenses of arenite. Rare clast size grading may be observed. Clasts are poorly sorted, sub-angular to sub-rounded, and generally matrix-supported in red-brown, calcareous quartzofeldspathic arenite. Blake *et al.* (1983) observed similar conglomerate at Grid Ref. 54K VB457124.

Bedding becomes obliterated, and phyllitic rocks are abundant around boundaries between the metasediments of the Staveley Formation and other units. Thinly banded to laminated, pink, green, brown and grey, calcsilicate rocks crop out immediately to the west of the Mount Dore granite, and also in the Kuridala area (Blake *et al.*, 1983; Donchak *et al.*, 1983). These consist of actinolite, calcite, epidote, K-feldspar, quartz, mica, diopsidic clinopyroxene and garnet.

All boundaries between the Staveley Formation and other units are strongly sheared, and therefore tectonic, or are not exposed. Sedimentary structures in these metasediments away from these contacts show both westward and eastward younging, with reversals around F_2 folds. Younging directions along the contact with the Maronan Supergroup are inconsistent, and the relative ages are unclear, although the Staveley Formation is conventionally regarded to be the younger unit. The clastic part of the Staveley Formation is interpreted to be conformable on the metabasaltic sub-unit, and conformable beneath the Agate Downs Siltstone (Blake *et al.*, 1983).

2.2.3 Double Crossing Metamorphics (Plm)

The Double Crossing Metamorphics are intimately intermixed with foliated and un-foliated granitoids in a north-trending, roughly elliptical composite body 24 km long, and up to 10 km wide, known as the Gin Creek Block (Figure 1.2). They characteristically crop out as low, heavily weathered hills, surrounded by plains covered in pale red-orange soil.

Blake *et al.* (1983) described this unit as quartzofeldspathic schists, gneisses, minor augen gneiss and amphibolite. Switzer (1987) describes the mineralogy as mainly quartz+microcline+plagioclase+biotite+ muscovite, with minor tourmaline, opaque oxides, rutile and sphene, and rare sillimanite. Feldspars occur in the relatively fine matrix, as poikiloblasts in the augen gneiss, and as vermicular intergrowths with quartz in the hinge zones of minor F_2 folds. He observed a gradation towards the central part of the Gin Creek Block from quartzofeldspathic schist, to augen gneiss, to migmatite, finally into foliated granite (see Gin Creek Granite), and also perceived them to be more quartzofeldspathic in the south, and more phyllosilicate-rich in the north.

The Double Crossing Metamorphics occupy a tectonic inlier, and have not been placed with certainty in the overall stratigraphy. Blake *et al.* (1983) suggest they are correlative with the Mitakoodi Quartzite, Marraba Volcanics and Argylla Formation, or perhaps pre-Argylla Formation basement rocks derived from deeper in the crust, and emplaced during intrusion of the Gin Creek Granite. Leishman (1983) interpreted them as higher-metamorphic-grade equivalents of the Argylla Formation, or of the Answer Slate, which lies to the west of the Double Crossing Metamorphics.

2.2.4 Gin Creek Granite

The Gin Creek Granite has an irregular, and as yet poorly defined outcrop pattern. Blake *et al.* (1983) mapped it as an undifferentiated body intruding the Double Crossing Metamorphics in the Gin Creek Block (Figure 1.2). Both strongly and weakly deformed varieties are present, and Switzer (1987) has constrained the Gin Creek Granite *sensu lato* to include only the strongly deformed material. Weakly to undeformed granite has been assigned to the Belgium Granite (see Williams Batholith). There are two distinct types of foliated granite (Blake *et al.*, 1983; Switzer, 1987). One is a fine- to medium-grained biotite granite. This grades uniformly into and contains abundant inclusions of the Double Crossing Metamorphics. Granite close to the contact with the Staveley Formation consists of fine- to coarse-grained, variably foliated leucogranite, containing quartz, plagioclase, microcline, muscovite and tourmaline. The foliation is parallel to the regional trend, and tourmaline defines a strong down-dip mineral elongation. Geochemical data are sparse, but two specimens of Gin Creek Granite collected by the AGSO reportedly contain 50 ppm Sn and 106 ppm Cu, and the muscovite-bearing granite is peraluminous (Blake *et al.*, 1983).

