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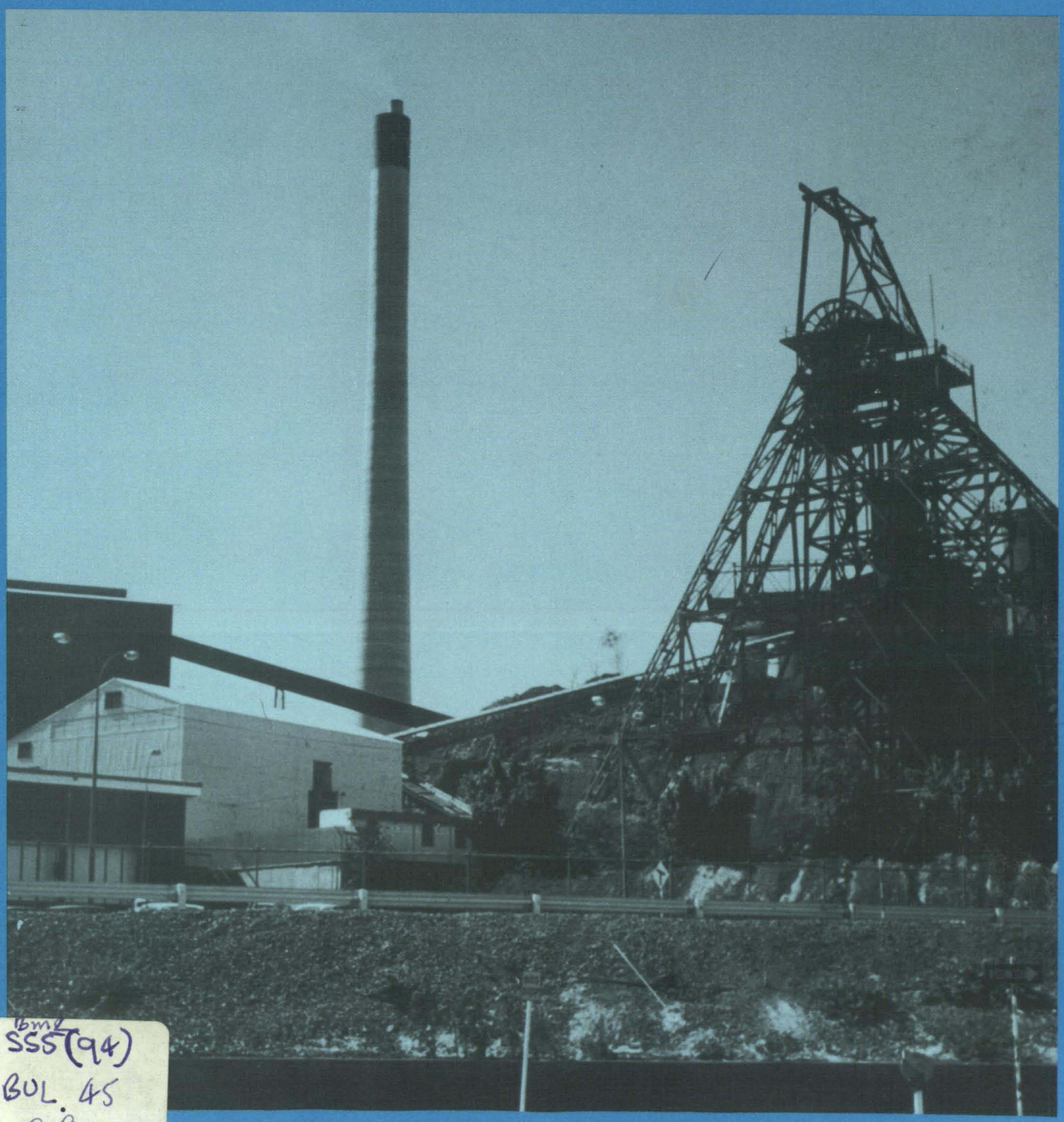
D. H. Blake



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BULLETIN 225

Geology of the Mount Isa Inlier and environs, Queensland and Northern Territory

D. H. BLAKE

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Cover: Mount Isa mine—with 270 m-high concrete stack for the lead smelter, completed in 1978, and the head-frame for the now disused No. 2 shaft. Photograph taken in July 1979. (M 2694/50)

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MAP

Geology of the Mt Isa Inlier and environs (1:500 000 scale)

ABSTRACT

Geological mapping of the Mount Isa Inlier and environs by the Bureau of Mineral Resources and Geological Survey of Queensland from 1969 to 1980 resulted in the production of the 1:100 000 maps which form the basis for the accompanying 1:500 000 geological map.

Three broad tectonic divisions are distinguished within the Mount Isa Inlier: the Western Fold Belt, Kalkadoon–Leichhardt Belt, and Eastern Fold Belt. These are formed of early and middle Proterozoic sedimentary and volcanic rocks many thousands of metres thick, which are assigned to four major sequences, and numerous igneous intrusions. Correlatives to the northwest are exposed within and around the younger Proterozoic South Nicholson Basin and along the Murphy Tectonic Ridge.

The oldest sequence in the region, designated basement, was deformed and regionally metamorphosed, in places forming migmatite, before about 1875 Ma. The three younger sequences are cover sequence 1 (1875–1850 Ma), consisting mainly of subaerial felsic volcanics, and cover sequences 2 (mostly 1790–1760 Ma) and 3 (mostly 1680–1670 Ma), comprising felsic and mafic volcanics and predominantly shallow-water sediments. These sequences are intruded by I-type granites isotopically dated (U–Pb zircon) at around 1860 Ma, 1840 Ma, 1820 Ma, 1800 Ma, 1720–1740 Ma, 1700 Ma, 1670 Ma, and 1500 Ma. Mafic intrusions, ranging in age from pre-1860 Ma to about 1100 Ma, form dykes, sills, and pod-like bodies, and also net-veined complexes with granite.

The cover sequences were mildly to strongly deformed and regionally metamorphosed up to upper amphibolite facies between about 1620 and 1550 Ma. The deformation included thrusting, faulting, and open to tight upright folding. Major displacements have taken place subsequently along faults trending between northwest and northeast.

The igneous rocks are markedly bimodal in composition. Four major chemically distinctive suites of felsic volcanics are identified, the oldest of which (cover sequence 1) is cogenetic with extensive granites. Most of the mafic igneous rocks are similar in chemistry to continental tholeiites.

The Mount Isa Inlier contains major deposits of copper, lead, zinc and silver, and significant deposits of gold, uranium and cobalt; it has also produced minor amounts of manganese, cadmium, bismuth, tungsten, beryl, and mica. Most copper occurs in brecciated sediment-hosted deposits within the Western Fold Belt, but there are also numerous small shear and fault-controlled vein copper deposits to the east; most of the gold production has come as a by-product from these veins. Large stratiform lead–zinc–silver ores are hosted in shales, such as at Mount Isa mine.

Geochemical, geographical, sedimentological and geophysical evidence favours an intracratonic tectonic setting for the Mount Isa Inlier and environs during the early and middle Proterozoic. Since about 1500 Ma, the region has been part of an essentially stable tectonic unit.

INTRODUCTION

This Bulletin and accompanying 1:500 000 geological map summarise the results of the 1:100 000 geological survey of the Mount Isa Inlier and environs (Fig. 1) carried out from 1969 to 1980 by the Bureau of Mineral Resources and Geological Survey of Queensland. (More detailed accounts of the geology are given in reports, maps and papers referred to in the text.)

The Mount Isa Inlier is an area of exposed early and middle Proterozoic rocks covering more than 50 000 km^2 in northwest Queensland. It is bounded by the younger Proterozoic South Nicholson Basin to the northwest, the Palaeozoic Georgina Basin to the west and south, the Mesozoic Eromanga Basin to the south and southeast, and the Mesozoic Carpentaria Basin to the northeast (Fig. 4). The rocks of the Mount Isa Inlier extend for considerable distances in the subsurface, as indicated by gravity and aeromagnetic data (Fig. 2). They are also exposed within the South Nicholson Basin and along the Murphy Tectonic Ridge to the northwest (partly in the Northern Territory) as well as west of the area covered by the 1:500 000 geological map accompanying this bulletin.

The area described is located between latitudes 17°30′S and 22°07′S, and longitudes 137°11′E and 141°00′E. It is semi-arid, and has a tropical monsoonal climate with a hot wet season from October to March and a mild to warm dry season from April to September. The maximum elevation is about 550 m above sea level near Mount Guide in the southwest, and the minimum is about 60 m above sea level in the northeast. The local relief is generally less than 100 m. A low divide in the south separates streams draining north to the Gulf of Carpentaria from southerly flowing streams of the Georgina–Diamantina inland drainage system. Outcrops of Proterozoic rocks typically have a sparse cover of shrubs, low trees, and spinifex.

The main population centres are Mount Isa (23 679 in 1981) and Cloncurry (1961 in 1981). A few small townships in the southern half of the area and station homesteads are the only other permanent settlements. Main industries are mining at Mount Isa and cattle raising on unimproved natural pastures.

Geological investigations

The Mount Isa Inlier and adjacent parts of northwestern Queensland were first mapped systematically by a joint Bureau of Mineral Resources (BMR)/ Geological Survey of Queensland (GSQ) survey in the early 1950s. The results of this broad reconnaissance were published as 4 miles to 1 inch geological maps (1:253 440) with accompanying explanatory notes, and as BMR Bulletin 51 (Carter & others, 1961), which includes the 1:253 440 geological maps as well as a 10 miles to 1 inch map (1:506 880). The Northern Territory parts of the area covered by the present Bulletin were mapped by the BMR in 1959 (Mount Drummond 1:250 000 Sheet area) and 1961 (Calvert Hills 1:250 000 Sheet area). References for the explanatory notes and accompanying maps are listed in Table 1.

A more detailed geological survey of the Mount Isa Inlier and environs was begun by BMR and GSQ in 1969 and largely completed by 1980. This survey has resulted in the publication of the 1:100 000 geological maps listed in Table 2. In addition, three 1:250 000 geological maps based on the 1:100 000 maps have been produced: one of the Duchess–Urandangi region, which accompanies BMR Bulletin 219 (Blake & others, 1984), and the others of the Cloncurry and Lawn Hill standard 1:250 000 Sheet areas (GSQ, 1983a, 1983b). The index to the published geological maps is shown in Fig. 3 and on the margin of the accompanying 1:500 000 map.

TABLE 1. STANDARD 1:253 440 (PRE-1962) AND 1:250 000 (POST-1962)-SCALE GEOLOGICAL MAPS COVERING THE MOUNT ISA INLIER AND ENVIRONS

Standard Map Sheet	*State*	*References*
Boulia	Qld.	Casey (1968)
Calvert Hills	N.T.	Roberts & others (1963)
Camooweal	Qld.	BMR (1961)
Cloncurry	Qld.	Carter (1959), GSQ (1983a)
Dobbyn	Qld.	Carter (1959), Smart (1973)
Donors Hill	Qld.	Ingram (1973)
Duchess[1]	Qld.	Carter & Öpik (1963)
Glenormiston	Qld.	Reynolds (1965)
Lawn Hill	Qld.	Carter & Öpik (1961), GSQ (1983b)
Mount Drummond	N.T.	Smith & Roberts (1963)
Mount Isa	Qld.	Öpik & others (1961)
Urandangi	Qld.	Noakes & others (1959)
Westmoreland	Qld.	Carter (1959), Grimes & Sweet (1979)

1. Scale 1:253 440.

Geologists who have taken part in the 1:100 000 mapping program are listed in Tables 3 and 4. A total of 19 geologists from BMR, five from GSQ and two from Mount Isa Mines (MIM) have been involved in the work. In conjunction with the mapping, geochronological studies have been undertaken by R. W. Page (BMR). Geochemical investigations have been carried out by geologists engaged in the survey and also, since 1978, by L. A. I. Wyborn (BMR).

The 1:500 000 geological map

The accompanying 1:500 000 geological map is based mainly on the recently published 1:100 000 maps (Table 2) and the 1:250 000 maps of Duchess- Urandangi region (Blake & others, 1984), Cloncurry (2nd edition; GSQ, 1983a) and Lawn Hill (2nd edition; GSQ, 1983b). Where the Precambrian outcrops extend into the Glenormiston and Boulia 1:250 000 Sheet areas in the south and the Donors Hills 1:250 000 Sheet area in the northeast, their boundaries have been photo-interpreted from 1:80 000-scale RC9 black and white aerial photographs. Boundaries of Proterozoic outcrops not covered by 1:100 000 geological maps in the northwest are taken from the Mount Drummond and Calvert Hills 1st edition 1:250 000 geological maps. Some small areas in the southern half of the Mount Isa Inlier (in DAJARRA[1], DUCHESS REGION, and MARY KATHLEEN) have been re-interpreted from field and laboratory data obtained by the author in 1983 and 1984. Minor changes have also been made to the geology shown on some of the other 1:100 000 maps. These changes are discussed in the appropriate section in this Bulletin.

Stratigraphic nomenclature

All Proterozoic stratigraphic and intrusive rock units on published maps covering the Mount Isa Inlier and environs are listed alphabetically in Appendix 1, which includes distribution, reference to definition, dominant lithology, stratigraphic or intrusive association, isotopic age (if available), and synonyms (where appropriate). The named units have been defined in various publications, mainly by BMR and GSQ authors, and are mostly in accord with the International Stratigraphic Guide of Hedberg (1976).

Terminology

Geological terms used are defined in the AGI Glossary of Geology (2nd Edition; Bates & Jackson, 1980). Sandstone descriptions are based largely on field observations, rather than microscopic examination (see Table 5 for sandstone

[1] Names of 1:100 000 geological maps are printed in capital letters.

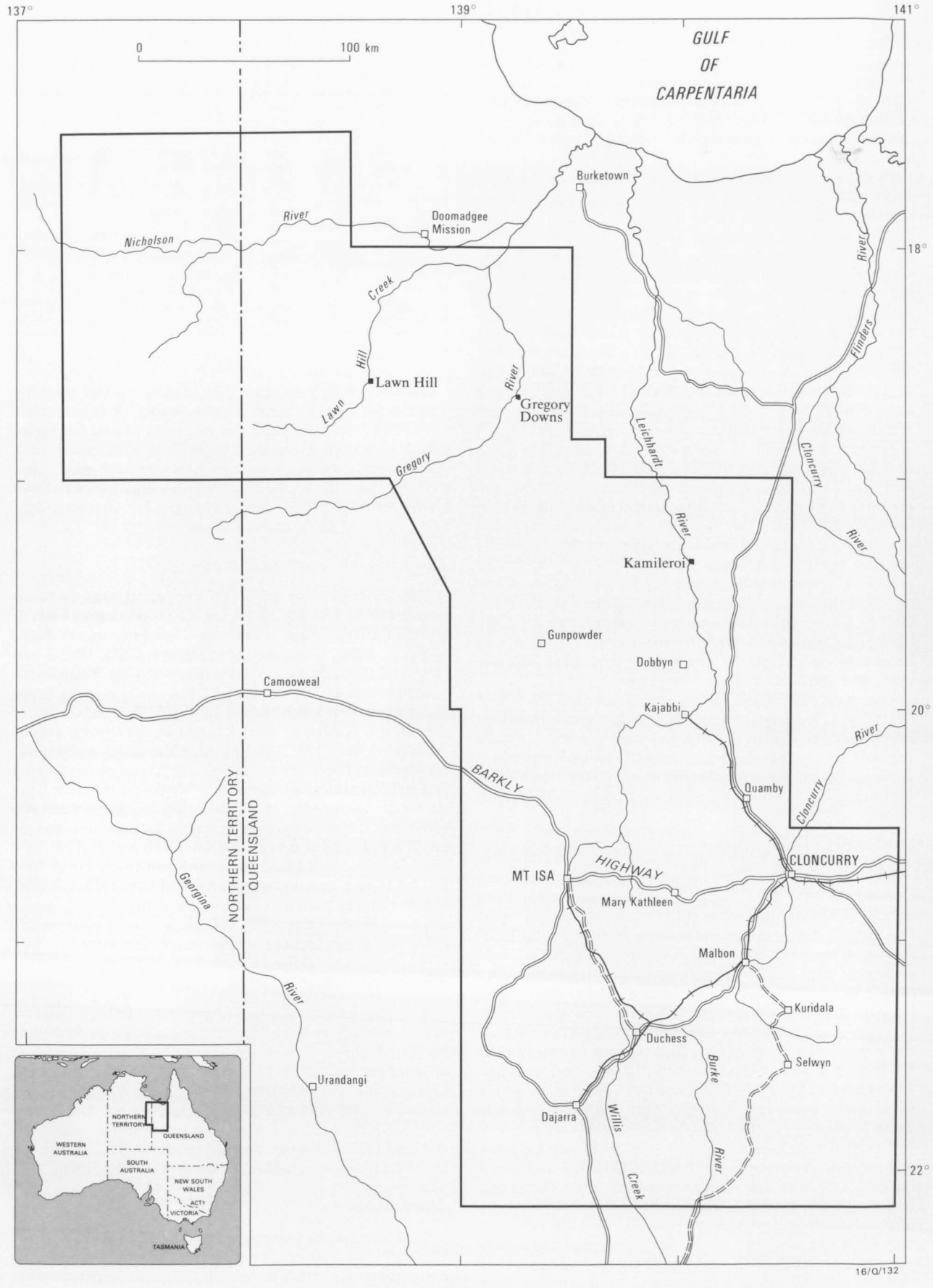


Fig. 1. Locality map.

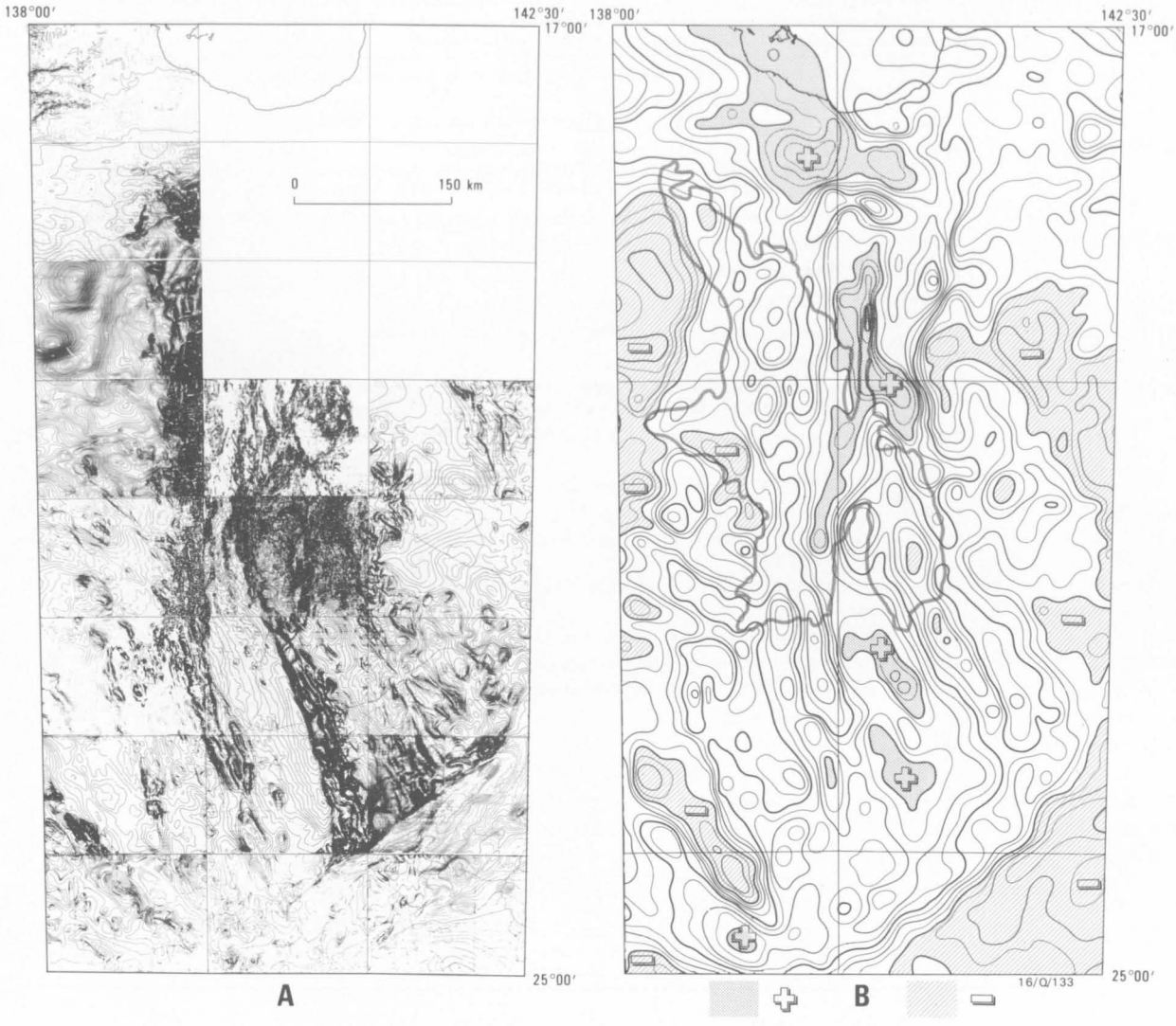


Fig. 2. Airborne magnetic anomaly map (A) and Bouguer gravity map (B) of the Mount Isa Inlier and adjacent parts of northwest Queensland.

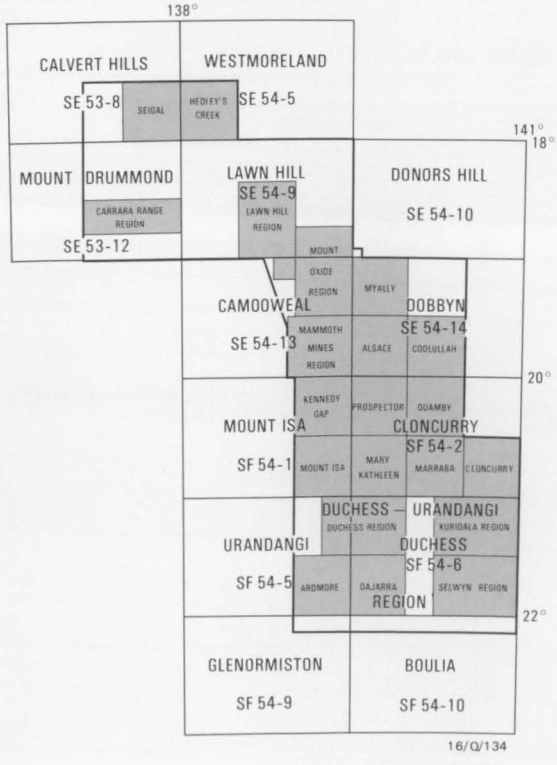
TABLE 2. PUBLISHED 1:100 000-SCALE GEOLOGICAL MAPS, MOUNT ISA INLIER AND ENVIRONS

Map Name (abbreviation used in Appendices 1 & 2)	*References*		
	Map Commentary	*Map (if no commentary available)*	*Preliminary Reports*
Alsace (AL)		BMR (1982)	Derrick & Wilson (1982)
Ardmore (AR)	Bultitude (1982)		Bultitude (1980)
Carrara Range Region (CRR)	Sweet (1984)		Sweet & Mond (1980)
Cloncurry (CL)	Ryburn & others (in prep.)		Glikson & Derrick (1970)
Coolullah (CO)	Wilson & Grimes (1986)		
Dajarra (DA)	Blake & others (1982)		Blake & others (1978)
Duchess Region (DUR)	Bultitude & others (1982)		Bultitude & others (1978); Mock (1978)
Hedleys Creek (HC)	Sweet & others (1981)		Sweet & Slater (1975); Mitchell (1976); Gardner (1978)
Kennedy Gap (KG)		BMR (1980a)	Wilson & others (1979a)
Kuridala Region (KUR)	Donchak & others (1983)		Noon (1978, 1979); Donchak & others (1979)
Lawn Hill Region (LHR)	Sweet & others (1982)		Sweet & others (1978, 1979, 1980)
Mammoth Mines Region (MMR)	Hutton & Wilson (1985)		
Marraba (MA)	Derrick (1980)		Derrick & others (1971)
Mary Kathleen (MK)	Derrick & others (1977c)		Derrick & others (1974)
Mount Isa (MI)		BMR (1978)	Hill & others (1975)
Mount Oxide Region (MOR)	Hutton & Wilson (1984)		
Myally (MY)	Wilson & Grimes (1984)		
Prospector (PR)		BMR (1979)	Wilson & others (1977)
Quamby (QU)		BMR (1980b)	Wilson & others (1979b)
Seigal (SE)	Sweet & others (1981)		Sweet & Slater (1975); Mitchell (1976); Gardner (1978)
Selwyn Region (SER)	Blake & others (1983)		Blake & others (1979)

terminology). The nomenclature for plutonic igneous rocks follows that recommended by Streckeisen & others (1973). Terms describing metamorphic facies are as defined by Turner & Verhoogen (1960). The term 'quartzite', where not part of a formal stratigraphic name, denotes a siliceous granoblastic metamorphic rock. The prefix 'meta' added to the rock name

TABLE 3. GEOLOGISTS WHO TOOK PART IN THE 1:100 000-SCALE MAPPING OF THE MOUNT ISA INLIER AND ENVIRONS

Geologist	*Organisation*	*1:100 000-Scale Geological Maps (years of fieldwork)*
D. H. Blake	BMR	Dajarra (1977, 1979), Duchess Region (1975, 1977), Kuridala Region (1978, 1979, 1980), Selwyn Region (1978, 1979, 1980)
R. J. Bultitude	BMR	Ardmore (1978, 1979), Dajarra (1977, 1979), Duchess Region (1975-77)
G. M. Derrick	BMR	Alsace (1976-77), Cloncurry (1969), Duchess Region (1975), Hedleys Creek (1972), Kennedy Gap (1974), Mammoth Mines Region (1978), Marraba (1969-70), Mary Kathleen (1970-71), Mount Isa (1970), Mount Oxide Region (1978), Myally (1978-79), Prospector (1973), Quamby (1974-75)
P. J. T. Donchak	GSQ	Dajarra (1977, 1979), Duchess Region (1977), Kuridala Region (1978-80), Selwyn Region (1978-80)
B. A. Duff	BMR	Kennedy Gap (1974), Prospector (1973), Quamby (1973-74)
D. J. Ellis	BMR	Prospector (1973)
R. N. England	BMR	Duchess Region (1975)
A. Y. Glikson	BMR	Cloncurry (1969), Marraba (1969-70), Mary Kathleen (1970)
S. Henley	BMR	Mount Isa (1971)
R. M. Hill	BMR	Alsace (1976-77), Cloncurry (1969, 1975), Duchess Region (1975, 1976), Kennedy Gap (1974), Marraba (1969-70), Mary Kathleen (1969-70), Mount Isa (1970-71), Prospector (1973), Quamby (1973-74)
L. J. Hutton	GSQ	Carrara Range Region (1977), Lawn Hill Region (1976-77), Mammoth Mines Region (1978), Mount Oxide Region (1978)
J. A. Ingram	BMR	Hedleys Creek (1972), Seigal (1972)
A. L. Jaques	BMR	Kuridala Region (1978), Selwyn Region (1978)
J. E. Mitchell	BMR	Cloncurry (1969), Hedleys Creek (1972-73), Marraba (1969-70), Mary Kathleen (1970), Mount Isa (1970), Seigal (1972-73)
C. M. Mock (née Gardner)	BMR	Duchess Region (1975-76), Hedleys Creek (1973), Seigal (1973-74)
A. Mond	BMR	Carrara Range Region (1977), Lawn Hill Region (1976-77)
T. A. Noon	GSQ	Duchess Region (1975-76), Kennedy Gap (1974), Kuridala Region (1975-76, 1980), Prospector (1973)
W. G. Perkins	MIM	Mammoth Mines Region (1978), Mount Oxide Region (1978)
W. J. Perry	BMR	Dajarra (1977)
K. A. Plumb	BMR	Hedleys Creek (1972)
R. E. Russell	MIM	Mary Kathleen (1970)
R. J. Ryburn	BMR	Cloncurry (1983-84)
P. J. Slater	GSQ	Hedleys Creek (1972-73), Seigal (1972-73)
I. P. Sweet	BMR	Carrara Range Region (1977), Hedleys Creek (1972-73), Lawn Hill Region (1976-77), Mammoth Mines Region (1978), Mount Oxide Region (1978), Seigal (1972-74)
K. R. Walker	BMR	Duchess Region (1975)
I. H. Wilson	GSQ	Alsace (1976-77), Cloncurry (1969), Coolullah (1977-79), Duchess Region (1975), Kennedy Gap (1974), Mammoth Mines Region (1978), Marraba (1969-70), Mary Kathleen (1970-71), Mount Isa (1970-71), Mount Oxide Region (1978), Myally (1978-79), Prospector (1973), Quamby (1973-75)



indicates that the rock now has a metamorphic fabric or mineralogy or both, but its original nature is readily apparent.

Acknowledgements

This Bulletin and accompanying 1:500 000 map are based on the work of the many BMR and GSQ geologists who took part in the initial broad reconnaissance survey of the area and in the later more detailed 1:100 000 mapping program.

CAMOOWEAL 1 : 250 000 map sheet

KENNEDY GAP 1 : 100 000 map sheet

Fig. 3. Key to published geological maps of Mount Isa Inlier and environs.

TABLE 4. 1:100 000-SCALE GEOLOGICAL MAP SHEETS AND GEOLOGISTS INVOLVED IN SURVEY

Map Sheet	*Period of Survey*	*Geologists involved in survey* BMR	GSQ
Alsace	1976–77	G. M. Derrick R. M. Hill	I. H. Wilson
Ardmore	1978–79	R. J. Bultitude	
Carrara Range Region	1977	I. P. Sweet A. Mond	L. J. Hutton
Cloncurry	1969	A. Y. Glikson G. M. Derrick R. M. Hill J. E. Mitchell	I. H. Wilson
	1975	R. M. Hill	
	1983–84	R. J. Ryburn	
Coolullah	1977–79		I. H. Wilson
Dajarra	1977, 1979	D. H. Blake R. J. Bultitude W. J. Perry (1977 only)	P. J. T. Donchak
Duchess Region	1975–77	R. J. Bultitude C. M. Mock R. N. England D. H. Blake R. H. Hill G. M. Derrick K. R. Walker	T. A. Noon P. J. T. Donchak I. H. Wilson
Hedleys Creek	1972–73	I. P. Sweet J. A. Ingram J. E. Mitchell K. A. Plumb G. M. Derrick C. M. Mock (née Gardner)	P. J. Slater
Kennedy Gap	1974	R. M. Hill B. A. Duff G. M. Derrick	I. H. Wilson T. A. Noon
Kuridala Region	1975–80	D. H. Blake A. L. Jaques	T. A. Noon P. J. T. Donchak
Lawn Hill	1976–77	I. P. Sweet A. Mond	L. J. Hutton
Mammoth Mines Region	1978	G. M. Derrick I. P. Sweet (also W. G. Perkins, MIM)	L. J. Hutton I. H. Wilson
Marraba	1969–70	G. M. Derrick R. M. Hill J. E. Mitchell A. Y. Glikson	I. H. Wilson
Mary Kathleen	1970–71	G. M. Derrick R. M. Hill J. E. Mitchell A. Y. Glikson (also R. E. Russell, MIM)	I. H. Wilson
Mount Isa	1970–72	R. W. Hill G. M. Derrick J. E. Mitchell S. Henley	I. H. Wilson
	1974	R. M. Hill	I. H. Wilson
Mount Oxide Region	1978	G. M. Derrick I. P. Sweet (also W. G. Perkins, MIM)	L. J. Hutton I. H. Wilson
Myally	1978–79	G. M. Derrick	I. H. Wilson K. G. Grimes
Prospector	1973	R. M. Hill G. M. Derrick B. A. Duff D. J. Ellis	I. H. Wilson T. A. Noon
Quamby	1973–75	R. M. Hill B. A. Duff G. M. Derrick	I. H. Wilson
Seigal	1972–74	I. P. Sweet J. E. Mitchell J. A. Ingram C. M. Mock (née Gardner)	P. J. Slater
Selwyn Region	1978–80	D. H. Blake A. L. Jaques	P. J. T. Donchak

TABLE 5. SANDSTONE TERMINOLOGY

Term	*Explanation*
Sandstone	Less than 15% matrix
Greywacke	More than 15% matrix
Arkose	More than 25% of grains are feldspar
Calcareous sandstone	Calcite cement and/or grains identified
Clayey sandstone	10–15% clay matrix
Dolomitic sandstone	Dolomite cement and/or grains identified
Feldspathic sandstone	5–25% of grains are feldspar
Ferruginous sandstone	Iron-stained
Hematitic sandstone	Hematitic matrix
Lithic sandstone	More than 5% of grains are rock fragments
Micaceous sandstone	Appreciable muscovite flakes present
Quartz sandstone	At least 95% of grains are quartz
Sericitic sandstone	Sericitic matrix
Volcaniclastic sandstone	More than 5% of grains are volcanic rock fragments.

GENERAL GEOLOGY

Stratigraphic framework

In this Bulletin the Proterozoic sedimentary and volcanic rocks of the Mount Isa Inlier and environs are assigned to four major sequences. The oldest of these, designated as basement, was folded and regionally metamorphosed before about 1875 Ma. The three younger sequences, which do not appear to have been deformed and metamorphosed on a regional extent before about 1620 Ma, form the Proterozoic cover. The first or earliest of these is cover sequence 1, which consists predominantly of felsic volcanics isotopically dated at between about 1875 and 1850 Ma (early Proterozoic). This sequence has been regarded previously as part of the basement and is described as such in the commentaries accompanying the 1:100 000 geological maps. Cover sequence 2 is represented mainly by 1790–1760 Ma-old sedimentary and bimodal volcanic rocks, and cover sequence 3 consists of sedimentary rocks and subordinate bimodal volcanics ranging in age from about 1680 Ma to probably about 1670 Ma. The sedimentary rocks of the cover sequences are mainly shallow-marine and fluvial types, and most of the volcanics are probably subaerial. Region-wide deformation between about 1620 Ma and 1550 Ma resulted in the Proterozoic cover rocks being tightly folded, extensively faulted, and regionally metamorphosed to mainly greenschist and amphibolite facies. Major granitic intrusions were emplaced at 1870–1840 Ma (Kalkadoon and Ewen Batholiths), 1740– 1720 Ma (most of the Wonga Batholith), 1670 Ma (Sybella Batholith), and around 1500 Ma (most of the Williams and Naraku Batholiths). Innumerable metamorphosed mafic dykes were intruded at various times prior to 1620 Ma. There are also some younger mafic dykes which are not metamorphosed.

Tectonic framework

The region described contains one major Proterozoic tectonic unit—the Mount Isa Inlier—and, to the north, parts of three others—the South Nicholson Basin, Murphy Tectonic Ridge, and McArthur Basin (Fig. 4).

Previous workers have divided the Mount Isa Inlier into various tectonic/structural/palaeogeographic/geographic units (e.g., Carter & others, 1961; 1:100 000 geological maps and commentaries; Plumb & Derrick, 1975; Plumb & others, 1980, 1981; Blake & others, 1984; Day & others, 1983); these are listed, together with all named structural features, in Appendix 2. The broad tectonic divisions of the Inlier used in this Bulletin largely follow the scheme of Day & others (1983). Three major units are distinguished: the Western Fold Belt, the Kalkadoon–Leichhardt Belt (Leichhardt Block of Day & others, 1983), and the Eastern Fold Belt (Fig. 4).

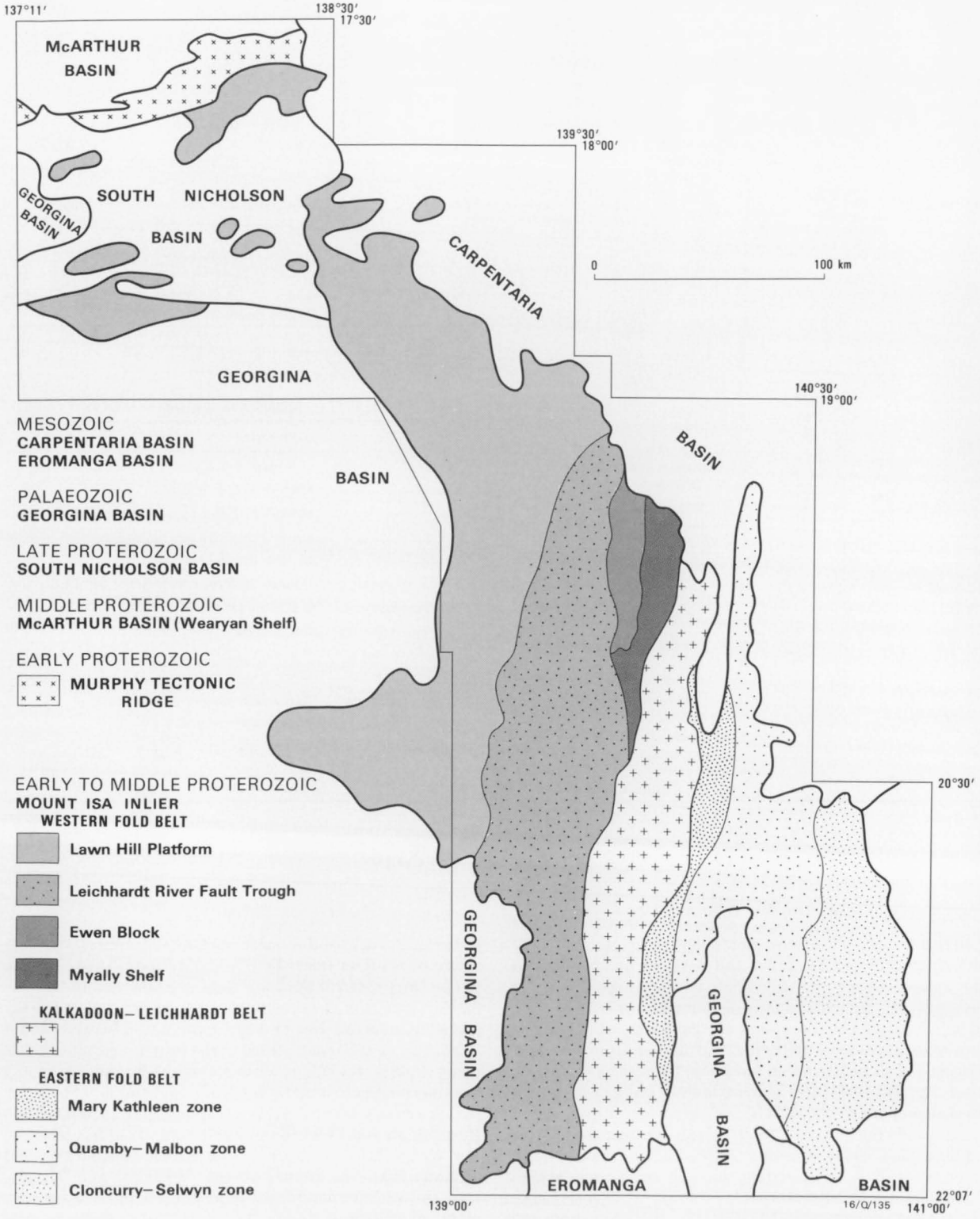


Fig. 4. Tectonic zones.

The *Western Fold Belt* corresponds in general to the western succession, western geosyncline, and similar terms of other workers. It is subdivided into the *Lawn Hill Platform, Leichhardt River Fault Trough* and *Myally Shelf,* all of which consist mostly of cover sequences 2 and 3, and the *Ewen Block,* comprising cover sequence 1 and Ewen Granite. The boundary between the Leichhardt River Fault Trough and Lawn Hill Platform largely follows the Mount Gordon Fault Zone. The Myally Shelf, which incorporates the White Hills Belt in ALSACE and the Mistake Creek Depression in MYALLY, is separated from the Leichhardt River Fault Trough by the Ewen Block.

The *Kalkadoon–Leichhardt Belt* comprises the Kalkadoon–Leichhardt Block, Blockade Block and part of the eastern succession of Derrick and co-workers (e.g, Derrick & others, 1977c) and covers much the same area as the tectonic welt of Carter & others (1961). The belt consists mostly of basement, cover sequence 1, cover sequence 2, and granite. The older Proterozoic rocks of the belt are partly overlain by and partly faulted against cover sequence 2 units of the Leichhardt River Fault Trough and Myally Shelf to the west. To the east, the Kalkadoon–Leichhardt Belt is separated from the Eastern Fold Belt by a major deformed zone (the Wonga Belt of Derrick, 1980; and the western part of the Duchess Belt of Blake & others, 1984).

The *Eastern Fold Belt* corresponds to most of the eastern succession, eastern geosyncline, and Mary Kathleen Shelf of other workers. It is subdivided from west to east into the highly deformed *Mary Kathleen zone,* the generally less deformed *Quamby–Malbon zone,* which includes the Malbon Block of Plumb & others (1980), and the complex *Cloncurry–Selwyn zone.* All three zones consist predominantly of cover sequence 2 and granite.

The *South Nicholson Basin* immediately to the north of the Mount Isa Inlier consists of the South Nicholson Group, which is a gently folded Proterozoic sedimentary sequence unconformably overlying cover sequence 3 rocks of the Lawn Hill Platform. Rocks of cover sequence 3 crop out on the southwestern and northern sides of the South Nicholson Basin and also form small inliers within it.

The *Murphy Tectonic Ridge,* also known as the Murphy Inlier, is formed of early Proterozoic basement, cover sequence 1, and granite. It is overlapped by middle Proterozoic cover sequence 3 rocks of the Lawn Hill Platform to the south and the Wearyan Shelf part of the *McArthur Basin* to the north, and also, in the south, by younger Proterozoic rocks of the South Nicholson Basin.

According to the Tectonic Map of Australia (Geological Society of Australia, 1971) and Plumb (1979), the Lawn Hill Platform of the Western Fold Belt and the South Nicholson and McArthur Basins are part of the North Australian Platform cover. The remainder of the Mount Isa Inlier forms the Mount Isa Orogenic Domain or Mount Isa Orogen, and is part of the Central Australian Orogenic Province. The Murphy Tectonic Ridge belongs to the North Australian Orogenic Province.

The Proterozoic rocks of the Mount Isa Inlier and environs are overlain by mainly flat-lying Phanerozoic sedimentary rocks. These include units of the early Palaeozoic *Georgina Basin* exposed mainly in the west and south, the Mesozoic *Eromanga Basin* in the south and southeast, and the Mesozoic *Carpentaria Basin* in the northeast. There are also Mesozoic units cropping out in the west and northwest, and widespread surficial Cainozoic sediments.

PROTEROZOIC STRATIGRAPHY

The oldest rocks exposed in the region are early Proterozoic sediments, volcanics and intrusives which were deformed and regionally metamorphosed prior to 1875 Ma. These rocks, which are assigned to the basement, crop out in the southern part of the Mount Isa Inlier and on the Murphy Tectonic Ridge. They are overlain by three Proterozoic cover sequences laid down after the early deformation and metamorphism of the basement, and before a period of major tectonism which began at about 1620 Ma.

The Proterozoic cover sequences are characterised by repetitions of similar rock types, such as quartz-rich and feldspathic sandstones, felsic and mafic volcanics, and calcareous sedimentary rocks, at different stratigraphic levels and metamorphic grades. Cross-bedding and ripple marks in sandstone, the presence of conglomerate bands and lenses, mudcracks, casts of evaporite minerals, and locally abundant stromatolites, together with extensive ignimbritic felsic volcanics and only very rare basaltic pillow lavas, show that mainly shallow-water to subaerial conditions prevailed during deposition. Depositional environments interpreted for the various stratigraphic units are based on details discussed in map commentaries and other references cited.

The oldest cover rocks of the Mount Isa Inlier, those of cover sequence 1, are mainly felsic volcanics which were erupted between about 1850 Ma and 1875 Ma. A time break of up to 70 Ma, but generally no marked angular discontinuity, separates cover sequence 1 from cover sequence 2, which comprises a variety of sedimentary and bimodal volcanic rocks ranging in age from about 1790 Ma to about 1760 Ma. Cover sequence 2 is overlain concordantly and disconcordantly by 1680 to 1670 Ma-old sedimentary and subordinate volcanic rocks of cover sequence 3.

To the northwest of the Mount Isa Inlier, volcanic rocks of cover sequence 1 form part of the Murphy Tectonic Ridge. They are overlapped by cover sequence 3 of the McArthur Basin to the north and the Lawn Hill Platform to the south. Proterozoic sediments deposited in the South Nicholson Basin, which separates the Mount Isa Inlier from the Murphy Tectonic Ridge, postdate cover sequence 3; they are considered to be younger than 1500 Ma and older than 1280 Ma.

The stratigraphy of the basement and cover sequences is summarised in Tables 6 to 12.

Basement (older than 1875 Ma)

The basement (Fig. 5) comprises those rocks of the Mount Isa Inlier and environs which were deformed and metamorphosed before the oldest cover rocks were laid down, and hence are older than about 1875 Ma. As such it does not include the Argylla Formation, Magna Lynn Metabasalt, and Leichhardt Volcanics of the Tewinga Group in the Kalkadoon–Leichhardt Belt, although these formations have been regarded as basement by most previous workers. Units that are assigned to the basement are the Murphy Metamorphics in the far northwest, the Yaringa Metamorphics in the Western Fold Belt, the Plum Mountain Gneiss and Kurbayia Migmatite in the Kalkadoon–Leichhardt Belt, and tentatively (because of uncertain stratigraphic and structural relationships) the May Downs Gneiss Member of the Mount Guide Quartzite (Table 8), Saint Ronans Metamorphics, Kallala Quartzite, and Sulieman Gneiss in the Western Fold Belt, and the Double Crossing Metamorphics in the Eastern Fold Belt (Table 6). Some rocks mapped as undivided Tewinga Group in the Kalkadoon–Leichhardt Belt and as part of the Corella

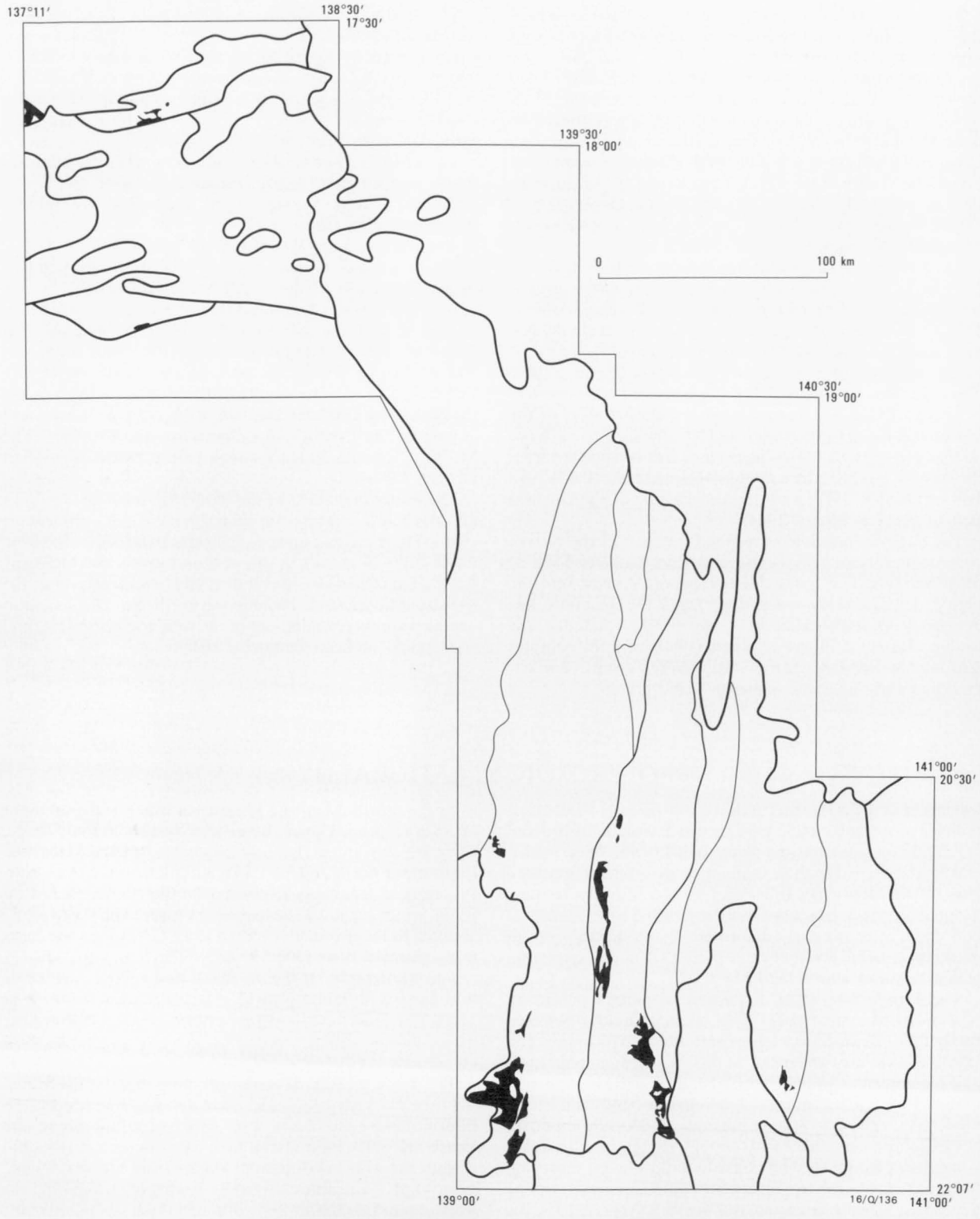


Fig. 5. Distribution of basement outcrops (in black).

Formation in the Eastern Fold Belt may also belong to the basement, as discussed in later sections.

The *Murphy Metamorphics* are exposed in the Little Range Fault Zone in CARRARA RANGE REGION and more extensively in the western part of the Murphy Tectonic Ridge (in SEIGAL and to the west). In CARRARA RANGE REGION, the formation is represented mainly by phyllitic to schistose metasediments and quartzite, which are inferred to be overlain unconformably by non-metamorphosed rocks of the Carrara Range Group (cover sequence 3). In SEIGAL, it consists of schistose to gneissic metasediments which are intruded by the Nicholson Granite Complex (minimum age 1800 Ma) and are inferred to be overlain unconformably by the Cliffdale Volcanics. The Murphy Metamorphics may be comparable in age to similar rocks in the early Proterozoic succession of the Pine Creek Geosyncline to the northwest.