The Gin Creek Granite has only intruded metasediments of the Double Crossing Metamorphics, prior to or during compressional deformation, and may have been derived by partial melting (anatexis) during metamorphism, though this requires confirmation. It was intruded earlier than the plutons of the Williams Batholith, but may still belong to this phase of magmatism, and therefore be similar to foliated granites such as the Blackeye, Cowie and Maramungee Granites, found along the far eastern margin of the Mount Isa Inlier. Alternatively, it may relate to one of the earlier plutonic episodes of Wyborn *et al.* (1988).

2.2.5 Williams Batholith

The Williams Batholith crops out over a total area of 2100 km^2 (Wyborn *et al.*, 1988), and all was originally collectively mapped as Williams Granite (Carter *et al.*, 1961; Joplin and Walker, 1961; Carter and Öpik, 1963). The AGSO subsequently subdivided the granite into several separate plutons. Six of these crop out in the Kuridala-Selwyn region - the Mount Dore, Yellow Waterhole, Squirrel Hills, Mount Cobalt, Wimberu and Belgium Granites. These names were provided by Blake *et al.* (1983), except for the Belgium Granite (new name).

The ***Mount Dore Granite*** is a medium-grained, weakly to unfoliated, quartz + K-feldspar + plagioclase ± biotite ± hornblende granite, and is largely non-porphyritic, although in parts the feldspar is slightly megacrystic. The ***Yellow Waterhole Granite*** consists predominantly of medium- to coarse-grained, non-porphyritic to porphyritic hornblende-biotite or biotite granite. Accessory magnetite is abundant, yielding a relatively high magnetic susceptibility ($K = 2000\text{-}4000 \times 10^{-5}$ S.I. units). The ***Squirrel Hills Granite*** is a large, composite body, consisting mostly of pink, medium- to coarse-grained, coarsely porphyritic, hornblende or biotite adamellite. Its northern extremity is non-porphyritic. Also present are minor monzonite, granodiorite and porphyritic microgranite (Blake *et al.*, 1983). Accessory minerals include apatite, zircon, sphene and magnetite. The ***Mount Cobalt Granite*** is a medium-grained biotite granite. The biotite is altered to sericite in places, minor accessory carbonate occurs as infill along fractures, and accessory magnetite accounts for up to 5% of the rock. The ***Wimberu Granite*** is mainly pink to brown porphyritic (plagioclase phyric) and non-porphyritic, coarse-grained granite and granodiorite, containing biotite or hornblende, or both, and accessory sphene and opaques. The coarse granite is cut by fine, non-porphyritic biotite granite with accessory sphene, pyrite, chalcopyrite, magnetite and local hornblende

(Donchak *et al.* (1983). The ***Belgium Granite*** (named after the nearby Belgium Mine, about nine kilometres north-northwest of Mount Dore) is here proposed for a collection of small (<1.5 km) stocks intruding the northern part of the Gin Creek Block. These consist of non-foliated, locally porphyritic (K-feldspar) biotite- or tourmaline-bearing granite which is texturally more akin to the Mount Dore Granite to the east than the foliated Gin Creek Granite.

Geochemically, the Williams Batholith consists largely of metaluminous I-type granitoids, with greater diversity within and between plutons than for other batholiths in the Mount Isa Inlier. Na_2O, Nb, Sr and P_2O_5 are higher, but K_2O, Cu, Pb and Zn lower than in older granites. In the northern part of the Kuridala-Selwyn region, plutons invade calc-silicates or evaporites of the Staveley or Doherty Formations, and there have noticeably higher Fe_2O_3/FeO and Na_2O, and lower K_2O, and Ba, reflected by mineralogies containing albite, clinopyroxene, red-brown euhedral sphene, and haematite (instead of magnetite)(Wyborn *et al.*, 1988).