The lithologically similar and possibly correlative *Yaringa Metamorphics,* considered to be possibly Archaean by Carter

TABLE 6. PROTEROZOIC STRATIGRAPHY—BASEMENT

Name of unit	*Lithology*	*Relationships*
Kallala Quartzite	Glassy quartzite, micaceous quartzite, and feldspathic? quartzite; minor amphibolite, mafic schist, gneiss	Concordant contacts with Sulieman Gneiss and Jayah Creek Metabasalt; intruded by Sybella Granite
Sulieman Gneiss	Quartzofeldspathic gneiss, augen gneiss, amphibolite, mafic schist, quartzite; minor calc-silicate gneiss, feldspar metaporphyry	Concordant contacts with Jayah Creek Metabasalt (cover sequence 2) and Kallala Quartzite; intruded by Sybella Granite, metadolerite, and dolerite
Saint Ronans Metamorphics	Mica schist, quartzofeldspathic gneiss, felsic and mafic metavolcanics, amphibolite; minor quartzite, metasiltstone	Overlain, probably unconformably, by Oroopo Metabasalt (cover sequence 2); intruded by Sybella Granite and metadolerite
Double Crossing Metamorphics	Micaceous and feldspathic gneiss and schist, migmatitic gneiss, augen gneiss, amphibolite, quartzite, minor banded quartz-tourmaline rock and quartz-hematite rock	Concordant (tectonic?) contacts with Answer Slate and Staveley Formation (cover sequence 2); intruded by Gin Creek Granite
Plum Mountain Gneiss	Quartzofeldspathic gneiss, augen gneiss, foliated granite; minor quartzitic to micaceous and schistose metasediments, calc-silicate rocks, amphibolite	Concordant (tectonic?) contacts with Corella Formation (cover sequence 2); intruded by granitic rocks of Kalkadoon and Wonga Batholiths, metadolerite dykes
Kurbayia Migmatite	Banded grey micaceous migmatite, massive quartzofeldspathic (dacitic) migmatite; foliated granitic rocks; minor amphibolite	Overlain unconformably by Bottletree Formation (cover sequence 2); intruded by granite rocks (including Kalkadoon Granite), felsic dykes of Bottletree-type, mafic dykes
Yaringa Metamorphics	Quartz-mica schist and gneiss, quartzite, migmatite; felsic metaporphyry	Overlain unconformably by McNamara Group (cover sequence 3); intruded by Big Toby Granite, Sybella Granite and metadolerite
Murphy Metamorphics	Micaceous quartz-feldspar schist and gneiss, phyllite, quartzite, metasiltstone; minor cherty ironstone, pyritic carbonaceous schist	Overlain unconformably by Cliffdale Volcanics (cover sequence 1) and younger cover rocks; intruded by Nicholson Granite Complex

& others (1961), crop out in MOUNT ISA to the west of Mount Isa mine. This formation was tightly folded and regionally metamorphosed before being overlain by sedimentary rocks of the McNamara Group (cover sequence 3). Ion-probe data on zircons from paragneiss within the Yaringa Metamorphics (Fig. 6) have been provisionally interpreted by Page (in Blake & others, 1983b) as indicating ages of up to 2600 Ma for detrital zircon, and post-depositional zircon growth during intense deformation and amphibolite facies regional metamorphism at between 1870 Ma and 1900 Ma. If this interpretation is correct, the sedimentary protoliths of the Yaringa Metamorphics were deposited before 1900 Ma and were at least partly derived from source rocks probably as old as Archaean. The Yaringa Metamorphics have been taken to include a band of schistose felsic porphyry which contains abundant small biotite-rich mafic inclusions and possibly represents a mixture of felsic and mafic magma. This porphyry, however, appears to be markedly less deformed and metamorphosed than adjacent gneiss and also contains some fragments of gneiss (Fig. 7); hence it may be much younger than most of the Yaringa Metamorphics.

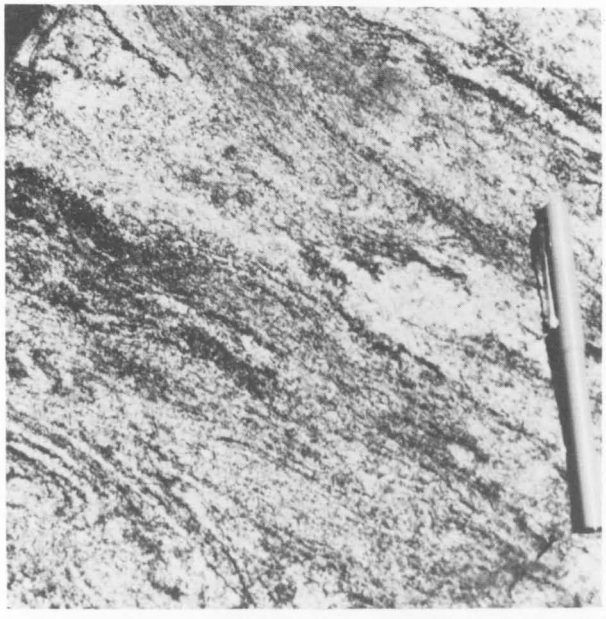


Fig. 6. Migmatitic paragneiss showing complex folding, Yaringa Metamorphics (basement), Western Fold Belt (MOUNT ISA GR 100900) — R. W. Page (M2688/57)

The *Kurbayia Migmatite* is exposed in a zone 70 km long and up to 8 km wide on the western side of the Kalkadoon–Leichhardt Belt east of Mount Isa, in DUCHESS REGION, where it has been shown as part of the undivided Tewinga Group, and in MARY KATHLEEN, where it has been included within the Leichhardt Metamorphics. A formal definition of the Kurbayia Migmatite is given in Appendix 3. The unit consists of complexly folded and thinly banded grey micaceous gneiss with fine to coarse leucosomes, probably representing metamorphosed greywacke-type sediments (Fig. 8); generally subordinate massive (non-banded) grey gneiss with crenulated wispy leucosomes (Fig. 9), representing metamorphosed felsic igneous rocks of probably both extrusive and intrusive origin; and minor amphibolite. To the west, the Kurbayia Migmatite is overlain unconformably by the Bottletree Formation, a 1790 Ma-old unit at the base of cover sequence 2 in the Leichhardt River Fault Trough of the Western Fold Belt. To the east, it is intruded by Kalkadoon Granite, which was emplaced at around 1860 Ma, and faulted against both this granite and the Leichhardt Volcanics of cover sequence 1. It is also cut by tonalite, granodiorite, granite, leucogranite, and pegmatite, by grey felsic dykes similar in chemistry and probably age to felsic volcanics of the Bottletree Formation, and by numerous mafic dykes. The field evidence indicates that the migmatite predates emplacement of the Kalkadoon Granite and may have been formed during the 1900 Ma-old deformation event thought to have affected the Yaringa Metamorphics. Hence, the Kurbayia Migmatite and Yaringa Metamorphics may be correlatives. This interpretation is favoured by the author, but is in conflict with U–Pb zircon dates of 1866±5 Ma (Page, 1983a) and 1850±16 Ma (Blake & Page, in preparation) obtained for migmatitic metadacite from the Kurbayia Migmatite.

Fig. 7. Schistose quartz–feldspar porphyry containing small mafic inclusions and a larger fragment of gneiss, Yaringa Metamorphics (basement) west of Mount Isa (MOUNT ISA GR 120033). The gneiss is similar to that exposed nearby and clearly predates the felsic porphyry. The mafic inclusions, on the other hand, may represent mafic magma incorporated at the time of felsic porphyry emplacement. (M2686/10)

The *Plum Mountain Gneiss* crops out on the east side of the Kalkadoon–Leichhardt Belt south of Duchess (in DUCHESS REGION and DAJARRA). It consists mainly of massive to banded granitic to dioritic gneiss and augen gneiss (Fig. 10) that probably represent metamorphosed intrusive and extrusive felsic igneous rocks. The unit is intruded by the One Tree Granite of the Kalkadoon Batholith and predates the Leichhardt Volcanics of cover sequence 1. The gness is considered to be probably early Proterozoic, but a late Archaean age, similar to that of some gneissic rocks in the Pine Creek region, cannot be ruled out.

Three units possibly belonging to the early Proterozoic basement are exposed in ARDMORE, in the far southwest of the Western Fold Belt. These are the *Sulieman Gneiss, Kallala Quartzite,* and *Saint Ronans Metamorphics,* which consist of highly deformed and metamorphosed volcanics and sediments. They are presumed to be overlain unconformably by Proterozoic cover sequence 2 units (Jayah Creek and Oroopo Metabasalts), and are possible correlatives of the Yaringa Metamorphics.

Another possible basement unit, the *Double Crossing Metamorphics,* crops out within the Quamby–Malbon zone of the Eastern Fold Belt in SELWYN REGION. It consists of quartzofeldspathic metasediments and subordinate felsic and mafic rocks which are probably metamorphosed volcanics, and appears to be much more deformed and metamorphosed than adjacent cover sequence 2 rocks (Answer Slate and Staveley Formation). However, the unit may be a correlative of the Argylla Formation to the west or the Soldiers Cap Group to the east, or both, and hence part of cover sequence 2.

Cover sequence 1 (1875–1850 Ma)

Cover sequence 1 (Fig. 11) comprises the Leichhardt Volcanics and part of the undivided Tewinga Group in the

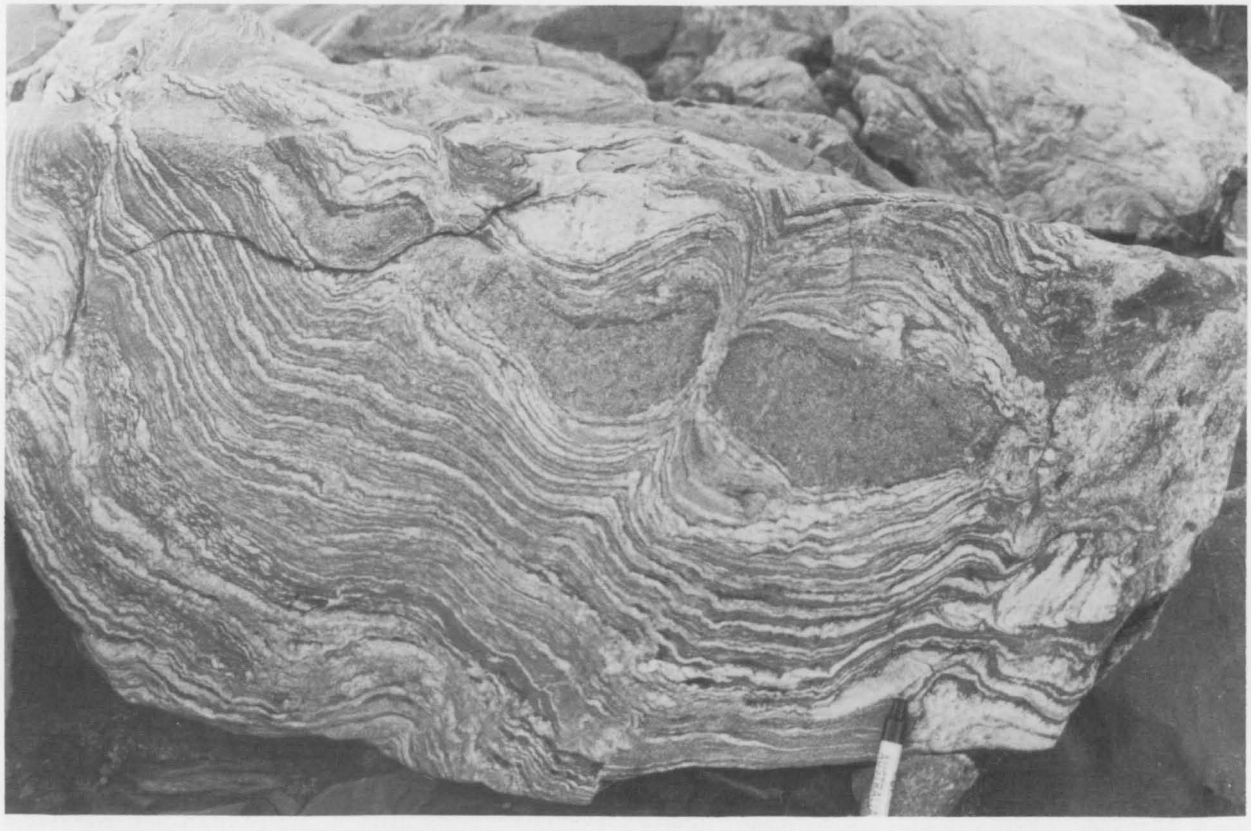


Fig. 8. Migmatitic metasediments of the Kurbayia Migmatite (basement) in the west of the Kalkadoon–Leichhardt Belt (DUCHESS REGION GR 565530). (M2685/15A)

Fig. 9. Migmatitic metadacite with crenulated wispy leucosomes, Kurbayia Migmatite (basement) at U–Pb zircon dating site in DUCHESS REGION (GR 685510), Kalkadoon–Leichhardt Belt. (M2625/31A)

Kalkadoon–Leichhardt Belt, the Leichhardt Volcanics and tentatively the Candover Metamorphics in the Ewen Block of the Western Fold Belt, and the Cliffdale Volcanics of the Murphy Tectonic Ridge (Table 7). The Leichhardt Volcanics form the lower part of the Tewinga Group of Derrick & others (1976a), the upper part of which is represented by the Magna Lynn Metabasalt and Argylla Formation of cover sequence 2.

Following Blake & others (e.g., 1981a, 1984), the *Leichhardt Volcanics* correspond to most of the rocks assigned to the Leichhardt Metamorphics by Carter & others (1961) and shown as Leichhardt Metamorphics on 1:100 000 geological map sheets north of latitude 21°S. The name Leichhardt Volcanics is preferred, because the modifier 'metamorphics' conceals the volcanic nature of the unit and implies, incorrectly, that the unit is more metamorphosed than all younger cover units. The Leichhardt Volcanics consist mainly of greyish felsic ignimbritic deposits and lava flows (Fig. 12), which are presumed to be subaerial. They range in composition from dacite to rhyolite, and typically contain small phenocrysts of sodic plagioclase, microcline, quartz, and altered ferromagnesian minerals. Phenocrysts are generally recognisable even where the volcanics have been metamorphosed to gneiss.

Unlike felsic volcanics in cover sequence 2, those of the Leichhardt Volcanics are typically either weakly magnetic or non-magnetic. This distinction applies at both greenschist and amphibolite facies regional metamorphism.

The base of the Leichhardt Volcanics is exposed in DAJARRA, where conglomerate underlying felsic porphyry is seen to overlie One Tree Granite (part of the Kalkadoon Batholiths), fragments of which occur in the conglomerate. This granite is also cut by dykes of Leichhardt Volcanics composition. Nearby, the Leichhardt Volcanics are intruded by the Wills Creek Granite of the Kalkadoon Batholith.

U–Pb zircon data indicate ages for the felsic volcanics of 1865 ± 3 Ma (Page, 1978) and 1867 ± 5 Ma and $1875 \pm {}^{26}_{19}$ Ma (Page, 1983a) in the Kalkadoon–Leichhardt Belt and 1852 ± 7 Ma (Page, 1983a) in the Ewen Block.

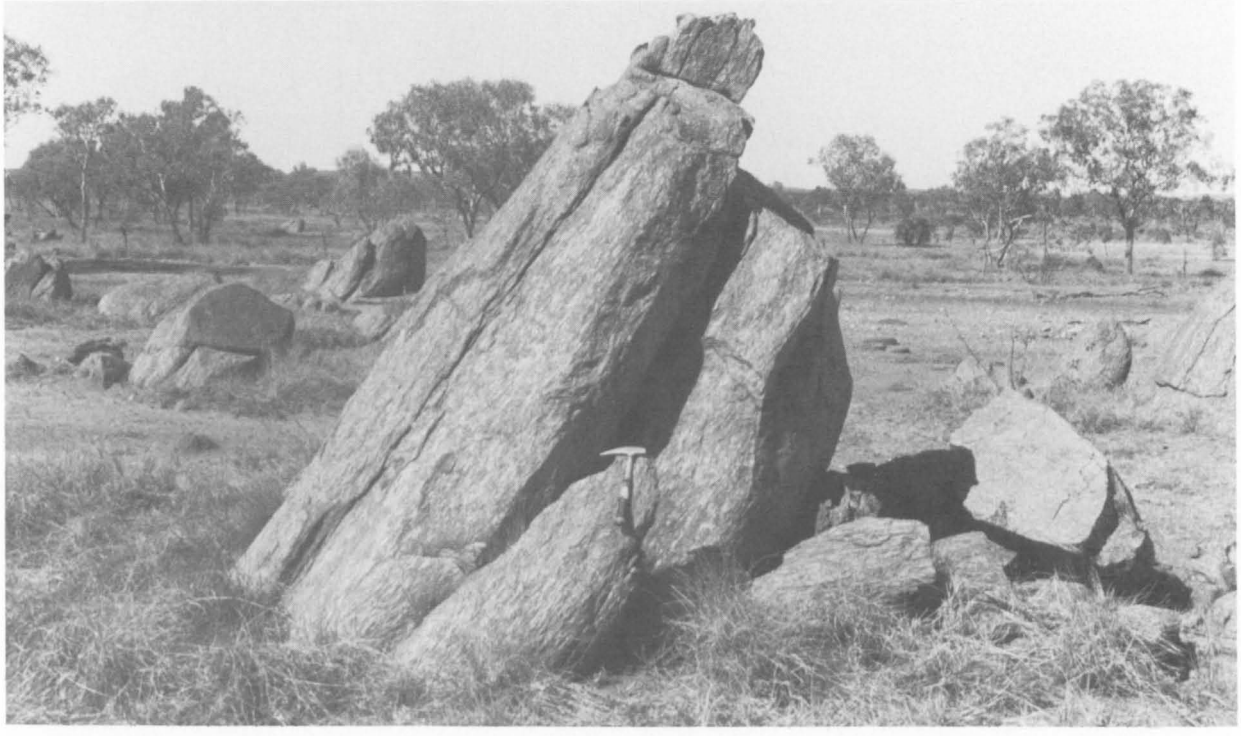


Fig. 10. Exposures of strongly foliated granitic augen gneiss, Plum Mountain Gneiss (basement) in northern DAJARRA (GR 725142), Kalkadoon–Leichhardt Belt. (M2624/42)

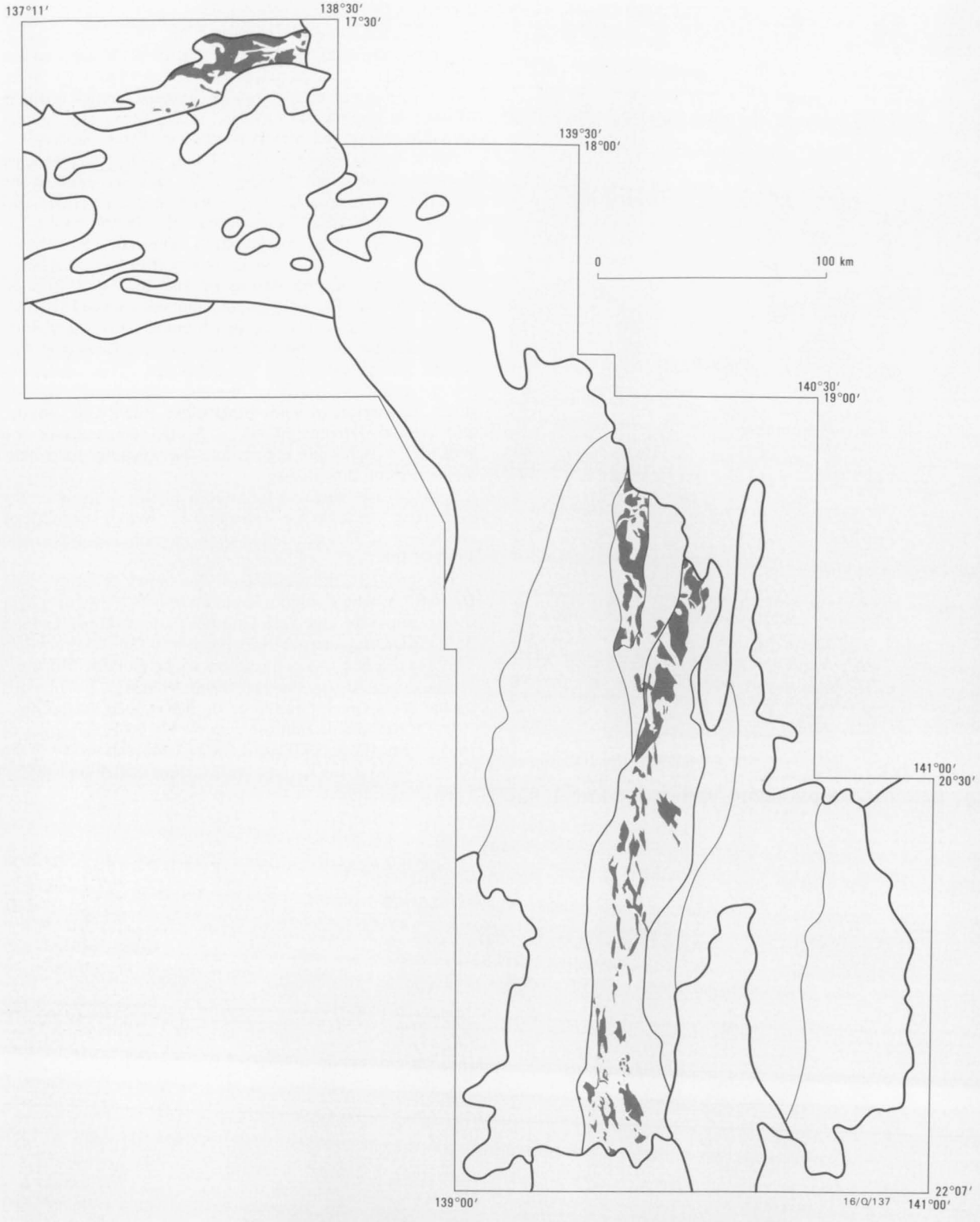


Fig. 11. Distribution of cover sequence 1 outcrops (in black).

Chemically and geochronologically, the felsic volcanics are similar to the granites of the Kalkadoon and Ewen Batholiths, and are considered to be part of the same comagmatic suite (e.g., Bultitude & Wyborn, 1982; Wyborn & Page, 1983). They are readily distinguishable in their chemistry from felsic volcanics in the two younger cover sequences.

Outcrops mapped as *undivided Tewinga Group* in the southern part of the Kalkadoon–Leichhardt Belt (in DUCHESS REGION and DAJARRA) consist mainly of pink to grey quartzofeldspathic orthogneisses representing metamorphosed felsic volcanics and granitic intrusives, but they also include some metamorphosed mafic rocks and metasediments. Some of the felsic gneisses are similar in chemistry and age to felsic volcanics of cover sequence 2 (those of the Bottletree and Argylla Formations), whereas others are chemically comparable to the Leichhardt Volcanics and are probably either similar in age, and hence belong to cover sequence 1, or are older and part of the basement.

TABLE 7. PROTEROZOIC STRATIGRAPHY—COVER SEQUENCE 1

Name of unit (Maximum thickness in metres)	*Lithology*	*Relationships*
TEWINGA GROUP		
Leichhardt Volcanics (1000+)	Rhyolitic to dacitic ignimbrite and minor flow-banded lava, generally porphyritic; rare volcaniclastic sandstone, bedded tuff, agglomerate, mafic lava, conglomerate, quartzite, and porphyritic andesite; little metamorphosed or deformed to extensively recrystallised and schistose to gneissic; weakly magnetic or non-magnetic	Unconformable on One Tree Granite; overlain unconformably by Magna Lynn Metabasalt and also by Argylla Formation, Eastern Creek Volcanics, Myally Subgroup, Quilalar Formation, Stanbroke Sandstone, and Makbat Sandstone (all cover sequence 2). Intruded by Kalkadoon Granite, Wills Creek Granite, and Woonigan Granite of Kalkadoon Batholith, Ewen Granite, mafic dykes, and felsic dykes
Undivided	Massive to banded quartzofeldspathic gneiss, augen gneiss, and schist; minor amphibolite, calc-silicate gneiss, quartzite	Generally obscure; intruded by Kalkadoon Granite and mafic dykes
Candover Metamorphics (1000+)	Mica schist, quartzite, felsic and mafic metavolcanics; minor meta-arkose, conglomerate	Base not seen; overlain unconformably? by Eastern Creek Volcanics (cover sequence 2); intruded by Ewen Granite and mafic dykes
Cliffdale Volcanics (4000+)	Rhyolitic to dacitic porphyritic ignimbrite and lava; minor bedded tuff, conglomerate	Inferred to be unconformable on Murphy Metamorphics; overlain unconformably by Wire Creek Sandstone Volcanics of cover sequence 3; intruded by Nicholson Granite Complex and felsic and mafic dykes

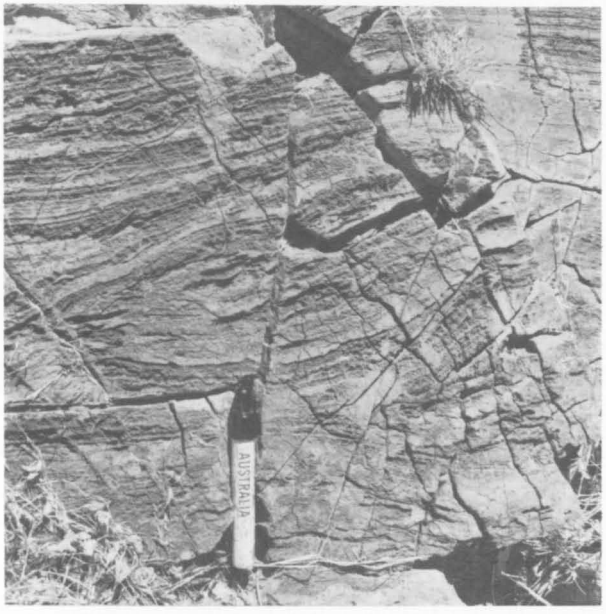


Fig. 12. Flow-banding in rhyolite lava which has been regionally metamorphosed to the amphibolite facies; Leichhardt Volcanics (cover sequence 1) west of Lake Mary Kathleen (MARY KATHLEEN GR 695017), Kalkadoon–Leichhardt Belt. (M2684/55)

Because of their distinctive chemistry, some of the felsic metavolcanics shown as undivided Tewinga Group on the DAJARRA and DUCHESS REGION maps are now assigned to the Argylla and Bottletree Formations. Undivided Tewinga Group mapped to the north, on the east side of the Myally Shelf in ALSACE, consists of slightly metamorphosed felsic and mafic volcanics which may belong partly to the Leichhardt Volcanics and partly to the Magna Lynn Metabasalt and Argylla Formation.

The *Candover Metamorphics* crop out in the southern part of the Ewen Block, in southern ALSACE (where they have been shown as Candover beds) and northern PROSPECTOR (shown as Leander Quartzite). The formation consists mainly of schistose metasediments and felsic and mafic metavolcanics. Its contact with overlying Eastern Creek Volcanics of cover sequence 2 is presumed to be an unconformity, as the formation is intruded by Ewen Granite, one phase of which has been dated at about 1840 Ma. However, the granite intruding the Candover Metamorphics could be a much younger phase, in which case, rather than being a correlative of the Leichhardt Volcanics, the Candover Metamorphics may belong to cover sequence 2.

The *Cliffdale Volcanics* are confined to the eastern part of the Murphy Tectonic Ridge (SEIGAL and HEDLEYS CREEK), where they are inferred to unconformably overlie the Murphy Metamorphics. They consist predominantly of felsic volcanic rocks (Figs 13, 14) of probably subaerial origin, which appear to be similar in chemistry, and possibly also in age, to those of the Leichhardt Volcanics. A Rb–Sr isochron age of 1733 ± 20 Ma for the Cliffdale Volcanics is regarded as only a minimum age (Page & others, 1984). The formation is intruded by the Nicholson Granite Complex, some phases of which are at least as old as 1800 Ma (Page & others, 1984),

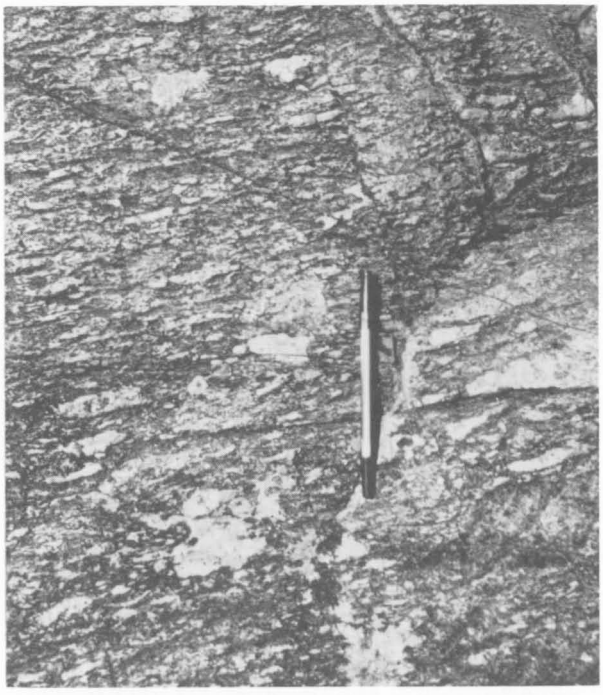


Fig. 13. Flattened fragments of altered pumice in rhyolitic ignimbrite of the Cliffdale Volcanics (cover sequence 1), Murphy Tectonic Ridge (HEDLEYS CREEK GR 995455) — J. E. Mitchell (GA9195)

Fig. 14. Pale rhyolitic ignimbrite overlain by dark dacitic ignimbrite, Cliffdale Volcanics (cover sequence 1), Murphy Tectonic Ridge (HEDLEYS CREEK GR 970440) — J. E. Mitchell (M1424/31)

and it is overlain unconformably by rocks of cover sequence 3 to the north (Tawallah Group of the McArthur Basin) and south (Wire Creek Sandstone of the Lawn Hill Platform sequence).

Cover sequence 2 (1790–1760 Ma or younger)

Units assigned to cover sequence 2 crop out in the Western Fold Belt, Kalkadoon–Leichhardt Belt, and Eastern Fold Belt of the Mount Isa Inlier, but are not exposed to the northwest (Fig. 15).

Western Fold Belt

The oldest unit of cover sequence 2 in the Western Fold Belt (Table 8) is probably the Bottletree Formation, which contains felsic volcanics dated at about 1790 Ma (Page, 1983a). It unconformably overlies basement rocks and Kalkadoon Granite of the Kalkadoon–Leichhardt Belt to the east and is overlain by the Haslingden Group either conformably (e.g., Blake & others, 1984) or unconformably (according to Derrick & Wilson, 1981b). The Haslingden Group passes conformably upwards into the Quilalar Formation, the youngest unit of cover sequence 2 in the Western Fold Belt. The Bottletree Formation and Haslingden Group, together with probable correlatives in the southwest (Oroopo Metabasalt and Jayah Creek Metabasalt), are thought to have been laid down mainly within a northerly trending basin or rift structure—the Leichhardt River Fault Trough of Glikson & others (1976) and Derrick (1982). Rocks belonging to the Haslingden Group, Quilalar Formation, and overlying cover sequence 3, also occur in fault-bounded outcrops to the east, in the western part of the Kalkadoon–Leichhardt Belt, where they have been mapped as Surprise Creek beds (in MARY KATHLEEN) and possible Surprise Creek Formation (in DUCHESS REGION).

During the deposition of the Bottletree Formation and much of the Haslingden Group, the Leichhardt River Fault Trough was flanked to the east by a landmass formed of early Proterozoic basement, cover sequence 1, and granite (Kalkadoon Batholith). Large amounts of sandy and coarser detritus deposited in the Trough were derived from this landmass. Additional detritus probably also came from the west (e.g., Derrick, 1982), but the nature and location of the western boundary of the depositional area are not clear, being concealed beneath cover sequence 3 of the Lawn Hill Platform and Cambrian sediments of the Georgina Basin.

Towards the end of Haslingden Group deposition, a marine transgression resulted in the Myally Subgroup of the Haslingden Group and the overlying Quilalar Formation spreading eastwards across the eastern margin of the Leichhardt River Fault Trough onto the Myally Shelf. Probable correlatives of the Quilalar Formation were deposited farther east, within the Kalkadoon–Leichhardt Belt and Eastern Fold Belt.

The *Bottletree Formation* is exposed in the southern part of the Leichhardt River Fault Trough, mainly in DUCHESS REGION, where it is up to 3000 m thick. Main rock types are dacitic to rhyolitic lava and tuff, basalt lava, greywacke, and conglomerate containing clasts of felsic volcanics, granite, and basement metamorphics. The felsic lavas are typically strongly magnetic. Most of the sedimentary rocks are probably shallow-marine and alluvial fan deposits derived from the east. The Bottletree Formation is taken to include outcrops which have been mapped as Argylla Formation in MARY KATHLEEN, and undivided Tewinga Group in DAJARRA. Chemically, the felsic volcanics of the formation are closely similar to those of the Argylla Formation, and are easily distinguishable from those of the Leichhardt Volcanics.

The overlying *Haslingden Group* has an average thickness of about 10 km (Derrick, 1982), and comprises, from base upwards, the Mount Guide Quartzite and Leander Quartzite, the Eastern Creek Volcanics; and four formations making up the Myally Subgroup—the Alsace Quartzite, Bortala Formation, Whitworth Quartzite, and Lochness Formation. The group is largely restricted to the Leichhardt River Fault Trough, and was probably laid down in fluvial and shallow-marine environments.

The *Mount Guide Quartzite* crops out in the southern part of the trough, where it typically consists of a lower part of mainly greywacke-type metasediments, including conglomerate, similar to those in the underlying Bottletree Formation, and an upper part of mostly ridge-forming quartz-rich sandstone metamorphosed to quartzite. The lower part in the Duchess–Urandangi region has been named the Yappo Member. In MOUNT ISA, the Mount Guide Quartzite is taken to include a unit of quartzofeldspathic gneiss, mica schist and minor quartzite. This is the *May Downs Gneiss Member,* which is exposed west of the Mount Isa Fault to the east and north of the basement Yaringa Metamorphics. According to C. J. L. Wilson (1975), the May Downs Gneiss Member was first deformed before the deposition of the Judenan beds (now mapped as Myally Subgroup). This early deformation may be the same as that thought to have affected the Yaringa Metamorphics at about 1900 Ma. Hence, the May Downs Gneiss Member may be a correlative of the basement Yaringa Metamorphics, rather than belonging to cover sequence 2. If this is the case, adjacent highly metamorphosed sediments and mafic volcanics to the east, at present assigned to the Mount Guide Quartzite and Eastern Creek Volcanics, may also be part of the early Proterozoic basement.

The *Leander Quartzite,* which crops out in the central part of the Leichhardt River Fault Trough, is similar in lithology, thickness, and age to the Mount Guide Quartzite. Both these formations are overlain conformably by the *Eastern Creek Volcanics,* a formation consisting mainly of massive to strongly cleaved basalt lava flows (Fig. 16), but also including interlayered quartz and feldspathic sandstones, conglomerate, and other sedimentary rocks. The Eastern Creek Volcanics extend northwest into the Lawn Hill Platform and east into the western parts of the Ewen Block in the north (where they overlie Candover Metamorphics) and the Kalkadoon–Leichhardt Belt to the south. Individual basalt lava flows

Fig. 15. Distribution of cover sequence 2 outcrops (in black).

are generally less than 40 m thick. Their sheet-like nature and the presence of stratiform amygdaloidal zones within them, an absence of pillows, and a paucity of associated basaltic tuffs are taken to indicate very shallow-water or subaerial eruption on a broad shelf or plain. Disseminated copper minerals are commonly present in the lavas, mainly in amygdaloidal zones (e.g., Robinson, 1968). Conglomerates in the formation contain clasts of quartzite, granite, and felsic volcanics of Leichhardt type, as well as of basalt. The sedimentary rocks generally are coarsest near the eastern margin of the Leichhardt River Fault Trough, suggesting derivation from the east. Four named members have been distinguished within the Eastern Creek Volcanics in the central and northern parts of the Leichhardt River Fault Trough. These are, from oldest to youngest, the Dynamite Creek Member (a sedimentary unit present locally at the base of the formation), Cromwell Metabasalt Member, Lena Quartzite Member, and the Pickwick Metabasalt Member.

TABLE 8. PROTEROZOIC STRATIGRAPHY—COVER SEQUENCE 2, WESTERN FOLD BELT

Name of unit (Maximum thickness in metres)	*Lithology*	*Relationships*
Quilalar Formation (1500+)	Upper part: carbonate-siltstone-sandstone facies—dolomitic siltstone and sandstone, stromatolitic dolomite, shale, feldspathic sandstone, calcareous siltstone, rhyolitic tuff, micaceous sandstone and siltstone, dolomitic breccia, quartz sandstone Lower part: sandstone facies-feldspathic sandstone, clayey sandstone; minor quartz sandstone, siltstone, shale, conglomerate, stromatolitic dolomite, mafic lava	Unconformable on Kalkadoon Granite and Leichhardt Volcanics; overlies Argylla Formation mainly concordantly; conformable to locally unconformable on Myally Subgroup; overlain unconformably (mainly disconformably) by Bigie Formation, Fiery Creek Volcanics, and Surprise Creek Formation; intruded by Weberra Granite
HASLINGDEN GROUP		
Myally Subgroup (3720+)	Feldspathic sandstone, quartz sandstone; minor siltstone, pebbly to conglomeratic sandstone, mudstone, arkose, shale, quartzite, schist, dolomitic sandstone, oolitic and stromatolitic dolomite; some felsic tuff at top and metabasalt near base	Unconformable on Leichhardt Volcanics and Ewen Granite; conformable on Eastern Creek Volcanics; overlain conformably by Quilalar Formation and unconformably (mainly disconformably) by Bigie Formation, Fiery Creek Volcanics, Surprise Creek Formation, Mount Isa Group and McNamara Group; intruded by Sybella Granite and metadolerite
Eastern Creek Volcanics (7200)	Schistose to massive metabasalt lava; generally subordinate quartzite, quartz sandstone, feldspathic sandstone, conglomerate, siltstone, marble, shale, greywacke, and schist.	Unconformable on Ewen Granite and probably Candover Metamorphics; conformable on Mount Guide Quartzite and Leander Quartzite; overlain conformably by Myally Subgroup and unconformably (commonly concordantly) by Carters Bore Rhyolite, Surprise Creek Formation, Mount Isa Group and McNamara Group; intruded by Sybella Granite, metadolerite
Leander Quartzite (5000+)	Upper part: quartz sandstone, feldspathic sandstone, quartzite; minor arkose and conglomerate Lower part: greywacke, schist, phyllite, feldspathic sandstone, basalt, tuff, pyritic siltstone	Base not exposed; overlain conformably by Eastern Creek Volcanics; intruded by mafic dykes
Mount Guide Quartzite (6200+)	Upper part: quartz sandstone, feldspathic sandstone (commonly sericitic), quartzite Lower part: metagreywacke, grit, conglomerate, arkose, feldspathic sandstone, micaceous sandstone, quartzite; minor metabasalt, felsic tuff, metasiltstone, schist	Unconformable on Kalkadoon Granite and some undivided Tewinga Group; conformable or disconformable on Bottletree Formation; overlain conformably by Eastern Creek Volcanics and possibly unconformably (in DAJARRA) by Carter Bore Rhyolite?; intruded by Sybella Granite, Garden Creek Porphyry, mafic dykes
May Downs Gneiss Member (500+)	Banded quartzofeldspathic gneiss with K-feldspar porphyroblasts, mica schist; minor quartzite	Base not exposed; overlain conformably? by quartzite assigned to Mount Guide Quartzite; intruded by Sybella Granite, pegmatite, and mafic dykes
Bottletree Formation (3000)	Commonly foliated porphyritic dacitic to rhyolitic lava and tuff; metabasalt lava; interlayered metagreywacke, conglomerate, quartzite and para-amphibolite	Unconformable on Kurbayia Migmatite, Kalkadoon Granite, and probably on some undivided Tewinga Group; overlain conformably or disconformably by Mount Guide Quartzite; intruded by mafic dykes
Oroopo Metabasalt (1000+)	Metabasalt lava; subordinate quartz, feldspathic and calcareous sandstone, metasiltstone, marble, dolomite, arkose; minor conglomerate, chloritic schist	Apparently concordant, but probably unconformable, on Saint Ronans Metamorphics; intruded by mafic dykes and probably Sybella Granite
Jayah Creek Metabasalt (15000?)	Metabasalt lava; subordinate schist, quartzite, sandstone, metasiltstone, para-amphibolite, metagreywacke, marble, conglomerate	Concordant, probably unconformable, on Sulieman Gneiss and Kallala Quartzite; intruded by Sybella Granite and mafic and felsic dykes
Kamarga Volcanics (1400+)	Basalt lava and minor interlayered feldspathic sandstone overlain by feldspathic sandstone, arkose, and conglomeratic sandstone	Overlies Yeldham Granite; overlain unconformably by McNamara Group

The *Myally Subgroup* conformably overlies the Eastern Creek Volcanics within the Leichhardt River Fault Trough and Lawn Hill Platform, and overlaps onto Leichhardt Volcanics and Ewen Granite in the Myally Shelf. The four formations of the subgroup—Alsace Quartzite, Bortala Formation, Withworth Quartzite, and Lochness Formation—consist predominantly of feldspathic and quartz sandstones. Some dolomitic and calcareous beds are present at the top of the Lochness Formation, part of which has been mapped separately as the Police Creek Siltstone Member. Minor felsic volcanics are present in the Lochness Formation and possibly in the Whitworth Quartzite, which in MAMMOTH MINES REGION also includes a 40 m-thick metabasalt lava (Scott & Taylor, 1982; Hutton & Wilson, 1985).

The *Jayah Creek Metabasalt* and *Oroopo Metabasalt* in the far southwest of the Leichhardt River Fault Trough (in ARDMORE) closely resemble the Eastern Creek Volcanics, a probable correlative, in lithology. They consist of basalt lava flows and mainly arenaceous sedimentary intercalations (which are generally finer grained than those in the Eastern Creek Volcanics), and are apparently concordant, but probably unconformable, on rocks tentatively assigned to the early Proterozoic basement. They are separated from each other, and from Eastern Creek Volcanics to the east, by major fault zones. The main sedimentary band within the Jayah Creek Metabasalt is the Timothy Creek Sandstone Member.

Another likely correlative of the Eastern Creek Volcanics is exposed on the eastern and southern flanks of the Kamarga

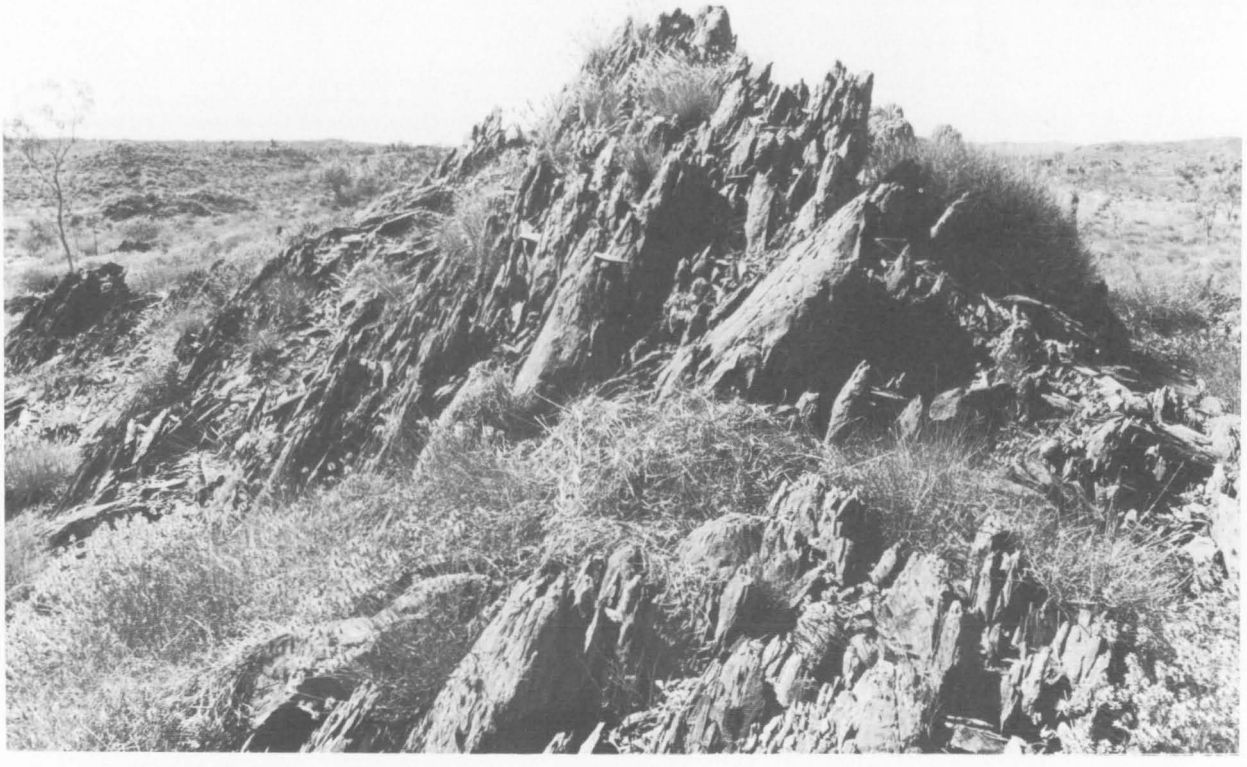


Fig. 16. Strongly cleaved amphibolitic metabasalt of the Eastern Creek Volcanics (cover sequence 2) 8 km west of Mount Isa, Leichhardt River Fault Trough, Western Fold Belt (MOUNT ISA GR 330100). R. M. Hill (M1338/14)

Dome of the Lawn Hill Platform in LAWN HILL REGION. This is the *Kamarga Volcanics,* a formation consisting of basaltic lava and minor interlayered sandstone overlain by feldspathic sandstone and arkose. Although reported by Hutton & Sweet (1980) to be intruded by Yeldham Granite (which has been dated at about 1820 Ma), more recent detailed mapping shows that the Kamarga Volcanics postdate this granite (D. Jones, personal communication 1984). As the formation is overlain unconformably by the McNamara Group of cover sequence 3, it may well belong to cover sequence 2 and be similar in age to the Eastern Creek Volcanics.

The *Quilalar Formation,* like the Myally Subgroup, which it overlies conformably and possibly disconformably, has not been identified in the southern part of the Western Fold Belt (in the Duchess–Urandangi region), but crops out extensively within the Lawn Hill Platform, Leichhardt River Fault Trough, and Myally Shelf to the north. It is also present in fault-bounded outcrops on the west side of the Kalkadoon–Leichhardt Belt in MARY KATHLEEN (GSQ, 1983a), where it was mapped as part of the Surprise Creek beds by Derrick & others (1977c). In the Myally Shelf the formation overlies, generally concordantly, felsic volcanics of the Argylla Formation (part of cover sequence 2 of the Kalkadoon–Leichhardt Belt). The lower part of the Quilalar Formation consists mainly of sandstone facies and the upper part mainly of carbonate–siltstone–sandstone facies (Table 8). Stromatolites and sedimentary structures in both parts indicate shallow-water environments, and the formation is considered to represent a regressive (lower part) to possibly transgressive (upper part) shoreline deposit (Derrick & others, 1980). Some basalt or trachybasalt is locally present near the base, and bands of rhyolitic tuff occur in the upper part.

Kalkadoon–Leichhardt Belt

In the Kalkadoon–Leichhardt Belt, the Leichhardt Volcanics of cover sequence 1 and comagmatic granitic intrusions of the Kalkadoon Batholith are overlain unconformably by cover sequence 2, which comprises the Magna Lynn Metabasalt and Argylla Formation of the Tewinga Group, the Ballara Quartzite and Corella Formation of the Mary Kathleen Group, and the Makbat Sandstone and Stanbroke Sandstone (Table 9). The Deighton Quartzite and White Blow Formation of the Mount Albert Group may belong to this cover sequence, but are tentatively assigned to cover sequence 3, as they have been correlated with the Surprise Creek Formation of cover sequence 3 by Derrick & others (1980). Fault-bounded outcrops of cover sequence 2 (and cover sequence 3) on the west side of the Kalkadoon–Leichhardt Belt (mainly in MARY KATHLEEN) are assigned to formations of the Western Fold Belt.