Plutons of the Williams Batholith intrude all metasedimentary units in the Kuridala-Selwyn region. Contact metamorphic aureoles are generally less than a few hundred metres wide, depending on the size of the pluton in question. Absolute ages are known only for the Yellow Waterhole, Mount Dore and Wimberu Granites. Richards *et al.* (1963) determined minimum biotite K-Ar ages of 1465 Ma for the Yellow Waterhole Granite, and 1439 Ma for the Wimberu Granite (both dates recalculated by Wyborn *et al.* (1988) using updated constants). The Wimberu and Mount Dore Granites have Rb-Sr whole rock ages of 1498 Ma (Richards, 1966) and 1509±22 Ma (Nisbet *et al.*, 1983), respectively. These are unlikely to be the true ages of the granites, as Rb-Sr and K-Ar systematics of rocks are notoriously susceptible to resetting by hydrothermal leaching, during even low-grade metamorphism and associated deformation events (Page, 1978; Page and Bell, 1986). The U-Pb zircon system is unaffected by metamorphism, at least in the Mount Isa Inlier (Page, 1978), and Wyborn *et al.* (1988) obtained ages of 1560^{+110}_{-60} Ma and 1480±28 Ma for the Wimberu and Yellow Waterhole Granites, respectively, using this technique. They obtained a U-Pb zircon age of 1508±70 for the Naraku Batholith to the north of

Cloncurry, which is similar to the Williams Batholith.

Structural evidence indicates that all major plutons were intruded after the main (D_2) deformation event, since they clearly cut across D_2 structures. They are noticeably foliated near major NNW-SSE or NNE-SSW shear zones (Wyborn *et al.*, 1988; this study), interpreted to be D_3 structures. D_3 in the Mount Isa area has an age of 1510±13 Ma (Page and Bell, 1986), which corresponds closely to the Rb-Sr whole rock ages for the Mount Dore and Wimberu Granites, and it therefore seems likely that D_3 was responsible for the resetting of the Rb-Sr clock. The western margins of the Mount Dore and Yellow Waterhole Granites are bounded by east-dipping reverse faults of D_3 or younger age (the Mount Dore Fault Zone; Figure 1.2). The maximum age of the granites in the Kuridala-Selwyn region is therefore earlier than 1510 Ma, but later than 1544 Ma (the age of D_2; Page and Bell, 1986), assuming deformation was synchronous across the Mount Isa Inlier. Intrusion probably persisted beyond the D_3 event. These age brackets are consistent with the U-Pb zircon geochronometry.

2.2.6 Dolerite

Several unmetamorphosed dolerite dykes intrude the Soldiers Cap Group and Staveley Formation, and are more common in the northern part of the Kuridala-Selwyn belt. They are distinct from amphibolites in their outcrop character and colour, occurring mainly as large (up to 1 metre), pale yellow-brown or green, spheroidal boulders, in linear depressions up to 50 metres wide and hundreds to thousands of metres long. Amphibolites tend to have a more angular weathering pattern, and be darker green to black. Fresh dolerite is greenish-black. Primary ophitic textures are well-preserved. Euhedral, interlocking plagioclase laths up to 1.5-2 mm long can comprise up to 60% of the rock, and are commonly nearly completely altered to clays. Interstitial clinopyroxene forms most of the remainder of the rock, and minor anhedral Fe-oxides and interstitial, micrographic quartz may also be observed.

Dolerite dykes cut across both metasedimentary units and Williams Batholith plutons (Blake *et al.*, 1983; Donchak *et al.*, 1983). They therefore post-date deformation and regional metamorphism. Blake *et al.* (1983) suggest this lithology may be related to the Lakeview Dolerite mapped on the BMR 1:100 000 Mary Kathleen and Marraba Sheets (6856 and 6956, respectively). These bodies have Rb-Sr whole rock ages of 1116±12 Ma (Derrick *et al.*, 1978; Page, 1983b).