The two *Tewinga Group* formations, which are essentially the same age, as they interfinger with one another, have been regarded as basement (e.g., Derrick & others, 1976a, 1977c). However, U–Pb zircon dating indicates that (1) they are about 80 Ma younger than the Leichhardt Volcanics/Metamorphics of cover sequence 1, which they overlie disconformably, and (2) they are closely comparable in age to the Bottletree Formation of cover sequence 2 in the Western Fold Belt. The older of the two formations, the *Magna Lynn Metabasalt,* represents a series of subaerial or shallow-water basaltic lava flows (Figs 17, 18), some intercalated fluvial or shallow-marine clastic sedimentary rocks, and minor felsic volcanics of Argylla type. The overlying *Argylla Formation* consists predominantly of felsic volcanics, both ignimbrites and lavas, but also includes sedimentary rocks, possible high-

TABLE 9. PROTEROZOIC STRATIGRAPHY—COVER SEQUENCE 2, KALKADOON-LEICHHARDT BELT

Name of unit (Maximum thickness in metres)	*Lithology*	*Relationships*
MARY KATHLEEN GROUP		
Corella Formation (1260)	Banded calc-silicate granofels; laminated grey to black metasiltstone, shale and slate; marble; feldspathic sandstone and quartzite; phyllite; mica schist; minor metabasalt and cordierite-anthophyllite rock. Metasediments are variably calcareous, commonly scapolitic and actinolitic	Conformable on Ballara Quartzite; overlain unconformably or tectonically by Deighton Quartzite; intruded by Wonga Granite and Hardway Granite of Wonga Batholith and by metadolerite
Ballara Quartzite (1250)	Quartz sandstone, feldspathic sandstone, volcaniclastic sandstone, quartzite; arkose, grit, conglomerate, felsic tuff, ashstone, and rare metabasalt locally present in lower part; minor calcareous sandstone, siltstone, marble, scapolitic calc-silicate rocks, biotite schist, and metabasalt in upper part; some cordierite-anthophyllite rock	Unconformable or conformable on Argylla Formation; overlain conformably by Corella Formation and unconformably or tectonically by Deighton Quartzite; intruded by Wonga Granite and metadolerite
Makbat Sandstone (300+)	Feldspathic sandstone, quartz sandstone; minor siltstone, conglomerate, greywacke, shale	Unconformable on Leichhardt Volcanics and Wills Creek Granite; cut by dolerite dyke
Stanbroke Sandstone (300)	Quartz, feldspathic, calcareous and sericitic sandstone; minor marble, dolomite, siltstone, conglomerate, arkose, micaceous greywacke	Unconformable on Leichhardt Volcanics, undivided Tewinga Group, Magna Lynn Metabasalt, Argylla Formation, Wills Creek Granite
TEWINGA GROUP		
Argylla Formation (2000+)	Felsic volcanics and metavolcanics—porphyritic rhyolitic to dacitic ignimbrite and lava; subordinate bedded tuff, metabasalt, feldspathic sandstone, siltstone, quartz sandstone, and conglomerate	Unconformable on Leichhardt Volcanics; conformable on and locally interfingers with Magna Lynn Metabasalt; overlain conformably or unconformably by Quilalar Formation and Ballara Quartzite and unconformably by Stanbroke Sandstone; intruded by granites of Wonga Batholith (Birds Well, Bowlers Hole, Mairindi Creek, and Wonga Granites; Bushy Park Gneiss), felsic dykes and sills, and mafic dykes
Magna Lynn Metabasalt (1500)	Massive to schistose metabasalt lava, some possible andesite; generally minor intercalated quartzite, feldspathic and calcareous sandstone, siltstone, conglomerate, greywacke, chert, mafic tuff, and felsic volcanics	Unconformable on Leichhardt Volcanics and mafic dykes; overlain conformably by, and locally interfingers with, Argylla Formation; overlain unconformably by Stanbroke Sandstone; intruded by granites of Wonga Batholith (Mairindi Creek, Bowlers Hole, and Birds Well Granites, Bushy Park Gneiss) and mafic and felsic dykes

Fig. 17. Margin of basaltic lava flow; fragments of scoriaceous metabasalt in matrix of fine-grained quartz sandstone. Magna Lynn Metabasalt (cover sequence 2), Kalkadoon–Leichhardt Belt (MARY KATHLEEN GR 734018). (M2657/21A)

Fig. 18. Amygdales in basaltic lava flow within the Magna Lynn Metabasalt (cover sequence 2), Kalkadoon–Leichhardt Belt (PROSPECTOR GR 813395) — I. H. Wilson (M1537/10)

level felsic intrusives, and some basaltic lavas. Mixtures of contemporaneous mafic and felsic volcanics are present locally at contacts between the two formations (Fig. 20 in Blake & others, 1984). Felsic volcanics in the Argylla Formation have been dated at 1777 ± 7 (Page, 1978) and 1783 ± 5 (Page, 1983a). Chemically, they are similar in general to the felsic volcanics of the Bottletree Formation, and are readily distinguished from the Leichhardt felsic volcanics (see Chapter on Geochemistry of Igneous Rocks). Like those of the Bottletree Formation, but not the Leichhardt Volcanics, the Argylla felsic volcanics are commonly strongly magnetic. These characteristics have enabled some of the felsic rocks shown as undivided Tewinga Group in DAJARRA and DUCHESS REGION and as Leichhardt Metamorphics in MARY KATHLEEN (east of the East Leichhardt Dam) to be remapped as Argylla Formation.

The Argylla Formation is overlain generally concordantly by Ballara Quartzite in the Kalkadoon–Leichhardt Belt and by Quilalar Formation on the east side of the Myally Shelf. Contacts are concordant, as bedding in the upper part of the Argylla Formation is invariably parallel to that in the overlying units. The concordant contacts may represent a negligible time interval, as suggested by Blake (1980, 1981b), who has correlated the Magna Lynn Metabasalt with the Eastern Creek Volcanics and the Argylla Formation with the Myally Subgroup, or may mark a major unconformity representing the period of Haslingden Group deposition, as stated, for example, by Derrick & others (1977c) and Derrick & Wilson (1981b), and supported by Page (1983a).

The Ballara Quartzite and overlying Corella Formation, which are considered to be correlatives of the Quilalar Formation of the Western Fold Belt (e.g. Derrick & others, 1980), crop out in the central and eastern parts of the Kalkadoon–Leichhardt Belt. They include part of the Charley Creek Formation of Carter & others (1961), the other part of which is now mapped as Deighton Quartzite (cover sequence 3). The *Ballara Quartzite* consists mainly of quartz and feldspathic sandstones, commonly metamorphosed to quartzite, which probably represent near-shore shallow-marine deposits (Derrick & others, 1977c). However, it includes a discontinuous lower unit of possible fluvial deposits—feldspathic and volcaniclastic sandstone, grit and conglomerate—together with felsic tuff and rare metabasalt. The volcanic material in this lower unit is of Argylla-type rather than Leichhardt-type. Calcareous and scapolitic interbeds occur towards the top of the formation.

The *Corella Formation,* which is characterised by scapolitic and calcareous rocks, has lower and upper parts dominated by pelites, separated by a middle sandy unit. Minor metabasalt is present in the upper part in PROSPECTOR, and some metadolerite mapped as sills within the Corella Formation (e.g., in the Little Beauty and Rosebud Synclines in MARY KATHLEEN) may be extrusive rather than intrusive. The formation may have been deposited on a near-shore evaporitic carbonate shelf (Derrick & others, 1977c) or possibly in a lagoonal environment. The presence of scapolite is considered to result from regional metamorphism of halite-bearing sediments (Ramsay & Davidson, 1970), rather than from regional metasomatism, as suggested by Edwards & Baker (1954).

The Ballara Quartzite and Corella Formation are overlain unconformably or, as studies in progress indicate, tectonically, by the Deighton Quartzite of the Mount Albert Group (see section on Structure), and they are intruded by the Hardway Granite, which is assigned to the Wonga Batholith. As phases of this batholith have been dated at 1740–1670 Ma (Page, 1978, 1979, 1983b), both formations are probably older than 1740 Ma.

The *Makbat Sandstone* and *Stanbroke Sandstone,* which crop out in the south of the Kalkadoon–Leichhardt Belt (in the Duchess–Urandangi region), are assigned to cover sequence 2 because they are similar to the Ballara Quartzite in their lithology and in their relationship to the Tewinga Group, and are thought to be comparable in age. Both the Makbat Sandstone and Stanbroke Sandstone are exposed in synclinal structures (like the Ballara Quartzite and Corella Formation), consist mainly of quartzose to feldspathic sandstone, locally have basal conglomerates containing felsic volcanic detritus, and were probably deposited in shallow-marine environments. The Makbat Sandstone and underlying Leichhardt Volcanics and Wills Creek Granite do not appear to be metamorphosed, whereas much of the Stanbroke Sandstone has been extensively recrystallised. The Stanbroke Sandstone, unlike the Makbat Sandstone, includes some calcareous and dolomitic beds, especially in the upper part. It overlies Magna Lynn Metabasalt and Argylla Formation with slight angular unconformity in DUCHESS REGION.

Eastern Fold Belt

Cover sequence 2 is represented in the Eastern Fold Belt by the Argylla Formation (Tewinga Group) and formations of the Malbon, Mary Kathleen, and Soldiers Cap Groups (Table 10).

The *Argylla Formation* crops out in the southern and central parts of the Quamby–Malbon zone, mainly in the Bulonga and Duck Creek Anticlines. The dominant rock types are pink porphyritic felsic volcanics, including both ignimbrites and lavas (Fig. 19), and feldspathic to quartzose sandstones. These become increasingly metamorphosed and deformed to the south. Sandstones predominate in the upper part of the formation, and are much more voluminous than in the Argylla Formation of the Kalkadoon–Leichhardt Belt to the west. Shallow-water and subaerial environments are indicated (Derrick, 1980). The felsic volcanics are similar in lithology and chemistry to those in the Argylla Formation in the Kalkadoon–Leichhardt Belt, and are comparable,

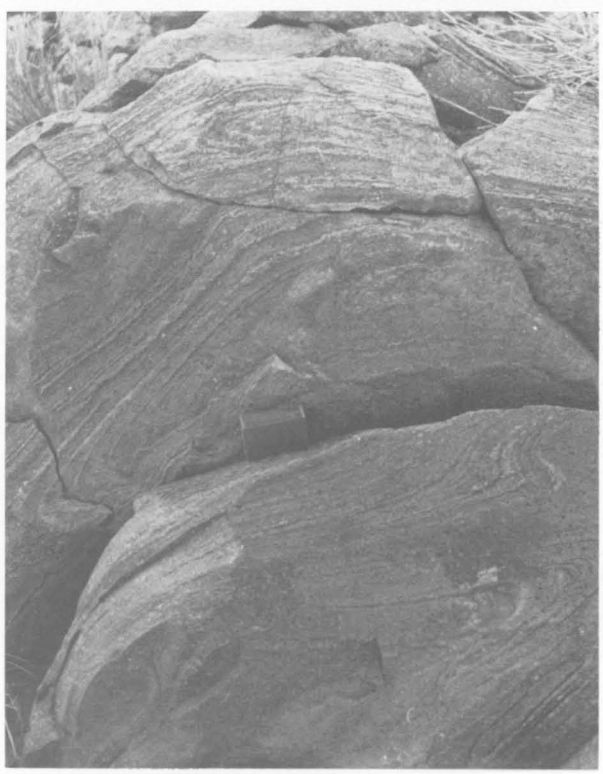


Fig. 19. Contorted flow-banding in rhyolite lava of the Argylla Formation (cover sequence 2), Quamby–Malbon zone, Eastern Fold Belt (MARRABA GR 190870). Scale given by matchbox in centre of photograph—G. M. Derrick (M929/15A)

though not necessarily identical in age: they have been dated at 1766^{+23}_{-19} Ma, which overlaps with the 1783 ± 5 Ma age for the Argylla volcanics to the west (Page, 1983a).

The conformably overlying *Malbon Group* comprises two formations, the Marraba Volcanics and Mitakoodi Quartzite, both of which are confined to the Quamby–Malbon zone. The older formation, the *Marraba Volcanics*, is made up mostly of basaltic lavas, which predominate in the lower part (Cone Creek Metabasalt Member), and calcareous and non-calcareous siltstone and sandstone, mainly in the upper part (Mount Start and Timberoo Members). Some possible pillow lavas have been reported in MARRABA, indicating that at least some of the lavas may have been subaqueous rather than subaerial. Day & others (1983) have interpreted shallow-marine or lacustrine environments for the formation. The Marraba Volcanics have been correlated with the Eastern Creek Volcanics to the west and part of the Soldiers Cap Group to the east (e.g., Carter & others, 1961; Derrick, 1980). This implies, presumably, that the conformably underlying Argylla Formation correlates with the lower part of the Haslingden Group, rather than being a significantly older unit, as stated for example by Derrick & Wilson (1981b). In contrast, Blake (1980) has suggested that both the Marraba Volcanics and Argylla Formation may postdate the Eastern Creek Volcanics. The overlying *Mitakoodi Quartzite* consists mainly of clastic rocks (Fig. 20) considered to represent fluvial, shallow shelf, or beach environments (Derrick, 1980), but it also includes basaltic lavas, some of which have been distinguished in MARRABA and KURIDALA REGION as the Wakeful Metabasalt Member, and felsic porphyry of Argylla type. The formation passes up conformably into Overhang Jaspilite and, in the southeast, Answer Slate, both of which are assigned to the Mary Kathleen Group.

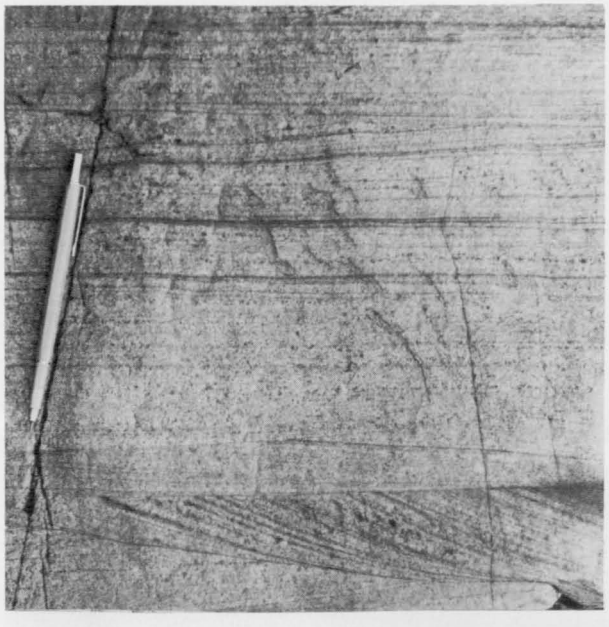


Fig. 20. Cross-bedded sandstone, Mitakoodi Quartzite (cover sequence 2), Quamby–Malbon zone, Eastern Fold Belt (MARRABA GR 295820). Cross-bedding is outlined by dark heavy mineral laminae—G. M. Derrick (M909/18)

In the Eastern Fold Belt, the *Mary Kathleen Group* is represented by the Ballara Quartzite, Corella Formation, Overhang Jaspilite (taken to include Chumvale Breccia of Carter & others, 1961; Derrick & others, 1977a; and Derrick, 1980), Answer Slate, Kuridala Formation, Staveley Formation, Agate Downs Siltstone, Marimo Slate, and Doherty Formation (Table 10).

The *Ballara Quartzite* forms a thin discontinuous band along the western edge of the highly deformed Mary Kathleen zone in MARRABA, PROSPECTOR, and QUAMBY. Here it is in concordant contact with mainly felsic orthogneisses of the Kalkadoon–Leichhardt Belt to the west and metasediments of the Corella Formation to the east.

The *Corella Formation* is the main unit exposed in the Mary Kathleen zone, where it consists predominantly of thinly banded calc-silicate rocks and marble that are commonly scapolitic (Fig. 21), but also includes brecciated calc-silicate rocks (Fig. 24), felsic and mafic metavolcanics (mainly in DUCHESS REGION), mica schist (some containing sillimanite), and quartzite. Some amphibolite shown as intrusive into the Corella Formation in DUCHESS REGION and MARRABA may be metamorphosed basaltic volcanics. A band of mafic volcanics, including pillow lava (Fig. 22), in MARRABA has been distinguished as the Lime Creek Metabasalt Member, and a pelitic unit in QUAMBY has been named the Dugald River Shale Member by Wilson (1984). The Corella Formation in this zone near Mary Kathleen is intruded by Burstall Granite (Fig. 23), associated rhyolite dykes, and Lunch Creek Gabbro, all of which have been dated at 1720–1740 Ma (Page, 1983b). In other parts of the zone, the formation is intruded by undated granites of the Wonga Batholith.

North of latitude 21°S, the Corella Formation has also been mapped in the Quamby–Melbon zone, where it is generally similar in lithology to the Corella Formation of the Mary Kathleen zone, and in the Cloncurry–Selwyn zone, where it is characterised by calc-silicate breccia (Fig. 24). In the Quamby–Malbon zone, it includes 'metarhyolite' dated at about 1600 Ma (U–Pb zircon; Page, 1983a). The dated rock is strongly sheared and recrystallised, and the zircons analysed may not be igneous. The 'metarhyolite' is possibly a volcanic (e.g., Blake, 1983), a volcaniclastic rock, an intrusive (e.g., Wilson, 1983b; Day & others, 1983), or a mylonite (e.g., M. A. Etheridge, personal communication, 1983).

The Corella Formation in the three zones of the Eastern Fold Belt differs from that in the Kalkadoon–Leichhardt Belt in being apparently much thicker (tectonically thickened?), in including abundant felsic and mafic volcanics, and in not being readily divisible into three lithologically distinct members (e.g., Blake, 1982). Also, not all of the Corella Formation in the Eastern Fold Belt may belong to cover

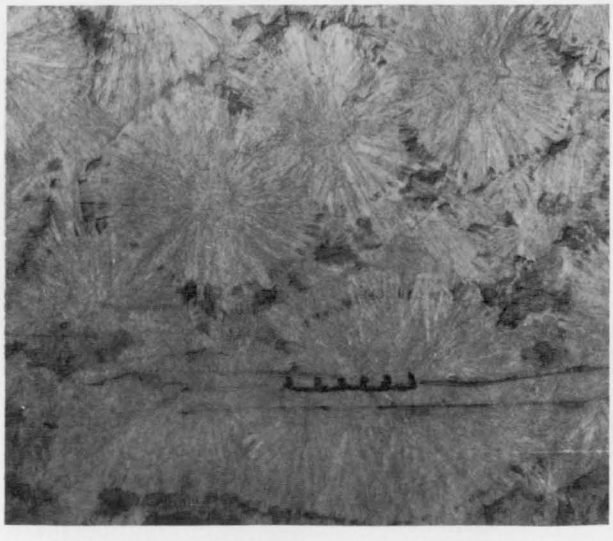


Fig. 21. Stellate clusters of scapolite crystals in calc-silicate granofels of the Corella Formation (cover sequence 2), Mary Kathleen zone of the Eastern Fold Belt (MARRABA GR 990025). Scale shown is in cm—G. M. Derrick (GA4299)

TABLE 10. PROTEROZOIC STRATIGRAPHY, COVER SEQUENCE 2—EASTERN FOLD BELT

Name of Unit (Maximum thickness in metres)	*Lithology*	*Relationships*
MARY KATHLEEN GROUP		
Corella Formation (4000+?)	Banded granulitic to gneissic calc-silicate rocks which are variably scapolitic, amphibolitic, siliceous, calcareous, feldspathic, and diopsidic/salitic; subordinate massive to schistose and gneissic mafic and felsic metavolcanics, metasiltstone, variably feldspathic, calcareous and micaceous quartzite, marble, mica schist, black slate, phyllite, breccia, dolomitic metasediments, shale	Concordant to W with Argylla Formation, Magna Lynn Metabasalt and Plum Mountain Gneiss of Kalkadoon-Leichhardt Belt. Conformable on Ballara Quartzite and overlain conformably or disconformably by Knapdale Quartzite (Mount Albert Group) in Mary Kathleen zone; conformable or disconformable on Overhang Jaspilite, conformable on Marimo Slate (in MARRABA) and overlain conformably or disconformably by Roxmere Quartzite of Mount Albert Group in Quamby-Malbon zone; probably overlies Soldiers Cap Group, either conformably or disconformably, in Quamby-Malbon and Cloncurry-Selwyn zones. Intruded by granitic rocks of Wonga, Naraku, and Williams Batholiths, Lunch Creek Gabbro, Mount Philp Breccia, metadolerite, and dolerite
Doherty Formation (1000+)	Thinly banded calc-silicate granofels and massive calc-silicate breccia; minor massive calc-silicate granofels, marble, mica schist, black slate, chert, variably calcareous and feldspathic quartzite, porphyritic rhyolite, metabasalt, para-amphibolite, and banded quartz-tourmaline rock	Probably overlies Soldier Cap Group either conformably or disconformably; faulted contacts with Staveley Formation, Kuridala Formation, and Marimo Slate; intruded by granitic rocks of Williams Batholith, and by mafic dykes and irregular bodies
Agate Downs Siltstone (500+)	Cherty and slaty metasiltstone, phyllite, quartzite; minor breccia	Conformable on Staveley Formation
Marimo Slate (2000)	Variably carbonaceous slate and siltstone; subordinate sandstone, chert, cherty siltstone, breccia, and marble	Conformable on, and may interfinger with, Staveley Formation; overlain conformably by Corella Formation and Roxmere Quartzite (in MARRABA); intruded by dolerite
Staveley Formation (2000+)	Interbedded sandstone, siltstone and phyllite/shale/mudstone which are variably calcareous, ferruginous, feldspathic, siliceous and micaceous; breccia; minor pyritic siltstone, marble, banded calc-silicate rocks, mica schist, conglomerate, banded quartz-hematite-magnetite rock, and altered basalt	Inferred to overlie, possibly unconformably, Double Crossing Metamorphics, Answer Slate, Overhang Jaspilite, Kuridala Formation, and Doherty Formation; overlain conformably by Marimo Slate, Agate Downs Siltstone, and Roxmere Quartzite; intruded by granitic rocks of Williams Batholith, metadolerite, and feldspar porphyry
Kuridala Formation (1000+)	Interbedded mica schist, schistose metagreywacke, graphitic and pyritic black slate and metasiltstone, phyllite meta-arkose, quartzite; minor banded calc-silicate granofels, chert, quartz-albite rock, banded iron formation, banded quartz-hematite-magnetite rock, mafic metavolcanics	Base not identified; appears to merge laterally with Answer Slate to W and Soldiers Cap Group to E; inferred to be overlain, possibly unconformably, by Staveley Formation; intruded by granite of Williams Batholith, metadolerite and dolerite
Answer Slate (1000+)	Metasiltstone, slate, phyllite, commonly graphitic and pyritic; minor feldspathic quartzite, metagreywacke, chert, quartz-albite rock, marble, mica-schist, quartz-hematite rock	Conformable on Mitakoodi Quartzite and Overhang Jaspilite; may be unconformable on Double Crossing Metamorphics; appears to merge laterally with Kuridala Formation; inferred to be overlain, possibly unconformably, by Staveley Formation; intruded by granite of Williams Batholith and metadolerite
Overhang Jaspilite (~1000)	Thinly bedded siltstone, chert, impure marble, jaspilite and breccia; minor sandstone, quartzite, phyllite, ironstone; locally scapolitic; some stromatolites	Conformable on Mitakoodi Quartzite; overlain conformably by Answer Slate and possibly unconformably in MARRABA by Corella Formation and Marine Slate and in KURIDALA REGION by Staveley Formation; intruded by granite of Williams Batholith and metadolerite
Ballara Quartzite (80)	Quartzite	Concordant on Argylla Formation of Kalkadoon-Leichhardt Belt; overlain conformably by Corella Formation
MALBON GROUP		
Mitakoodi Quartzite (3000?)	Feldspathic quartzite and sandstone; minor calcareous quartzite, metagreywacke, metasiltstone, phyllite, schist, metabasalt, felsic porphyry, conglomerate, jaspilite, scapolitic calc-silicate rocks, quartz-hematite rock, chert, marble	Concordant (conformable?) on Argylla Formation; conformable on Marraba Volcanics; overlain conformably by Overhang Jaspilite and Answer Slate; intruded by granite of Williams and Naraku Batholiths and metadolerite
Marraba Volcanics (3500)	Metabasalt, metasiltstone, siltstone, feldspathic and calcareous sandstone and quartzite, biotite schist; minor slate, marble, dolomitic marl, shale, felsic metavolcanics, possible andesite, and conglomerate	Conformable on Argylla Formation; overlain conformably by Mitakoodi Quartzite; intruded by granite of Williams Batholith and metadolerite

TABLE 10 (Continued)

Name of unit (Maximum thickness in metres)	*Lithology*	*Relationships*
TEWINGA GROUP		
Argylla Formation (2000+)	Felsic volcanics and metavolcanics; quartz, feldspathic, and rare calcareous sandstone; quartzite; minor metabasalt, andesite? and mafic schist	Base not exposed. Overlain conformably by Marraba Volcanics, concordantly (conformably?) by Mitakoodi Quartzite; intruded by granitic rocks of Williams and Naraku Batholiths and by metadolerite
SOLDIERS CAP GROUP		
Undivided (1000+)	Mica schist, gneiss, migmatitic gneiss, quartzite, feldspathic quartzite, metagreywacke, metabasalt, para-amphibolite; minor calc-silicate rocks, chert, banded iron formation, metarhyolite, pegmatite	Base not exposed. Inferred to be overlain conformably or unconformably or tectonically by Corella Formation (N of latitude 21°S) and Doherty Formation (to S); appears to merge laterally with Kuridala Formation in S; intruded by granite of Naraku and Williams Batholiths, metadolerite and dolerite
Toole Creek Volcanics (2800+)	Metabasalt, metasiltstone, phyllite, mica schist, quartzite, feldspathic quartzite, chert, jaspilite, banded calc-silicate rocks, banded iron formation, slate	Conformable on Mount Norna Quartzite; overlain unconformably? by Corella Formation and Doherty Formation; intruded by granite of Naraku and Williams Batholiths and metadolerite
Mount Norna Quartzite (2700)	Feldspathic quartzite, quartzite, phyllite, mica schist; minor metabasalt, metagreywacke, conglomerate, banded iron formation, marble, chert, tuff, felsic metavolcanics	Conformable on Llewellyn Creek Formation, overlain conformably by Toole Creek Volcanics, unconformably? by Corella Formation, and tectonically by Doherty Formation; intruded by granite of Naraku and Williams Batholiths and metadolerite
Llewellyn Creek Formation (2000+)	Mica schist, phyllite, and metagreywacke; minor metabasalt, feldspathic quartzite	Base not exposed. Overlain conformably by Mount Norna Quartzite and conformably or unconformably or tectonically by Corella Formation; intruded by granite of Williams Batholith and metadolerite