2.3 DISCUSSION

2.3.1 Obsolescence of the Kuridala Formation

The internal stratigraphy within the Kuridala Formation has been resolved through a combination of regional mapping over the whole Kuridala-Selwyn region by past workers (Honman, 1938; Broadhurst, 1938; Searl, 1952; Carter *et al.*, 1961; Blake *et al.*, 1983; Donchak *et al.*, 1983) with this latest systematic mapping in the Selwyn region. Four lithologically distinct and conformable packages are recognized in the Kuridala Formation. These would ordinarily be given member status, but observations from further afield have led to the conclusion that the Kuridala Formation is actually an agglomeration of previously defined or newly recognized units having formation status, and is not a valid stratigraphic entity,

A 1986 field party, of which I was a member, examined a stratigraphic section across the central part of the Soldiers Cap Group (upper part of the Llewellyn Creek Formation, and nearly the entire thickness of Mount Norna Quartzite; GR 7056-675875 to 7056-705888), approximately one kilometre to the north of the type sections defined by Derrick *et al.* (1976e). Very close similarities between the constituent formations of the Soldiers Cap Group and rock types in the Kuridala Formation were noted during this traverse (Table 2.1).

The psammite-psammopelite sequence throughout the Kuridala-Selwyn region is indistinguishable from type Llewellyn Creek Formation, and the two overlying packages in the Kuridala Formation show many elements similar to the Mount Norna Quartzite and Toole Creek Volcanics. Similarities are actually so remarkable in the Kuridala area that these packages of rocks assigned to the Kuridala Formation are considered to be extensions of the Soldiers Cap Group. The similarity of Kuridala Formation rocks to the Soldiers Cap Group (then known as the Soldiers Cap series) was recognized over fifty years ago (Honman, 1938), but Carter *et al.* (1961) apparently arbitrarily chose to assign the former to a separate unit. Kuridala Formation lithologies above the psammite-psammopelite package in the Selwyn region are similar to only parts of the Mount Norna Quartzite and Toole Creek Volcanics, and are much reduced in thickness. Differences are attributed to tectonic attenuation during the complex deformation history (see Chapter 3).

The corridor of metasediments between the Gin Creek Block and Mount Dore Fault Zone was consigned to the Kuridala Formation by Blake *et al.* (1983), although Carter *et al.* (1961) recognized it as an extension of the Staveley Formation. Lithologies in this belt are more consistent with the former interpretation, and are herein reassigned to the Staveley Formation.

The only package for which there is no previously defined stratigraphic equivalent in the Kuridala-Selwyn belt is the meta-arkose. This is interpreted to be conformably beneath the Llewellyn Creek Formation. The base of the Llewellyn Creek Formation is not exposed in the type area, so the meta-arkose is therefore older than defined Soldiers Cap Group metasediments. It is of sufficient extent to deserve formation status, and is hereafter referred to as the New Hope Arkose. A formal definition is given in Appendix A.

There are therefore no units unique to the Kuridala Formation. The Soldiers Cap Group has priority over the Kuridala Formation terms of stratigraphic rank, and it is recommended that the latter be noted as obsolete in the stratigraphic register.

2.3.2 Regional stratigraphic relationships and absolute ages?

The Soldiers Cap Group has been identified in the Kuridala-Selwyn region (this work), and in the previously undifferentiated unit in the Soldiers Cap belt along the eastern margin of the Mount Isa Inlier (Newbery, 1990). Its total thickness is about 6000 m (Derrick *et al.*, 1976e). Two previously undifferentiated quartzofeldspathic units with a total thickness of at least 5000 m (the Glen Idol Schist and Gandry Dam Gneiss) occur conformably beneath the Soldiers Cap Group (Newbery, 1990). The newly recognized New Hope Arkose is similar lithologically and in stratigraphic position to the Glen Idol Schist (Table 2.1), and is probably correlative. The quartzofeldspathic units are of generally higher metamorphic grade and sufficiently different lithologic character compared to the Soldiers Cap Group that they are assigned to the separate Fullarton River Group (Beardsmore *et al.*, 1988; Appendix A; based on Newbery (1990) and this work).