Fig. 22. Pillow lava in the Lime Creek Metabasalt Member of the Corella Formation (cover sequence 2), Mary Kathleen zone, Eastern Fold Belt (MARRABA GR 095175). Top is to left—G. M. Derrick (GA2796)

Fig. 23. Thinly banded calc-silicate granofels of the Corella Formation (cover sequence 2) cut by Burstall Granite of the Wonga Batholith, Mary Kathleen zone, Eastern Fold Belt (MARRABA GR 037060) — G. M. Derrick (GA2775)

sequence 2: Blake (1980, 1981b, 1982, 1983) has suggested that one part may be older than the Leichhardt Volcanics and belong to the pre-1875 Ma basement, and another part may be younger than 1700 Ma. This suggestion has been refuted by Derrick & Wilson (1981b) and Wilson (1983b), but is partly supported by Wilson (see GSQ, 1983a), who has re-interpreted some of the quartzitic rocks shown as Corella Formation in the Mary Kathleen zone of MARRABA as Knapdale

Fig. 24. Calc-silicate breccias in the Eastern Fold Belt mapped as Corella Formation (cover sequence 2). Top: in the Quamby–Malbon zone (at MARRABA GR 477987) — G. M. Derrick (M895/1). Bottom: in the Cloncurry–Selwyn zone (CLONCURRY GR 685013). (M2684/33)

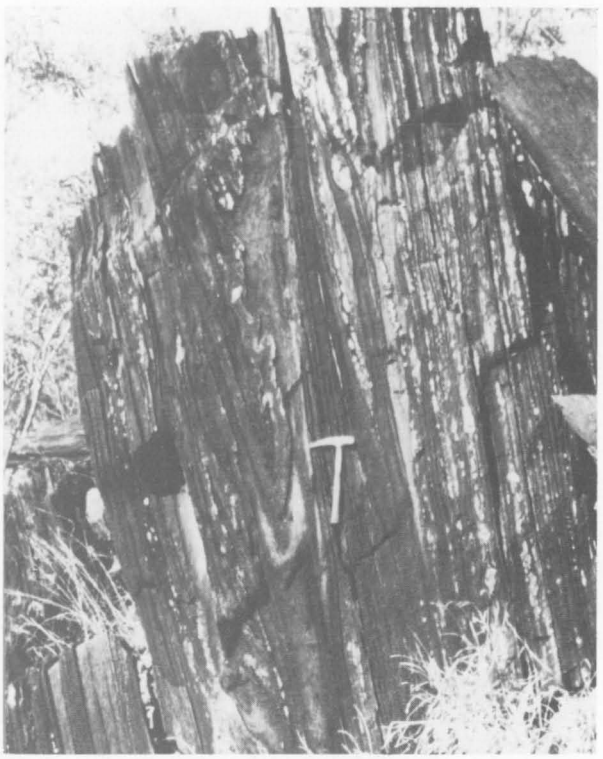


Fig. 25. Tight folds in calcareous siltstone and chert of the Overhang Jaspilite (cover sequence 2) adjacent to the Pilgrim Fault, Quamby–Malbon zone, Eastern Fold Belt (MARY KATHLEEN GR 975810). (M2657/12A)

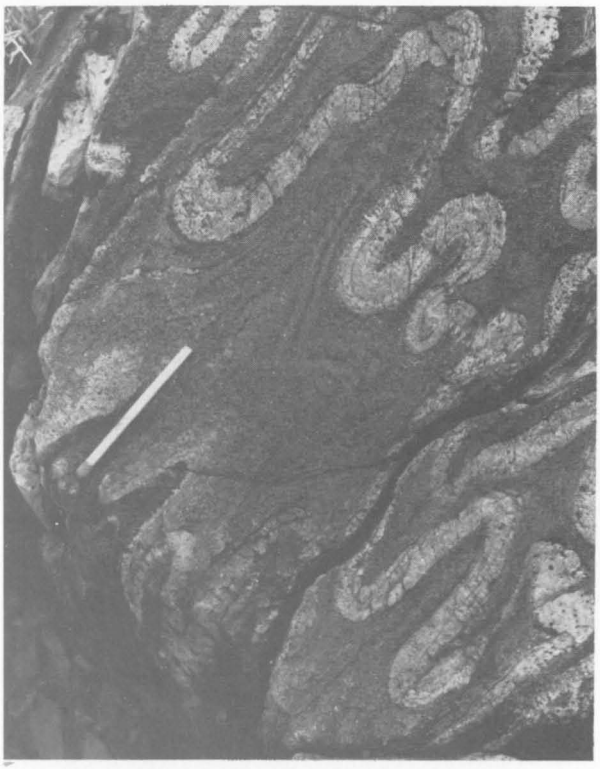


Fig. 26. Contorted cherty beds, Overhang Jaspilite (cover sequence 2), Quamby–Malbon zone, Eastern Fold Belt (MARRABA GR 370780) — G. M. Derrick (M909/14A)

Quartzite; a formation assigned to the Mount Albert Group: this group is correlated by Derrick & others (1980) with the Surprise Creek Formation, which belongs to cover sequence 3 of the Western Fold Belt and is younger than 1680 Ma. Presumably, the contact between the revised Corella Formation and Knapdale Quartzite is disconformable. The possible basement Corella Formation includes calc-silicate rocks which were tightly folded before they were intruded by granitic rocks of the Wonga Batholith. Corella rocks possibly younger than 1700 Ma, include those associated with the metarhyolite dated at 1600 Ma in the Quamby-Malbon zone.

The basal formations of the Mary Kathleen Group in the Quamby-Malbon zone are the Overhang Jaspilite and, in the southeast, the Answer Slate. The *Overhang Jaspilite* consists mainly of thin-bedded calcareous and cherty rocks (Figs 25, 26), some of which are stromatolitic, and is regarded as a shallow platform or lagoonal unit. The top of the formation is generally, if not invariably, marked by breccia (part of which has been mapped as Chumvale Breccia in MARRABA). The breccia may be a fossil regolith marking

an unconformity, or a tectonic feature related to subsequent folding and faulting (e.g., Derrick, 1980). A concordant contact with overlying Corella Formation in MARRABA may be either an unconformity (Day & others, 1983) or a fault or thrust plane. The *Answer Slate,* a largely carbonaceous and commonly pyritic formation, appears to be a correlative of the Overhang Jaspilite (both units have gradational contacts with underlying Mitakoodi Quartzite) and may be a distal facies equivalent of turbiditic and other sedimentary rocks of the Kuridala Formation exposed to the east, in the Cloncurry–Selwyn zone. It may have been deposited in a quiet-water environment with local reducing conditions.

The *Kuridala Formation,* which is largely confined to the southern part of the Cloncurry–Selwyn zone, consists mainly of greywacke, siltstone, and shale, now mostly metamorphosed to schist. These are thought to be derived from an eastern source, as their grain-size and feldspar content generally increases to the east, where the formation appears to merge laterally with the Soldiers Cap Group. Also present are quartzite, carbonaceous and pyritic slate (the Mount Elliott and Hampden Slate Members of White, 1957), calc-silicate rocks, and banded iron-formation of possibly exhalative type which in places, as at the Pegmont prospect, contains subeconomic syngenetic Pb–Zn–Cu deposits. The top and base of the Kuridala Formation have yet to be satisfactorily established (Blake & others, 1984).

The *Staveley Formation* is mainly restricted to the Quamby–Malbon zone. It is characterised by well-bedded to locally brecciated calcareous, ferruginous, feldspathic, siliceous and micaceous sedimentary rocks, and is considered by Donchak & others (1983) to probably overlie the Kuridala Formation, possibly unconformably. Carter & others (1961), on the other hand, considered the Staveley Formation to be the older unit. Contacts between these two formations are not clearly defined, and some rocks mapped as Kuridala Formation west and north of the Mount Cobalt mine in SELWYN REGION may be better assigned to the Staveley Formation.

The *Agate Downs Siltstone* and *Marimo Slate,* both of which are confined to the Quamby–Malbon zone, overlie the Staveley Formation with apparent conformity. The Marimo Slate (Fig. 27) is similar in lithology to the Answer Slate, with which it has been correlated (e.g., Carter & others, 1961), but is tentatively considered by Blake & others (1984) to be a younger unit. In places, the Marimo Slate contains abundant small holes possibly representing altered porphyroblasts, diagenetic sulphide-clay spherules, or organic structures (Derrick, 1980). Some calcareous rocks interlayered with Marimo Slate have been mapped as Corella Formation in MARRABA. The Toby Barty and Mick Creek Sandstone Members of the Marimo Slate mapped in MARRABA, and extending south into KURIDALA REGION, are now assigned to the Roxmere Quartzite (GSQ, 1983a) of cover sequence 3: their contacts with adjacent units are commonly marked by zones of probably tectonic red-brown breccia formed of Marimo Slate or Staveley Formation rock fragments.

The *Doherty Formation* has been mapped only in the Cloncurry–Selwyn zone. Although consisting mainly of thinly banded calc-silicate granofels and massive calc-silicate breccia, it includes some carbonaceous slate, like most other formations of the Mary Kathleen Group, and also porphyritic rhyolite dated at 1720±7 Ma (Page, 1983a). The Doherty Formation, therefore, appears to be younger than the Corella Formation of the Mary Kathleen zone, which is intruded by 1720–1740 Ma felsic and mafic igneous rocks. Breccia in the Doherty Formation, and also that in the correlative Corella Formation in CLONCURRY (Fig. 24), typically contains angular to partly rounded fragments of calc-silicate rocks, ranging in size from less than a few centimetres to tens of

Fig. 27. Folded and cleaved laminated siltstone of the Marimo Slate (cover sequence 2), Quamby–Malbon zone, Eastern Fold Belt (MARRABA GR 382885) — G. M. Derrick (M909/1)

metres long, in an abundant to sparse matrix of generally similar overall composition to the enclosed fragments. Some breccia contains fragments of several rock types, including a variety of calc-silicate rocks and, in some cases, jasper, chert, amphibolite, leucogranite, possible felsic volcanics, and Soldiers Cap-type schist.

Several interpretations have been put forward to account for the breccias, including a pyroclastic origin (Honman, 1939) and a reef debris origin (Carter & others, 1961). However, most of the breccia is probably tectonic, and related to post-depositional folding, faulting, and igneous activity (Glikson, 1972; Blake & others, 1984). Some breccia forms dyke and pod-like bodies which postdate a deformation and metamorphic event affecting the calc-silicate rocks (R. J. Ryburn, personal communication 1984).

The stratigraphic relationship of the Doherty Formation and correlative Corella Formation to the Soldiers Cap Group in the Cloncurry–Selwyn zone is not clear, because contacts appear to be generally tectonic, typically being marked by calc-silicate breccia. However, where bedding can be identified in these units close to the contact, it is approximately parallel to the contact, indicating a possible conformable or disconformable relationship (Blake & Derrick, 1980; Blake & others, 1984). Certainly, no major angular unconformity, as stated for example by Glikson (1972), Derrick & others (1976e, 1977a), and Day & others (1983), has been demonstrated. The Doherty Formation/Corella Formation is considered to be the younger unit.

The *Soldiers Cap Group* crops out in the north of the Quamby–Malbon zone (in COOLULAH and QUAMBY), where it forms part of the northerly trending Boomarra Horst, and more extensively in the Cloncurry–Selwyn zone. In neither zone is the base of the group exposed. In the

Quamby-Malbon zone, the Soldiers Cap Group consists mainly of quartzitic metasediments, schist, and amphibolite, but also includes some calc-silicate rocks and felsic metavolcanics. Here it is thought to be overlain, possibly unconformably, by calcareous metasediments of the Corella Formation (Wilson & Grimes, 1986).

In the northern part of the Cloncurry-Selwyn zone (in CLONCURRY and northern KURIDALA REGION), the Soldiers Cap Group has been divided into three formations: from oldest to youngest, the *Llewellyn Creek Formation, Mount Norna Quartzite*, and *Toole Creek Volcanics*. These formations have not been identified in the southern part of the zone nor in the Quamby-Malbon zone. The main rock types of the group in the Cloncurry-Selwyn zone are mica schist, phyllite, and metagreywacke (Fig. 28), which characterise the Llewellyn Creek Formation but also occur in other units; variably feldspathic quartzite, predominating in the Mount Norna Quartzite (Fig. 29); metabasalt, which is most abundant in the Toole Creek Volcanics; and gneiss and migmatitic gneiss, common in the undivided Soldiers Cap Group of the Duchess-Urandangi region. Other rock types present include calc-silicate rocks, felsic metavolcanics, some of which are petrographically similar to the Potosi Gneiss of the Broken Hill area, New South Wales (Blake & others, 1984), and banded iron formation like that in the Kuridala Formation.

The abundance of greywacke, which in the north commonly has graded-bedding preserved, shows that much of the group probably represents turbiditic deposits (e.g., Ryburn & others in preparation). A general decrease in grain-size and feldspar content westwards in the south indicates that the source for much of the detritus may have been to the east.

The Soldiers Cap Group is inferred to be overlain by the Doherty Formation and Corella Formation either conformably or unconformably. In the south, it appears to merge laterally westwards into the Kuridala Formation. Its age is uncertain, because of uncertain stratigraphic correlations and a lack of isotopic dates.

Fig. 28. Turbiditic metagreywacke showing graded bedding, Llewellyn Creek Formation of the Soldiers Cap Group (cover sequence 2), Cloncurry–Selwyn zone, Eastern Fold Belt (CLONCURRY GR 667808), The beds grade up from left to right, but their originally fine-grained tops are now crowded with andalusite porphyroblasts— R. J. Ryburn (M2686/22 and 11)

Cover Sequence 3 (1680 to 1670 Ma or younger)

Sedimentary and volcanic rocks assigned to cover sequence 3 (Fig. 30) are extensively exposed west of the Kalkadoon-Leichhardt Belt — in the Western Fold Belt, on the north and south sides of the Murphy Tectonic Ridge, and in small inliers within and southwest of the South Nicholson Basin. Here they make up the Lawn Hill Platform cover of Hutton & Sweet (1982), and also include the Tawallah Group of the McArthur Basin and the Mount Isa Group of the eastern part of the Western Fold Belt (Table 11). Units of possibly similar age in the eastern part of the Kalkadoon-Leichhardt Belt and in the Eastern Fold Belt are assigned to the Mount Albert Group (Table 12).

West of the Kalkadoon-Leichhardt Belt

The oldest formations of cover sequence 3 in the Western Fold Belt are the Carters Bore Rhyolite, exposed in the central

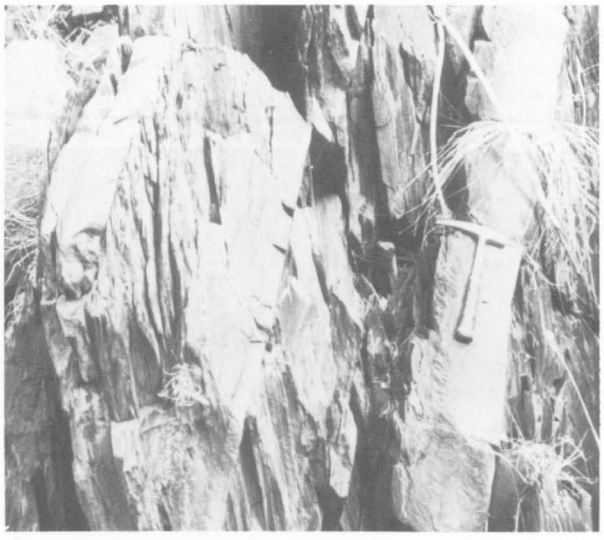


Fig. 29. Beds of feldspathic quartzite grading up (to left) into phyllite, Mount Norna Quartzite of the Soldiers Cap Group (cover sequence 2), Cloncurry–Selwyn zone, Eastern Fold Belt (KURIDALA REGION GR 718778) — R. J. Ryburn (M2686/23)

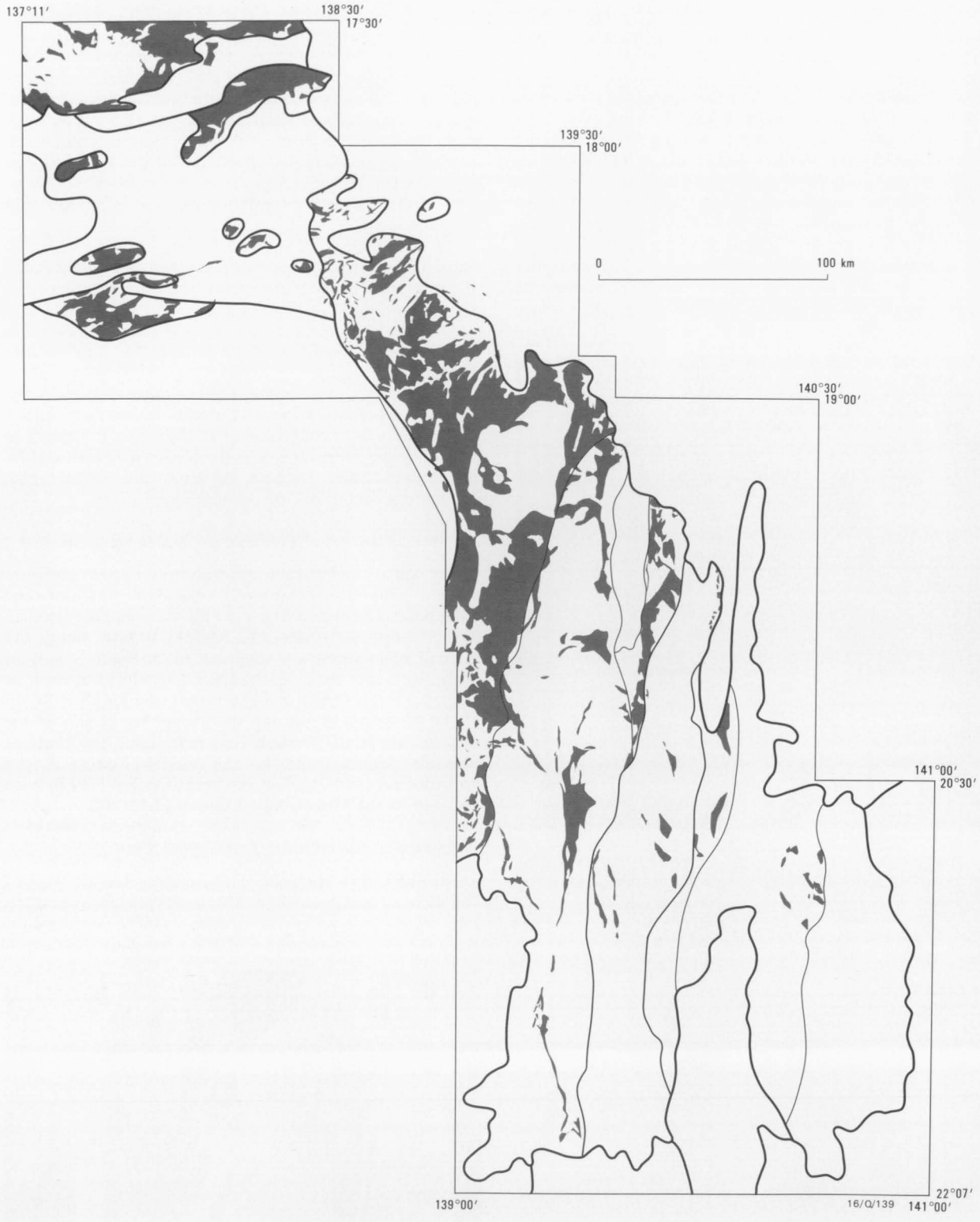


Fig. 30. Distribution of cover sequence 3 outcrops (in black).

part of the Leichhardt River Fault Trough, and the Bigie Formation and Fiery Creek Volcanics, which crop out in the northern parts of the Leichhardt River Trough and Myally Shelf and in the eastern part of the Lawn Hill Platform. These formations are overlain disconformably and locally with angular unconformity by the Surprise Creek Formation, which in turn is overlain comformably, disconformably, and also with slight angular unconformity, by the Mount Isa Group in the Leichhardt River Fault Trough and the McNamara Group in the Lawn Hill Platform. To the north, the McNamara Group is exposed as inliers within the South Nicholson Basin, and also crops out on the southwest side of this basin, where it is unconformable on the Carrara Range Group, a correlative of the Bigie Formation and Fiery Creek Volcanics. The Carrara Range Group correlates with the Wire Creek Sandstone and Peters Creek Volcanics, exposed on the south side of the Murphy Tectonic Ridge and with the Tawallah Group of the McArthur Basin to the north. The

TABLE 11. PROTEROZOIC STRATIGRAPHY—COVER SEQUENCE 3, WEST OF KALKADOON-LEICHHARDT BELT

Name of Unit (Maximum thickness in metres)	*Lithology*	*Relationships*
FICKLING GROUP (950+)	Oolitic, stromatolitic, and intraclastic dolomite; dolomitic siltstone and shale; chert, quartz sandstone, micaceous siltstone; some conglomerate lenses in basal part	Unconformable on Peters Creek Volcanics and Wire Creek Sandstone (cover sequence 3), Nicholson Granite Complex, and Murphy Metamorphics (basement); overlain unconformably by South Nicholson Group
McNAMARA GROUP (8500)	Upper part: siltstone, sandstone dolomite, shale, greywacke; minor felsic tuff Lower part: dolomite, stromatolitic dolomite, siltstone, sandstone, stromatolitic chert; some conglomerate at base; minor felsic tuff	Unconformable on Surprise Creek Formation (mainly disconformable), Carters Bore Rhyolite, and Carrara Range Group (cover sequence 3); on Myally Subgroup, Eastern Creek Volcanics, Leander Quartzite, and Kamarga Volcanics (cover sequence 2); on Yaringa Metamorphics (basement); on Yeldham Granite and possibly also on Sybella Granite. Overlain unconformably by South Nicholson Group
MOUNT ISA GROUP (4500)	Siltstone and shale which are commonly dolomitic, calcareous or pyritic; minor sandstone and conglomerate, mainly at base, and felsic tuff	Unconformable on Surprise Creek Formation (mainly disconformable) and possibly on Carters Bore Rhyolite? (in DAJARRA) of cover sequence 3; on Myally Subgroup and Eastern Creek Volcanics (cover sequence 2); intruded by a few mafic dykes
Surprise Creek Formation (2000+)	Sandstone, siltstone, shale; minor conglomerate, dolomite. Beds become generally finer grained towards top	Unconformable on Fiery Creek Volcanics and Bigie Formation (cover sequence 3); on Quilalar Formation, Myally Subgroup, Eastern Creek Volcanics, and Argylla Formation (cover sequence 2); on Kalkadoon Granite; overlain mainly disconformably by Mount Isa and McNamara Groups
TAWALLAH GROUP (3500)	Sandstone, conglomerate, basalt, siltstone, dolomite	Unconformable on Cliffdale Volcanics (cover sequence 1) and Nicholson Granite Complex
Peters Creek Volcanics (2000)	Basalt, rhyolite, intermediate volcanics; minor interlayered sandstone, siltstone, tuff, dolomite, conglomerate, mudstone	Conformable on Wire Creek Sandstone; overlain unconformably by Fickling Group
Wire Creek Sandstone (50)	Sandstone with scattered pebbles, conglomerate	Unconformable on Cliffdale Volcanics (cover sequence 1) and Nicholson Granite Complex; overlain conformably by Peters Creek Volcanics
CARRARA RANGE GROUP (2000)	Basalt/trachyte, porphyritic rhyolite, sandstone; minor conglomerate in basal part	Unconformable on Murphy Metamorphics (basement); overlain unconformably by McNamara Group
Fiery Creek Volcanics (250)	Rhyolite, trachybasalt, interlayered sandstone and conglomerate	Unconformable on Myally Subgroup and Quilalar Formation (cover sequence 2); conformable on Bigie Formation; overlain unconformably by Surprise Creek Formation
Bigie Formation (600)	Hematitic lithic and feldspathic sandstone, pebbly sandstone, conglomerate; minor siltstone, shale, marl, limestone	Unconformable on Myally Subgroup and Quilalar Formation (cover sequence 2); overlain conformably by Fiery Creek Volcanics and unconformably by Surprise Creek Formation
Carters Bore Rhyolite (200+)	Porphyritic rhyolite, rhyolitic tuff and agglomerate; minor schistose quartz porphyry, altered basalt	Unconformable (mainly disconformable) on Myally Subgroup and Eastern Creek Volcanics (cover sequence 2); overlain unconformably by McNamara Group (cover sequence 3). In Dajarra possible Carters Bore Rhyolite is concordant with Mount Guide Quartzite and Mount Isa Group

Peters Creek Volcanics are overlain unconformably by the Fickling Group, a correlative of the McNamara Group. A major unconformity separates the Fickling and McNamara Groups from the younger Proterozoic (less than 1500 Ma old) South Nicholson Group of the South Nicholson Basin.