There is thus an apparently conformable sequence up to 11 000 metres thick of quartzofeldspathic metasediments (Fullarton River Group), generally maturing texturally and compositionally up-sequence, and accompanied by increasing mafic volcanism (Soldiers Cap Group). This sequence occupies a block lithologically and tectonically distinct from other major units in the region, and is defined as the Maronan Supergroup (Beardsmore *et al.*, 1988; Appendix A).

The Maronan Supergroup is nowhere seen in stratigraphical contact with other units in the Kuridala-Selwyn region; all boundaries are tectonic. No absolute age has yet been determined for the Maronan Supergroup, and there is only one datum from metasediments for the entire Cloncurry fold belt, from the Doherty Formation (see below). Age estimates are therefore poorly constrained, and discussion of stratigraphic relations is limited to considering interpreted relative ages with respect to adjacent units for which there is geochronologic information.

The oldest possible exposed sediment source for the lower Maronan Supergroup comprises the predominantly subaerial felsic volcanics and gneisses of the

Leichhardt Volcanics, lying even after deformation at least 100 km to the west. These have U-Pb zircon ages of 1875 to 1865 Ma (Page, 1978; 1983a). However, the sediment provenance for the Maronan Supergroup is not constrained, and the general coarsening of units towards the east and southeast suggest a source in this direction.

The adjacent Doherty Formation has been assigned a U-Pb zircon age from a contained rhyolite lens of 1720±7 Ma (Page, 1983a). This body may in fact be an intrusive body, providing only a minimum age for the host metasediments. In addition, the contact between this unit and the Maronan Supergroup in the Kuridala-Selwyn region is along the Mount Tracey Fault, and along its eastern contact with the Maronan Supergroup is marked by major shear zones (Newbery, 1990).

The Soldiers Cap Group has been correlated with the Malbon and Haslingden Groups in the central and western Mount Isa Inlier, apparently on the basis of lithological similarity (Derrick *et al.*, 1976e). These latter units have maximum ages of about 1810 Ma (Page, 1983a). It has been correlated with the Malbon and Mary Kathleen Groups in the eastern Mount Isa Inlier (Blake *et al.*, 1983), which are constrained to have been deposited between about 1780 and 1740 Ma (Page, 1983a,b).

In reality, then, there are presently no constraints on the absolute age of the Maronan Supergroup, nor on its stratigraphic relationship to other units. Hope exists, however, that the recently initiated joint geochronological programme between James Cook University and the AGSO will remove some of the stratigraphic mysteries.

2.3.3 Palaeodepositional environments

The two main metasedimentary units of concern to this study are the Maronan Supergroup and the Staveley Formation. Understanding sedimentary basin tectonics requires knowledge of the nature and evolution of depositional environments throughout the history of the basin. Palaeodepositional interpretations presented herein are based on the work of Newbery (1990, 1991) and this study.

The estimated minimum thickness of the Maronan Supergroup is 5500 m in the Kuridala-Selwyn region, where it is tectonically thinned, and 11 000 m in the Soldiers Cap belt. Neither its base nor top are exposed. Metasediments comprising this unit generally become both texturally and compositionally more mature up-sequence.

The Fullarton River Group is predominantly coarse, thickly-bedded, massive meta-arkose and lesser pelite, with minor amphibolite, iron formation and calc-silicate rocks towards the base of the exposed section. Coarse, internally massive quartzofeldspathic metasediments are tentatively interpreted to have been derived from a texturally and compositionally immature source (possibly acid volcanics) and deposited from mass-flow turbidity currents in a subsiding, shallow to moderately deepwater environment.