The *Carters Bore Rhyolite* consists of felsic volcanics, a sample of which has been dated at 1678 ± 1 Ma (Page, 1978). It is tentatively taken to include a band of interbedded rhyolitic tuff and quartz sandstone exposed in southwestern DAJARRA. The *Bigie Formation* and conformably overlying *Fiery Creek Volcanics* are correlated with the Carters Bore Rhyolite (Derrick & others, 1980; Hutton & others, 1981; Hutton & Sweet, 1982). Redbed sandstone, pebbly sandstone and conglomerate (Fig. 31A) predominating in the Bigie Formation are regarded as mainly fluvial deposits (Hutton & Sweet, 1982) laid down on an uplifted and dissected land surface. Succeeding felsic and mafic lavas of the Fiery Creek Volcanics are probably subaerial. They are generally much altered and highly potassic. Both units are hematitic, possibly due to diagenetic alteration of detrital and igneous iron minerals under dry tropical conditions (Hutton & Sweet, 1982).

The correlative *Carrara Range Group* of CARRARA RANGE REGION to the west comprises a basal sandstone unit (Don Creek Sandstone), a middle unit of mainly basaltic or trachytic extrusives (Mitchiebo Volcanics), and an upper unit of mainly felsic porphyry (Top Rocky Rhyolite). The basal unit is inferred to be unconformable on the Murphy Metamorphics of the basement and to be overlain conformably by the middle unit, which is separated from the upper unit by an erosional unconformity with a relief of up to 120 m (Sweet, 1983b).

TABLE 12. PROTEROZOIC STRATIGRAPHY—COVER SEQUENCE 3, KALKADOON-LEICHHARDT BELT AND EASTERN FOLD BELT

Name of Unit (Maximum thickness in metres)	*Lithology*	*Relationships*
MOUNT ALBERT GROUP		
Undivided (2000+)	Feldspathic sandstone, pebbly sandstone, conglomerate; minor mudstone, quartz sandstone	Unconformable on Corella Formation
Lady Clayre Dolomite (3000)	Dark brown to black dolomite and dolomitic siltstone, commonly pyrrhotitic and scapolitic; minor quartz sandstone, siltstone, micaceous sandstone	Considered to be conformable on Coocerina Formation, though contact marked by fault zone
Coocerina Formation (400)	Calcareous black shale, scapolitic metasiltstone; minor pyritic shale, micaceous metasiltstone, sandstone, and laminated calc-silicate granofels	Conformable on Knapdale Quartzite; may be overlain conformably by Lady Clayre Dolomite
Knapdale Quartzite (2000+)	Feldspathic, quartzose, calcareous and micaceous sandstone and quartzite; minor siltstone, conglomerate	Concordant with (disconformable or conformable on?) Corella Formation; overlain conformably by Coocerina Formation
White Blow Formation (1000)	Micaceous siltstone, phyllite, schist, porphyroblastic (garnet, staurolite, andalusite) schist, laminated marble and scapolitic calc-silicate granofels, quartzite, black slate, calcareous and feldspathic sandstone and siltstone	Conformable to locally unconformable on Deighton Quartzite
Deighton Quartzite (2700)	Feldspathic, lithic and quartz sandstone, pebbly sandstone; minor siltstone, marble, shale, phyllite, schist, conglomerate	Unconformable (or thrust over?) Corella Formation, Ballara Quartzite, and Magna Lynn Metabasalt (cover sequence 2) and Leichhardt Volcanics (cover sequence 1); overlain conformably and locally unconformably by White Blow Formation
Roxmere Quartzite (2000+)	Feldspathic and quartz sandstone; minor calcareous and micaceous siltstone, calcareous sandstone, conglomerate, breccia	Conformable or disconformable on (or thrust over) Corella Formation, Staveley Formation, Marimo Slate

Correlative units to the north, on the Murphy Tectonic Ridge (in HEDLEYS CREEK and SEIGAL), unconformably overlie the early Proterozoic Cliffdale Volcanics (cover sequence 1) and Nicholson Granite Complex. These units are the *Wire Creek Sandstone* and *Peters Creek Volcanics* in the south and the *Tawallah Group* of the McArthur Basin sequence in the north. The Wire Creek Sandstone (Fig. 31B) and the oldest formation of the Tawallah Group, the Westmoreland Conglomerate (Fig. 31C), are considered to be alluvial fan and braided stream deposits which, though of the same age, were always separated by the Murphy Tectonic Ridge (Sweet & others, 1981). According to Ahmad & others (1984), the detritus forming the Westmoreland Conglomerate was derived from the northeast, not from the Murphy Tectonic Ridge as suggested by Plumb & Derrick (1975), although the source consisted of igneous and metamorphic rocks similar to those exposed on this Ridge. Basaltic and rhyolitic extrusives of the Peters Creek Volcanics, like those of the correlative Fiery Creek Volcanics, are generally highly potassic and much altered; whether the high potash content is an original igneous feature or is due to diagenetic or subsequent alteration has not been determined. In the Tawallah Group, the Westmoreland Conglomerate is succeeded by the basaltic Seigal Volcanics (a correlative of the Peters Creek Volcanics), above which come near-shore marine and lagoonal dolomite, sandstone and siltstone of the McDermott Formation, sandstone and minor conglomerate of the Sly Creek Sandstone (which overlies both the Seigal Volcanics and McDermott Formation probably unconformably), and poorly exposed sedimentary rocks of the Aquarium Formation and extrusives of the Settlement Creek Volcanics.

In the Western Fold Belt, the Bigie Formation and Fiery Creek Volcanics are overlain generally disconformably, but locally with an angular unconformity, by the *Surprise Creek Formation*, which also overlies older units. Fault-bounded outcrops mapped as Surprise Creek beds in MARY KATHLEEN on the west side of the Kalkadoon-Leichhardt Belt are now mapped partly as Surprise Creek Formation, and partly as Myally Subgroup, Quilalar Formation, and Mount Isa Group (GSQ, 1983a). The Surprise Creek Formation becomes generally finer-grained upwards (Derrick & others, 1980), with conglomerate and sandstone representing braided stream and alluvial fan deposits in the lower part, passing up into probably shallow-marine sandstone, siltstone, and shale (Fig. 32). The basal part shows some pronounced variations in thickness; on the Myally Shelf near Dobbyn, for example, it ranges from 400 m to 2000 m thick along 4 km of strike length, reflecting the sudden appearance of conglomeratic channel-fill deposits (Derrick & others, 1980). Conglomerates near the base of the formation consist mainly of quartzite clasts, but also contain some jasper and rare volcanic and plutonic clasts. No correlatives of the Surprise Creek Formation have been identified to the north and west of the Mount Isa Inlier. The formation is overlain unconformably (mainly disconformably), and also apparently conformably, by the Mount Isa Group on the Myally Shelf and in the Leichardt River Fault Trough and by the McNamara Group on the Lawn Hill Platform.

The *Mount Isa Group* crops out in the Leichhardt River Fault Trough and Myally Shelf of the Western Fold Belt and in fault-bounded outcrops in the west of the Kalkadoon-Leichhardt Belt. It comprises eight formations: from oldest to youngest, the Warrina Park Quartzite, Moondarra Siltstone (Fig. 33), Breakaway Shale, Native Bee Siltstone, Urquhart Shale (which hosts the Cu and Pb-Zn-Ag orebodies at Mount Isa), Spear Siltstone, Kennedy Siltstone (generally not readily distinguished from the Spear Siltstone), and Magazine Shale. These formations are shown separately on the 1:100 000 geological maps, but not on the 1:500 000 map. Numerous thin tuff beds are present in the Native Bee Siltstone and especially in the Urquhart Shale,

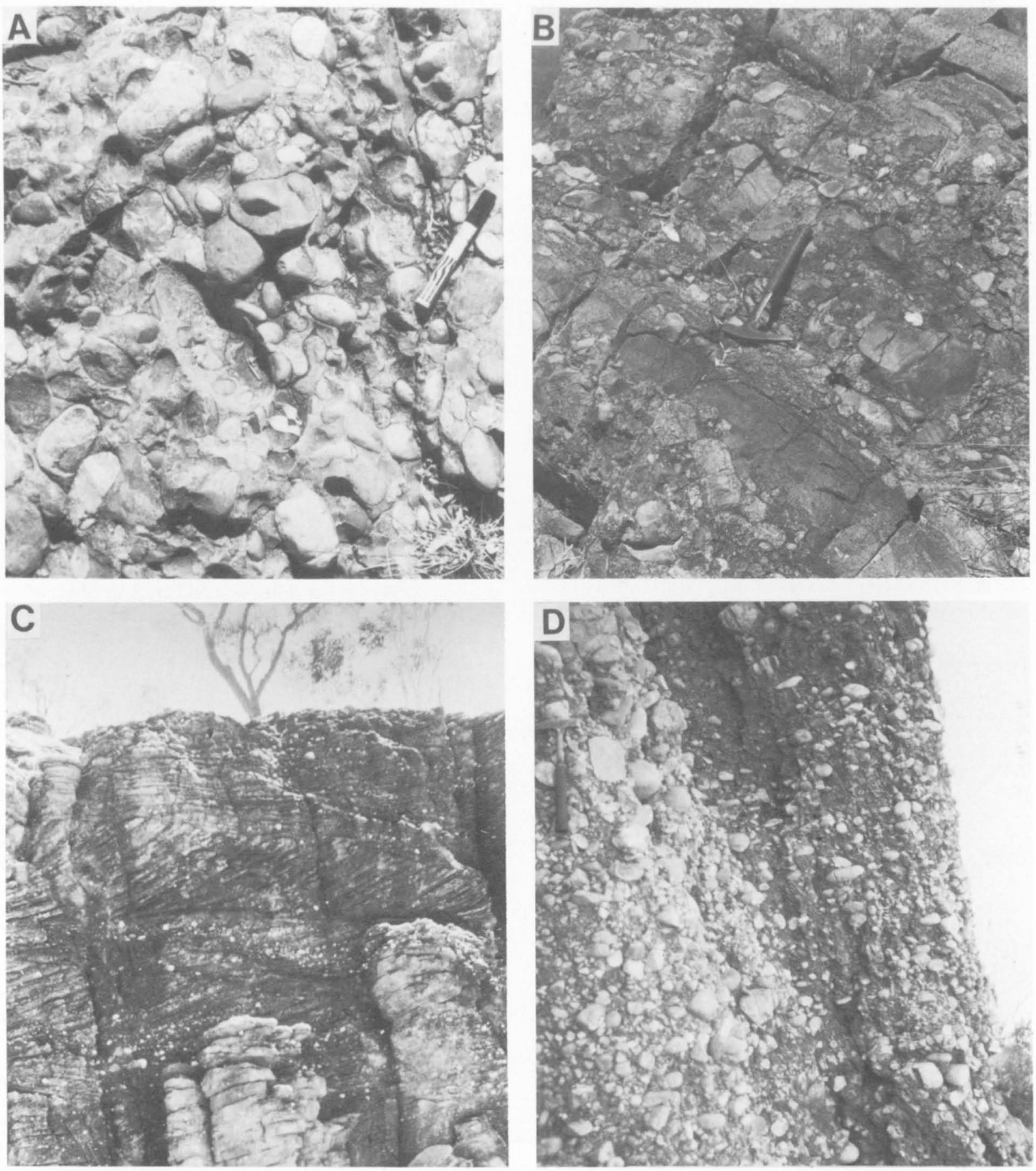


Fig. 31. Coarse clastic rocks in cover sequence 3. A, Polymictic conglomerate in the Bigie Formation, Leichhardt River Fault Trough (PROSPECTOR GR 665575) (M2686/16). B, Conglomerate and sandstone of the Wire Creek Sandstone on the south side of the Murphy Tectonic Ridge (HEDLEYS CREEK GR 990413) — I. P. Sweet (M1375/32). C, Cross-bedded pebbly sandstone, Westmoreland Conglomerate, north side of the Murphy Tectonic Ridge (HEDLEYS CREEK east of the Cliffdale Fault) — P. J. Slater (GAB/7). D, Conglomerate within the Musselbrook Formation, lower McNamara Group, Lawn Hill Platform (NE of CARRARA RANGE REGION at GR 748550, Cleanskin 1:100 000 Sheet area) — I. P. Sweet (M2686/28A)

where more than 80 'Tuff Marker Beds' have been recorded (Croxford, 1964; Bennett, 1965). Zircon from one tuff bed in the Urquhart Shale has been dated at 1670^{+20}_{-17} Ma by Page (1981b). The Warrina Park Quartzite at the base of the Mount Isa Group represents a shallow-marine deposit (e.g., Derrick & others, 1977c) transgressing underlying formations of cover sequences 2 and 3. Succeeding formations consist mainly of siltstone and shale which are variably dolomitic and pyritic. They show features such as stromatolites, halite casts, pseudomorphs after gypsum and anhydrite (McClay & Carlile, 1978), cross-bedded channel deposits, and flat-pebble conglomerates, indicating shallow-water deposition with intermittent hypersaline and emergent conditions (Neudert & Russell, 1981). Lacustrine or sabkha environments, rather than shallow-marine to supratidal environments, are favoured for the Mount Isa Group by Neudert & Russell (1981).

The arbitrary boundary between the *McNamara Group* and the Mount Isa Group to the east is taken to be the Mount Gordon Fault Zone in the north and the Hero–Mount Isa–

Fig. 32. Thin-bedded fine-grained sandstone and siltstone, probable Surprise Creek Formation, in outlier of cover sequence 3 on west side of the Kalkadoon–Leichhardt Belt (MARY KATHLEEN GR 540985). (M2686/17)

Fig. 33. Laminated red and white siltstone, Moondarra Siltstone, Mount Isa Group (cover sequence 3), Leichhardt River Fault Trough (KENNEDY GAP GR 435385) — I. H. Wilson (M1791/1)

Mount Annable Fault system to the south. This means that the McNamara Group is largely restricted to the Lawn Hill Platform. However, it extends in places into the western part of the Leichhardt River Fault Trough, being exposed in the Bonus Basin in KENNEDY GAP and, to the south, in MOUNT ISA and DUCHESS REGION.

For the purpose of the 1:500 000 geological map, the McNamara Group is subdivided into a lower part, consisting mainly of shallow to very shallow-water deposits, and an upper, generally deeper-water, part.

In the Western Fold Belt, east of longitude 138°E, the lower part of the McNamara Group consists of six formations. From oldest to youngest, these are the Torpedo Creek Quartzite, Gunpowder Creek Formation, Paradise Creek Formation, Esperanza Formation, Lady Loretta Formation, and Shady Bore Quartzite. The Torpedo Creek Quartzite was mapped as an unnamed basal member of the Gunpowder Creek Formation in MOUNT ISA and as part of the Mammoth Formation (informal name, now abandoned) in KENNEDY GAP. It consists of a discontinuous band of poorly sorted alluvial conglomerate, resting in places on a probably regolithic breccia, and an overlying distal alluvial, marginal marine, and shallow-marine sandstone representing a widespread marine transgression (Hutton & Sweet, 1982). An eastern source for the sediments has been suggested in KENNEDY GAP, a local source in the Kamarga Dome area in LAWN HILL REGION, and a source from the south for equivalent sediments on the south side of the Murphy Tectonic Ridge (Sweet & Slater, 1975). The overlying formations making up the remainder of the lower McNamara Group consist mainly of dolomite and chert which are commonly stromatolitic (Fig. 34), siltstone, and fine sandstone. The Paradise Creek Formation includes at its base the Mount Oxide Chert Member, which is a laminated chert band up to 10 m thick. This chert may be silicified algal-laminated dolomite; the silicification possibly marking the onset of felsic volcanism and a sudden influx of silica into the environment (Hutton & Sweet, 1982). The formation also contains thin tuff bands which are probably correlatives of those in the Native Bee Siltstone and Urquhart Shale of the Mount Isa Group. The overlying Esperanza Formation consists largely of stromatolitic chert, probably resulting from diagenetic silicification of carbonate. The upper deeper-water part of the McNamara Group east of longitude 138°E crops out mainly to the west of the lower part. In consists of three formations: from oldest to youngest, the Riversleigh Siltstone, Termite Range Formation (Fig. 35), and Lawn Hill Formation (which includes the Bulmung and Widdallion Sandstone Members). These units consist mainly of shale, siltstone, and sandstone. Some of the shale and siltstone are carbonaceous.

West of longitude 138°E, in CARRARA RANGE REGION, the lower part of the McNamara Group is represented by the Musselbrook Formation, which consists mostly of sandstone and siltstone but includes conglomerate near the base (Fig. 31D). The upper part consists of siltstone, shale and sandstone assigned to the Plain Creek Formation and Lawn Hill Formation. Just to the north in the Maloney Creek Inlier (Sweet, 1985), the Plain Creek Formation is missing, and the Musselbrook Formation, which here consists largely of fluvial sandstone and conglomerate, is overlain conformably by the Lawn Hill Formation.

Correlatives of the McNamara Group exposed on the south side of the Murphy Tectonic ridge (in HEDLEYS CREEK and SEIGAL) are mapped as the *Fickling Group*. The basal formation of this group, the Fish River Formation, consists of cross-bedded sandstone (Fig. 36), siltstone, shale, and minor conglomerate which lie unconformable on Peter Creek Volcanics of cover sequence 3, Cliffdale Volcanics of cover sequence 1, and the Nicholson Granite Complex. It is overlain conformably by oolitic, stromatolitic, and intraclastic dolomite of the Walford Dolomite, above which comes the Mount Les Siltstone, a formation that includes some beds of flaggy dolomite containing pseudomorphs of limonite after pyrite and dolomite after gypsum. These three formations are considered to represent shallow-marine to supratidal depositional environments. The youngest unit of the Fickling Group, conformably or disconformably overlying the Mount Les Siltstone, is the Doomadgee Formation. This unit is made up of conglomerate, sandstone, siltstone, shale, and dolomite, and may have been deposited in fluvial to offshore-marine environments (Sweet & others, 1981). The lower three formations are correlated with the lower part of the McNamara Group, and the Doomadgee Formation is

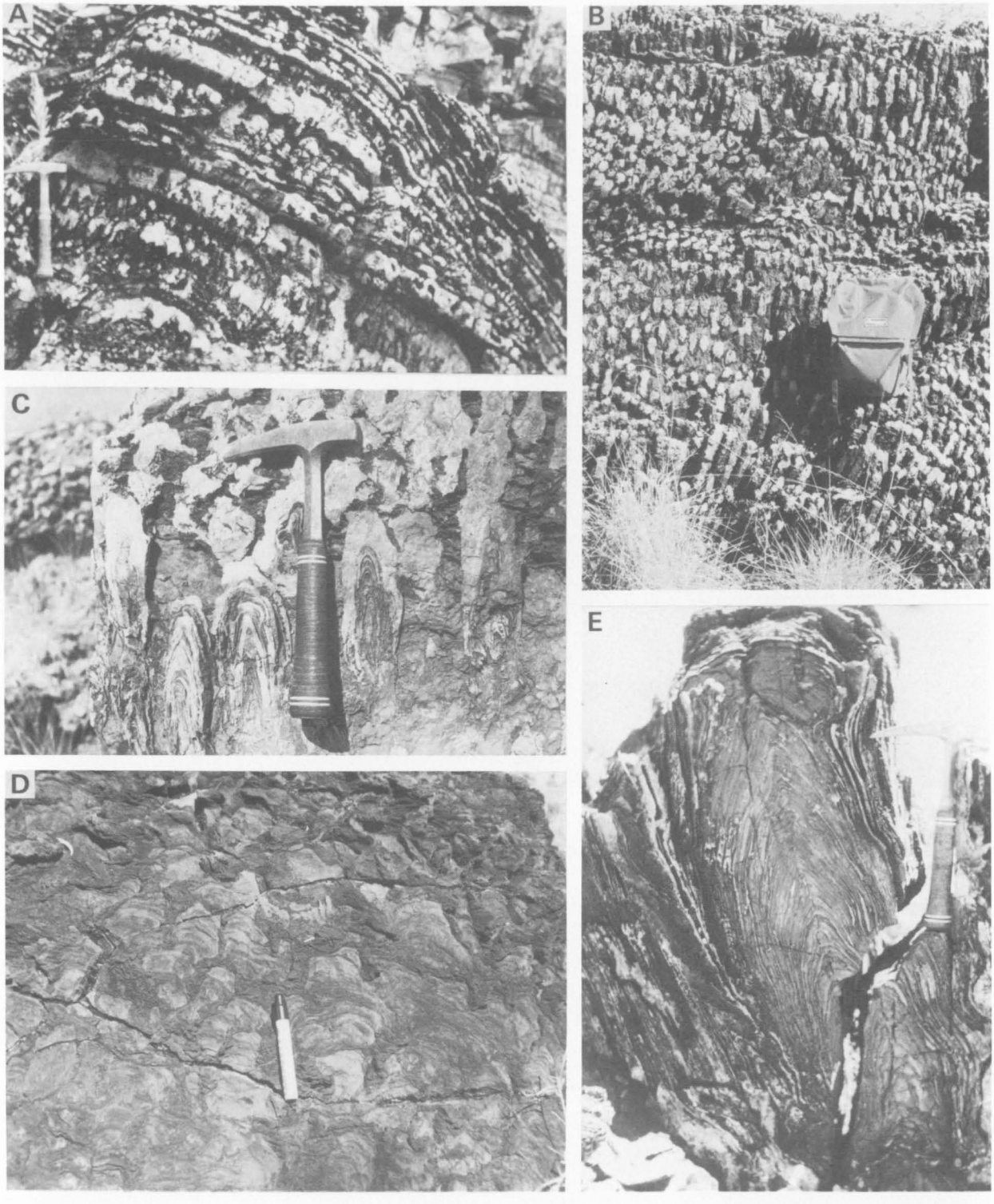


Fig. 34. Stromatolites in the lower McNamara Group (cover sequence 3), Lawn Hill Platform. A, Partly silicified stromatolite bioherm within the Esperanza Formation (MOUNT OXIDE REGION GR 936650) — I. P. Sweet (M2685/26A). B, Partly silicified 'organ pipe' stromatolites at the top of the Esperanza Formation (MOUNT OXIDE REGION GR 936650) — I. P. Sweet (M2685/21A). C, Detail of stromatolites shown in B — I. P. Sweet (M2685/23A). D, Branching columnar stromatolites in the Gunpowder Creek Formation in LAWN HILL REGION, at locality GR 767305: *Conophyton* near this locality was recognised and described by Cloud & Semikhatov (1969) — I. P. Sweet (M2685/25A). E, *Conophyton* in a biostrome within the Lady Loretta Formation (LAWN HILL REGION GR 680280 — I. P. Sweet (M2685/27A)

correlated with the upper part of this group (Hutton & Sweet, 1982). In the Bauhinia Dome to the west, the Fickling Group consists predominantly of dolomite, conglomerate, sandstone and greywacke (Sweet, 1985).

Kalkadoon-Leichhardt Belt and Eastern Fold Belt

Formations which may belong to cover sequence 3 in the Kalkadoon–Leichhardt Belt and Eastern Fold Belt (Table 12) are those assigned to the *Mount Albert Group* by Derrick

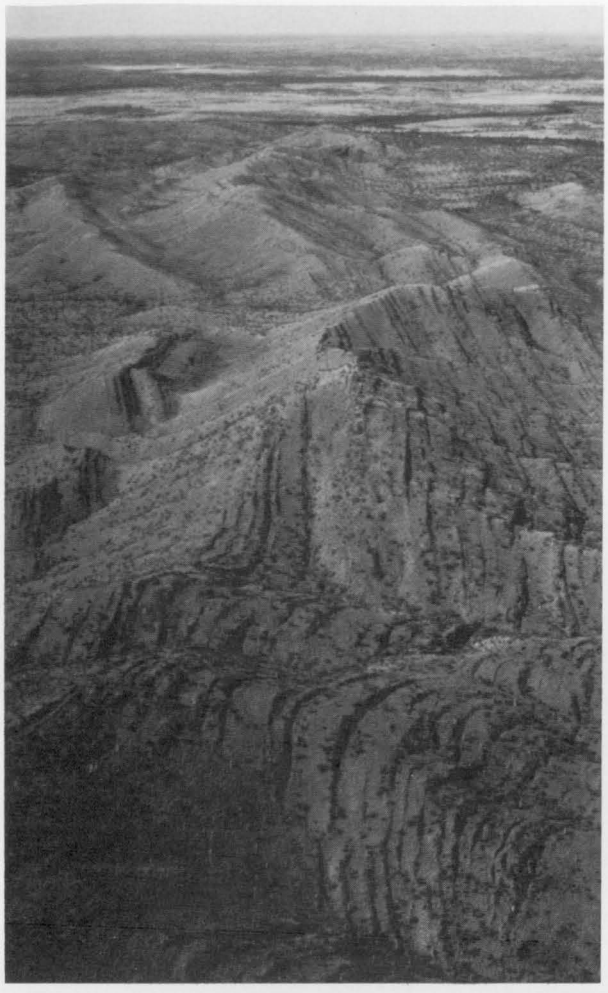


Fig. 35. Ridge formed of Termite Range Formation, upper McNamara Group (cover sequence 3), Lawn Hill Platform (LAWN HILL REGION) showing typical banded appearance from the air — I. P. Sweet (GB1403)

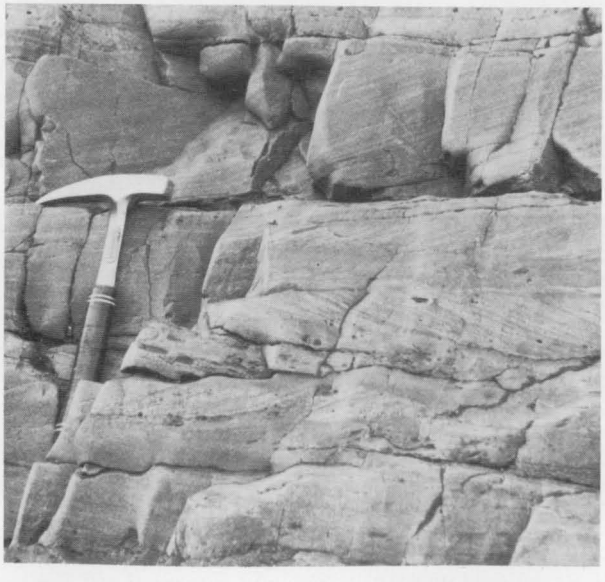


Fig. 36. Herringbone-like cross-bedding in sandstone of the Fish River Formation, Fickling Group (cover sequence 3), south side of the Murphy Tectonic Ridge (SEIGAL GR 888195) — I. P. Sweet (M1506/18A)

& others (1977b, c) and Wilson (1984). This group is correlated with the Surprise Creek Formation of cover sequence 3 in the Western Fold Belt by Derrick & others (1980), and is thought to represent mainly shallow-marine shelf deposits.