The transition into the Soldiers Cap Group is marked by a reduction or hiatus in volcanism, and deposition the Llewellyn Creek Formation as thickly-to-thinly bedded, submature siliciclastic sediments with well-developed turbidity and traction current structures (partial to complete Bouma sequences). These indicate mass-flow transportation into a continually deepening basin distal from the sediment source (Llewellyn Creek Formation).

Metasediments of the Mount Norna Quartzite initially continue the upward-fining and maturing trend, being represented by thinly-bedded psammites, psammopelites and an increasing abundance of pelites. Minor iron-formation and associated sediments occur in several horizons throughout the sequence. Towards the top of this unit medium to thickly bedded, massive quartzites and spatially associated thick, concordant amphibolite bodies become more common interbedded with the finer metasediments. This local upward coarsening may indicate progradation of submarine fans across the region. Amphibolites may be basaltic flows or metadolerite sills. If this mafic igneous activity is broadly synchronous with sedimentation, it may help explain the change in pattern, and also the fact that the Mount Norna Quartzite is notably enriched in iron and basemetals compared to older units.

The finely laminated pelites and carbonaceous slates of the Toole Creek Volcanics show no tractional structures, and indicate pelagic sedimentation in a quiet, anoxic, environment. Amphibolites are common, as bedding-parallel flows or sills, and banded iron-formation is a minor but distinctive component. These features suggest a stable, deep to shallow basin, subject to extensive basaltic igneous activity.

The nearest possible provenance area for Maronan Supergroup sediments in the Selwyn Region is the Argylla Formation, 25 to 30 km to the north-west (this distance would have been greater prior to deformation). This consists of felsic granofels and gneiss, interpreted as metamorphosed felsic volcanics (rhyolites, ignimbrites and tuffs) and associated quartzo-feldspathic metasediments (Blake *et al.*, 1983). Thickening and coarsening of the supergroup towards the east and southeast implies, however, that the sediment source, and hence crystalline Precambrian continental basement, also lay in this direction.

The Staveley Formation can be broadly subdivided into a lower basaltic member and an overlying, variably calcareous, quartzofeldspathic (± haematite), generally fine clastic member. The lower member indicates an early period of mafic volcanism, and sedimentary structures in the upper member indicate either a sub- to inter-tidal marine, or shallow, saline, intracontinental basin environment. This interpretation is supported by the presence of occasional evaporitic horizons. The quartz pebble/cobble conglomerate lenses are interpreted as fluviatile or alluvial fan deposits marking the points of discharge of river-systems into the basin. The post-depositional ball-and-pillow structures indicate progressive post-depositional loading, suggesting continuing basin subsidence. The ironstones in their present form are interpreted by Switzer (1987) and Laing *et al.* (1988) as tectonic rather than sedimentary in origin, having developed at the base of the metasediments where shearing between upper and lower members occurred. Iron was probably derived from the abundant detrital haematite in the sediments, but minor volcanogenic iron-formation may have been locally abundant.

2.3.4 The tectonostratigraphic evolution of the Kuridala-Selwyn region

Deposition of Maronan Supergroup sediments occurred over an extensive area, medially distant from a volcanically active source. Early, rapid erosion produced coarse (but not conglomeratic), poorly sorted volcaniclastics. Provenance areas became more distal with basin evolution, and the overall trend of sedimentation was towards greater textural and compositional maturity up-sequence. Palaeodepositional indicators demonstrate initial deepening of the basin, followed by stabilization and perhaps eventual gradual shallowing. The Staveley Formation consists of mafic volcanics and shallow water to emergent shoreline facies deposited in a slowly subsiding, generally shallow basin.

Tectonic models for sedimentation in the Mount Isa Inlier have evolved with improved understanding of the distribution and nature of, and relationships between different units. Glikson *et al.* (1976) proposed the existence of the ensialic, fault-bound Leichhardt River Fault Trough (LRFT) to explain sedimentation in the western Mount Isa Inlier. Volcanics and sediments in the central and eastern Mount Isa Inlier were interpreted using very limited geochemical data to have been deposited at a convergent plate margin (Glikson *et al.*, 1976; Wilson, 1978). Derrick (1982) first suggested that sedimentation in the LRFT was in a zone of ensialic or continental margin rifting. A more detailed examination of all available evidence led Wyborn and Blake (1982) to propose ensialic rifting for the entire Mount Isa Inlier. Using a general model for rift basin evolution proposed by McKenzie (1978), Blake (1987) recognized two major episodes of rifting in the western Mount Isa Inlier, and further assigned metasediments and volcanics to active rifting, and post-rift sag phases of basin evolution.

The sedimentological evidence from the Maronan Supergroup, and its overall similarity to the sedimentary successions in the rift cycles recognized by Blake (1987), indicate that the former is also a cycle of rift sedimentation. The features of the Staveley Formation are more characteristic of sag-phase sedimentation. These conclusions are more fully explored in Beardsmore *et al.* (1988).

Rifting is interpreted to have been totally ensialic, without the formation of oceanic crust. Basic volcanism is, however, important in the later stages of the rift cycle. Its increasing prevalence may reflect significant underplating of basic material to the base of the crust at this time. Wyborn *et al.* (1988) recognized several episodes of crustal underplating. Basic **volcanics** within them could therefore only be associated with one of these events. Underplating may be intimately related to the initiation of rifting and subsequent basin evolution. Rapid thinning of crust and lithosphere during rift may cause or be caused by adiabatic rise and partial melting of aesthenosphere. In the case of the Kuridala-Selwyn region, however, underplating occurred well after rift initiation. The effect of the crustal thickening was therefore likely to cause initial isostatic uplift and subsequent shallowing of the basin, a feature consistent with the sedimentology.

2.4 CONCLUSIONS

The Kuridala Formation of Carter *et al.* (1961) is a conglomeration of previously defined or newly recognized units, and the name is therefore obsolete. Three of the four distinct, conformable packages are so similar to the constituent formations of the Soldiers Cap Group that they are regarded as extensions of the latter. The remaining, older unit (the newly named New Hope Arkose) has no recognized correlatives in the type Soldiers Cap Group, but is interpreted to correlate with newly recognized units in the Soldiers Cap belt (Glen Idol Schist and Gandry Dam Gneiss; Beardsmore *et al.*, 1988; Newbery, 1990; Appendix A). These three predominantly thick-bedded, clastic, quartzofeldspathic metasedimentary units collectively comprise the Fullarton River Group. The Fullarton River and Soldiers Cap Groups are conformable and together comprise the Maronan Supergroup.

The absolute age of the Maronan Supergroup and its stratigraphic relationship to other units are presently unconstrained. It may be older than the Staveley Formation, but all present boundaries are tectonic. The Gin Creek Block is also tectonically juxtaposed against the Staveley Formation. The pattern of sedimentation is best explained by an ensialic rift model, which is consistent with interpretations for other parts of the Mount Isa Inlier. The Maronan Supergroup represents a near-complete sequence of rift sedimentation. Rock types generally mature compositionally and texturally up-sequence, and reflect initial rapid deepening of a riftogenic basin, and later basin widening and shallowing. The Staveley Formation consists of basic volcanics and shallow water sedimentary facies, interpreted to have been deposited during an episode of post-rifting thermal relaxation of the lithosphere (Beardsmore *et al.*, 1988). The Maronan Supergroup and Staveley Formation may have been deposited during the same rift-sag cycle in the same or separate basins, or in different rift-sag cycles.

The Williams Batholith is a collection of largely late tectonic plutons intruded into all metasedimentary units in the Kuridala-Selwyn region between 1490 and 1560 Ma (Wyborn *et al.*, 1988).