Two formations of the Mount Albert Group, the Deighton Quartzite and conformably overlying White Blow Formation, are exposed in the Kalkadoon–Leichhardt Belt. The *Deighton Quartzite* crops out in MARY KATHLEEN and PROSPECTOR, where it has concordant to locally discordant contacts with underlying units, mainly the Corella Formation, of cover sequence 2. The *White Blow Formation*, which consists mostly of pelitic and calcareous rocks not unlike those forming much of the Corella Formation in the Kalkadoon–Leichhardt Belt, is confined to MARY KATHLEEN. According to Carter & others (1961) and Derrick & others (1977b, 1977c, 1980), the basal contact of the Deighton Quartzite is an unconformity, but a recent detailed study has shown that this contact is invariably tectonic, rather than sedimentary, and may represent a thrust plane (BMR, 1985). The striking lithological similarity of the Deighton Quartzite to the Ballara Quartzite and the White Blow Formation to the Corella Formation may, therefore, be due to these formations being correlative cover sequence 2 units brought together by large-scale thrusting. Rocks mapped as undivided Mount Albert Group in the north, on the eastern margin of the Kalkadoon–Leichhardt Belt (in COOLULLAH), are lithologically similar to those of the Deighton Quartzite; they are reported to overlie the Corella Formation unconformably (Wilson & Grimes, 1986).

In the Eastern Fold Belt, the Mount Albert Group is represented by the Knapdale Quartzite, Coocerina Formation, and Lady Clayre Dolomite, which crop out in the Mary Kathleen zone, and the Roxmere Quartzite, which is restricted to the Quamby–Malbon zone. The *Knapdale Quartzite* is apparently conformable on the Corella Formation in QUAMBY. It was not mapped originally in MARRABA, but according to the Cloncurry 2nd edition 1:250 000 map (GSQ, 1983a) it includes calcareous sandstone previously mapped as part of the Corella Formation near Mary Kathleen and to the northeast. The newly mapped Knapdale Quartzite crops out in synclinal areas, and is presumably concordant with adjacent rocks still assigned to the Corella Formation. The *Coocerina Formation*, a unit of mainly fine-grained calcareous and scapolitic beds, is lithologically similar to much of the Corella Formation in the Mary Kathleen zone and to the White Blow Formation. It conformably overlies the Knapdale Quartzite, and is faulted against, but is inferred to underlie, the *Lady Clayre Dolomite* (Wilson, 1984), which consists mainly of dark thinly bedded dolomite and dolomitic siltstone. The Coocerina Formation and Lady Clayre Dolomite are confined to QUAMBY, but have not been distinguished on the QUAMBY map, where the Coocerina Formation is mapped as the upper part of the Knapdale Quartzite and the Lady Clayre Dolomite is shown as an unnamed unit; however, they are shown as named units on the Cloncurry 1:250 000-scale map, 2nd edition (GSQ, 1983a).

The *Roxmere Quartzite* is taken to include rocks mapped in MARRABA and KURIDALA REGION as the Mick Creek Sandstone and Toby Barty Sandstone Members of the Marimo Slate, following GSQ (1983a). Contacts between the Roxmere Quartzite and underlying units assigned to cover sequence 2 appear to be concordant and have been described as conformable. However, they are commonly faulted or marked by zones of breccia, and may be tectonic like basal contacts of the Deighton Quartzite.

Although tentatively assigned to cover sequence 3, the Mount Albert Group may well belong to cover sequence 2, and be significantly older than the Surprise Creek Formation of the Western Fold Belt. In support of this suggestion, the Mount Albert Group is similar in lithology and aspect to

underlying units of cover sequence 2, and its basal contacts appear to be either conformable or tectonic, rather than unconformable.

Late Proterozoic (younger than 1500 Ma)

Two late Proterozoic sedimentary units, the Quamby Conglomerate and South Nicholson Group, are distinguished on the 1:500 000 map. The *Quamby Conglomerate* is exposed in two grabens in the central part of the Quamby-Malbon zone, Eastern Fold Belt. It is up to 300 m thick and overlies the Corella Formation of cover sequence 2 unconformably. Although forming synclines, probably resulting from down-faulting, it is considered to be post-metamorphic (Derrick, 1980). Main rock types are conglomerate, arkose, quartz sandstone (commonly hematitic), and greywacke. The conglomerate contains clasts of metasiltstone, slate, schist, quartzite, and vein quartz. The formation postdates the metamorphism and deformation affecting the adjacent Corella Formation, and is considered to be younger than 1500 Ma.

The *South Nicholson Group* occupies the South Nicholson Basin northwest of the Mount Isa Inlier. It consists of gently folded shallow-marine sedimentary rocks, at least 1000 m thick, which unconformably overlie the McNamara, Carrara Range, and Fickling Groups of cover sequence 3 (Sweet & others, 1981). The oldest formation of the South Nicholson Group is the Constance Sandstone, which consists mainly of quartz sandstone and quartz-rich lithic sandstone but includes some conglomerate and also three lenticular bodies of siltstone: the Pandanus Creek Siltstone Member near the base, Wallis Siltstone Member in the central part, and Bowthorn Siltstone Member near the top. The conformably overlying Mullera Formation is made up mainly of siltstone, sandstone and shale. It includes two named members: the Middle Creek Sandstone Member, and, near the top, the Train Range Ironstone Member (named the Train Range Ironstone Formation by Harms, 1965), which contains ferruginous sandstone that is sideritic and chamositic at depth, and also some oolitic ironstone. The Mullera Formation is overlain conformably by the youngest formation of the South Nicholson Group, the Tidna Sandstone.

The South Nicholson Group is correlated with the Roper Group (e.g., Plumb & Sweet, 1974), which is intruded by dolerite sills dated at 1280 Ma (McDougall & others, 1965).

PROTEROZOIC INTRUSIONS

Rocks of the basement and cover sequences 1, 2, and 3 are intruded by granite plutons, innumerable mafic dykes and sills, and subordinate hypabyssal felsic intrusions, all of Proterozoic age.

Granites

Granites crop out extensively in the region (Fig. 37). Six major batholiths are present within the Mount Isa Inlier—from west to east, the Sybella, Ewen, Kalkadoon, Wonga, Williams, and Naraku Batholiths—and another, the Nicholson Granite Complex, forms part of the Murphy Tectonic Ridge to the north. Each batholith consists of spatially associated granitic intrusions that in general appear to be genetically related to one another and are probably similar in age. There are also three granite bodies in the Western Fold Belt which have not been assigned to a major batholith: these are the geographically isolated Yeldham and Weberra Granites, and the Big Toby Granite which, although situated close to the Sybella Batholith, is much older than the granites of this batholith. Details of the various granites are summarised in Table 13.

A common feature of the granites in the Mount Isa Inlier is the presence of net-veined complexes, in which leucocratic granite and dolerite/gabbro, together with intermediate hybrid rocks, are intimately mixed (Blake, 1981a). The mafic rocks in these complexes occur as angular to rounded pillow-like inclusions enclosed in and veined by granite (Figs 38, 42), and are considered to represent mafic magma intruded into either granitic magma or melted granitic rock; i.e., they are either similar in age or younger than the associated granite.

Kalkadoon Batholith

The oldest dated granites of the Mount Isa Inlier are those of the Kalkadoon Batholith, exposed in the western part of the Kalkadoon-Leichhardt Belt. This batholith extends for 270 km along the belt and covers an area of about 1600 km^2. It is made up of One Tree, Wills Creek, and Woonigan Granites (restricted to DAJARRA and DUCHESS REGION), and Kalkadoon Granite which comprises the remainder of the batholith. All the intrusions of the batholith were mapped as Kalkadoon Granite by Carter & others (1961). They range in composition from tonalite to granodiorite and granite, and are commonly xenolithic. Most are foliated to varying extents, and all show some metamorphic effects, as documented by Wyborn & Page (1983). The intrusions appear to be related chemically to one another and also to the felsic Leichhardt Volcanics, which are considered to be comagmatic with the granites. Biotite, almost invariably a low-Ti metamorphic variety, is the dominant mafic mineral present. Hornblende, magnesian-hastingsite to hastingsite in composition, and scapolite are present in some granite which has been metamorphosed to amphibolite facies. Primary igneous mafic minerals are rarely preserved. Phenocrysts, mostly of microcline, are commonly present, especially in mafic granodiorite.

The *One Tree Granite* consists of two main phases, a biotite-rich phase and a paler coarser one which contains xenoliths of the biotite-rich phase. The granite is overlain unconformably by the Leichhardt Volcanics of cover sequence 1, and is cut by felsic dykes related to these volcanics, whereas the *Wills Creek Granite, Woonigan Granite,* and some phases of *Kalkadoon Granite* intrude and metamorphose the Leichhardt Volcanics. The Kalkadoon Granite has been dated at 1862^{+27}_{-21} Ma (Page, 1978) and 1856^{+11}_{-9} Ma (Wyborn & Page, 1983). A minimum age of 1830 Ma ($^{207}Pb/^{206}Pb$ zircon age) has been obtained on the Wills Creek Granite (Wyborn & Page, 1983). The granites of the Kalkadoon Batholith are overlain unconformably by cover sequences 2 and 3, and are cut by numerous mafic and some felsic dykes.

Ewen Batholith

The Ewen Batholith (Wyborn & Page, 1983) forms part of the Ewen Block, and has an outcrop area of about 345 km^2. It consists of Ewen Granite, which is similar in chemistry and age to the granites of the Kalkadoon Batholith and to the Leichhardt extrusives, and is probably part of the same magmatic suite. Unlike most of the Kalkadoon Granite, the Ewen Granite is generally massive or only weakly foliated, and primary igneous minerals and textures are commonly preserved. The biotite present is typically a high-Ti igneous variety, and an igneous amphibole, edenite, is common in the more mafic granitic rocks. The Ewen Granite is dated at 1820–1860 Ma (U-Pb zircon) and 1840 ± 50 (Rb-Sr, initial $^{87}Sr/^{86}Sr$ of 0.704 ± 0.002), and it intrudes Leichhardt Volcanics dated at 1852 ± 7 Ma (U-Pb zircon).

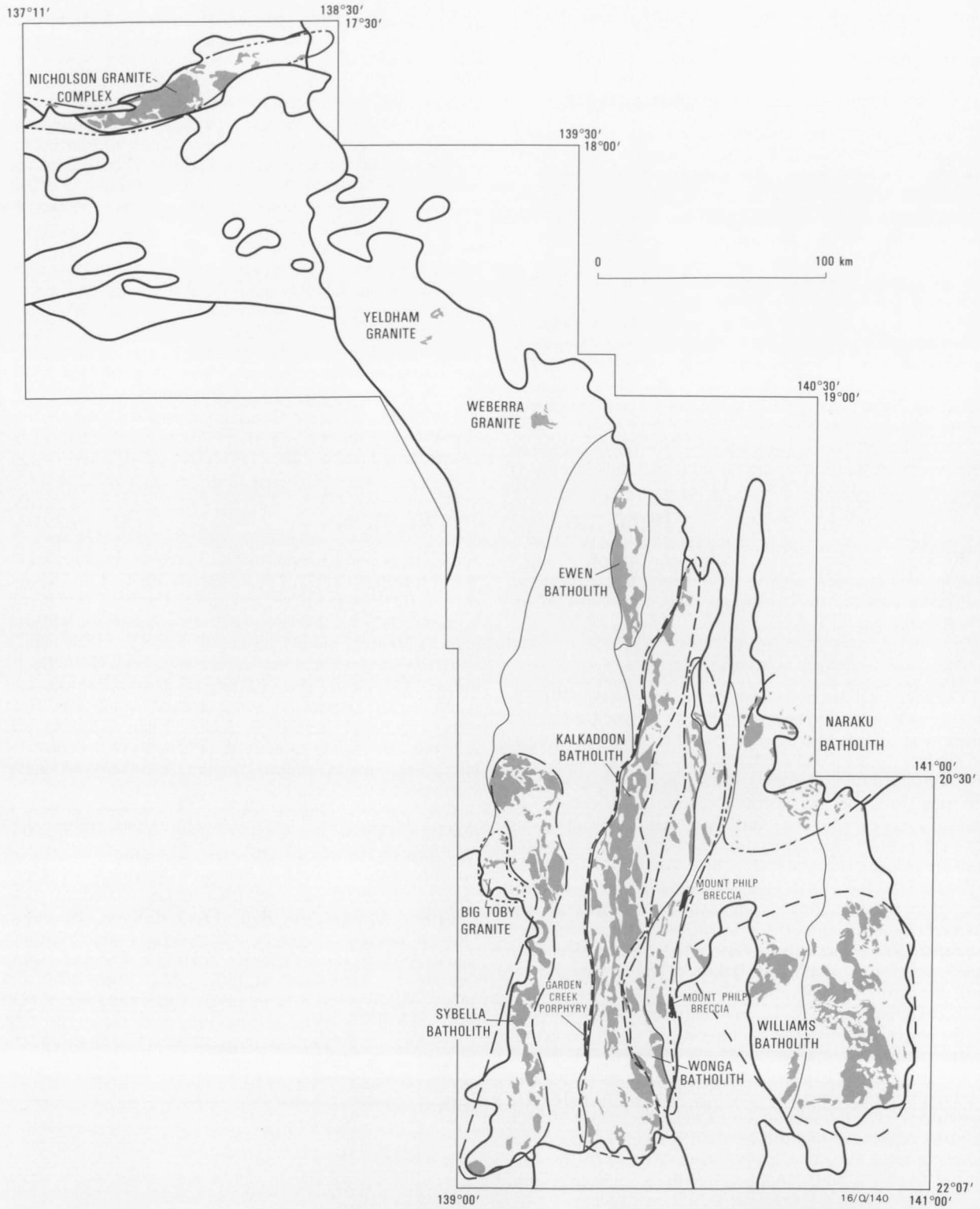


Fig. 37. Distribution of granitic rocks (outcrops in grey), Garden Creek Porphyry and Mount Phillip Breccia.

Wonga Batholith

The Wonga Batholith extends for at least 190 km along the eastern side of the Kalkadoon–Leichhardt Belt and in the adjoining Mary Kathleen zone of the Eastern Fold Belt. It is made up of several discrete, mainly composite, intrusions which are mapped as the *Birds Well, Bowlers Hole, Hardway, Mairindi Creek, Saint Mungo, Burstall, Overlander, Revenue,* and *Wonga Granites, Bushy Park Gneiss,* and *Mount Erle* and *Myubee Igneous Complexes.* These intrusions are younger than most or all of the intrusions of the Kalkadoon Batholith, as they intrude rocks of cover sequence 2, and hence are younger than 1790 Ma. They generally form elongate bodies, parallel to regional northerly trends, and are weakly to strongly deformed (Fig. 39) and regionally metamorphosed mainly to amphibolite facies. The granitic rocks of the Wonga Batholith are mostly shades of pink and commonly contain metamorphic dark blue-green or blue-grey amphibole (ferrohastingsite?) and phenocrysts or augen of

TABLE 13. PROTEROZOIC GRANITES OF THE MOUNT ISA INLIER AND ENVIRONS

Name of unit	*Distribution*	*Lithology*	*Relationships*
WILLIAMS BATHOLITH	Confined to Eastern Fold Belt		
Blackeye Granite	1.6 km long pluton, SE Cloncurry-Selwyn zone	Foliated leucocratic granodiorite; minor pegmatite	Intrudes Doherty Formation
Cowie Granite	Body 11.5 km long, up to 3 km wide in SE Cloncurry-Selwyn zone	Foliated leucocratic biotite granite, granodiorite, and tonalite; minor pegmatite	Intrudes Soldiers Cap Group and Doherty Formation
Gin Creek Granite	Composite body 24 km long, up to 6 km wide, in SE Quamby-Malbon zone	Non-foliated, partly porphyritic, biotite granite, weakly foliated tourmaline-muscovite leucogranite, strongly foliated xenolithic biotite granite; minor biotite microgranite, aplite, greisen	Intrudes Double Crossing Metamorphics, Answer Slate, Staveley Formation, Kuridala Formation, metadolerite
Maramungee Granite	Elongate pluton 5 km long, SE Cloncurry-Selwyn zone	Foliated biotite-bearing leucocratic granite, granodiorite, tonalite; minor pegmatite	Intrudes Soldiers Cap Group; cut by dolerite dyke
Mount Angelay Granite	Crops out over 200 km^2 in central Cloncurry-Selwyn zone	Non-foliated, partly porphyritic granite with biotite and/or hornblende and/or clinopyroxene; minor leucogranite, porphyritic microgranite, contaminated granite, aplite, pegmatite	Intrudes Soldiers Cap Group, Doherty Formation; cut by dolerite dykes
Mount Cobalt Granite	Stock 1 km across in S Cloncurry-Selwyn zone	Non-foliated biotite granite; minor aplite	Intrudes Kuridala Formation, metadolerite
Mount Dore Granite	NE-trending pluton 14 km long, 7 km wide, SE Cloncurry-Selwyn zone	Non-foliated, partly porphyritic, biotite and hornblende-biotite granite; minor microgranite, aplite, pegmatite, greisen	Intrudes Kuridala Formation, metadolerite
Saxby Granite	Irregular plutons up to 10 km across, E central Cloncurry-Selwyn zone	Non-foliated biotite and hornblende-bearing granite; minor leucogranite, xenolithic diorite, monzonite, granodiorite, aplite, pegmatite, net-veined complex	Intrudes Soldiers Cap Group, Doherty Formation, metadolerite; cut by dolerite
Squirrel Hills Granite	Composite body 100 km long, up to 25 km wide, S Cloncurry-Selwyn zone	Non-foliated, partly porphyritic granite containing hornblende and/or biotite and/or clinopyroxene; minor aplite, porphyritic microgranite, monzonite, granodiorite; rare pegmatite	Intrudes Soldiers Cap Group, Kuridala Formation, Doherty Formation, Staveley Formation, Cowie Granite, metadolerite; cut by dolerite dykes
Wimberu Granite	Composite body 42 km across in S Quamby-Malbon zone	Non-foliated, partly porphyritic granite and granodiorite containing biotite and/or hornblende and/or clinopyroxene; fine-grained biotite granite; minor aplite, pegmatite	Intrudes Argylla Formation, Marraba Volcanics, Mitakoodi Quartzite, Overhang Jaspilite, Answer Slate, Staveley Formation, metadolerite
Yellow Waterhole Granite	E-trending body 19 km long, up to 2.5 km wide, SW Cloncurry-Selwyn zone	Non-foliated, partly porphyritic biotite and hornblende-biotite granite; minor aplite	Intrudes Kuridala Formation
Unnamed granitic rocks	Small bodies mainly in Cloncurry-Selwyn zone	Foliated leucocratic tonalite, non-foliated biotite granite; minor hornblende-biotite tonalite, pegmatite	Intrude Soldiers Cap Group, Mary Kathleen Group
NARAKU BATHOLITH	Eastern Fold Belt		
Naraku Granite	Group of plutons in northern parts of Quamby-Malbon and Cloncurry-Selwyn zones	Locally foliated, partly porphyritic granite with hornblende and/or biotite; minor granodiorite, pegmatite with muscovite and/or tourmaline, aplite	Intrudes Argylla Formation, Mitakoodi Quartzite, Soldiers Cap Group, Corella Formation
SYBELLA BATHOLITH	Western Fold Belt		
Sybella Granite	Group of plutons extending N-S for 190 km in S Leichhardt River Fault Trough	Medium to coarse, partly porphyritic biotite granite, generally weakly to strongly foliated; minor leucogranite, pegmatite (commonly containing tourmaline and/or muscovite, less commonly beryl), gneissic granite, microgranite, dolerite and gabbro (in net-veined complexes), aplite, pegmatite; xenoliths common	Intrudes basement, cover sequence 2, and metadolerite; faulted against cover sequence 3; cut by metadolerite, dolerite

TABLE 13 (Continued)

Name of unit	*Distribution*	*Lithology*	*Relationships*
Weberra Granite	One or more plutons in NE Lawn Hill Platform, Western Fold Belt	Non-porphyritic medium to coarse granite and leucogranite, some containing garnet; minor graphic granite	Intrudes Myally Subgroup and Quilalar Formation of cover sequence 2; cut by felsic and mafic dykes
WONGA BATHOLITH	Kalkadoon-Leichhardt Belt and Eastern Fold Belt		
Birds Well Granite	One pluton, outcrop area about 79 km^2, in DUCHESS REGION, possibly another to S, outcrop area about 30 km^2, in DAJARRA, Kalkadoon-Leichhardt Belt	Weakly to strongly foliated, partly porphyritic biotite granite; minor hornblende-biotite granite, gneiss, aplite, microgranite; rare pegmatite	Intrudes Leichhardt Volcanics, Magna Lynn Metabasalt, Argylla Formation, Kalkadoon Granite; possibly also intrudes Corella Formation, Plum Mountain Gneiss, One Tree Granite; cut by metadolerite dykes
Bowlers Hole Granite	Oval pluton 11 km long in SE central Kalkadoon-Leichhardt Belt	Foliated to gneissic, weakly porphyritic biotite-hornblende granite; minor biotite granite, microgranite, aplite, pegmatite; xenoliths common	Intrudes Leichhardt Volcanics, Magna Lynn Metabasalt, Argylla Formation; cut by metadolerite dykes
Burstall Granite	Two main bodies covering about 49 km^2 in centre Mary Kathleen zone, Eastern Fold Belt	Foliated, leucocratic, even-grained to porphyritic hornblende-biotite granite; minor tonalite and diorite (in net-veined complex); aplite, pegmatite, microgranite, porphyritic rhyolite dykes	Intrudes Corella Formation, metadolerite; forms net-veined complexes with Lunch Creek Gabbro; cut by dolerite dyke
Bushy Park Gneiss	Bands of deformed pods along eastern margin of Kalkadoon-Leichhardt Belt in DUCHESS REGION	Weakly foliated to more commonly gneissic, porphyritic and even-grained biotite-hornblende and biotite granite; minor gneissic leucogranite, aplite, pegmatite	Intrudes Magna Lynn Metabasalt, Corella Formation
Hardway Granite	Bodies covering about 20 km^2 in E central Kalkadoon-Leichhardt Belt	Non-foliated leucogranite, partly porphyritic biotite granite; minor aplite, tonalite, granodiorite, diorite	Intrudes Leichhardt Volcanics, Argylla Formation, Corella Formation; cut by metadolerite and dolerite dykes
Mairindi Creek Granite	Pluton 5 km long in S Kalkadoon-Leichhardt Belt	Foliated porphyritic biotite granite; minor aplite	Intrudes Magna Lynn Metabasalt, Argylla Formation; cut by metadolerite dykes
Mount Erle Igneous Complex	Covers about 30 km^2 in S Mary Kathleen zone, Eastern Fold Belt	Locally foliated, leucocratic biotite-hornblende granite, metadolerite, gabbro and intermediate hybrid rocks (partly as net-veined complexes), minor aplite, pegmatite	Intrudes Corella Formation
Myubee Igneous Complex	Circular body 2 km across in S Mary Kathleen zone, Eastern Fold Belt	Locally foliated, leucocratic hornblende-biotite granite, metadolerite, gabbro, and diorite, partly as net-veined complexes	Intrudes Corella Formation, cut by metadolerite and dolerite dykes
Overlander Granite	Bodies up to 10 km long in S central Mary Kathleen zone, Eastern Fold Belt	Foliated leucocratic granite, even-grained to slightly porphyritic hornblende-biotite granite; minor pegmatite, aplite	Intrudes Corella Formation, metadolerite; cut by dolerite dyke
Revenue Granite	Main body 13 km long in S central Mary Kathleen zone, Eastern Fold Belt	As for Overlander Granite; also crenulated gneissic granite	Intrudes Corella Formation, metadolerite
Saint Mungo Granite	Bodies covering about 90 km^2 in SE Kalkadoon-Leichhardt Belt	Weakly foliated to gneissic, porphyritic hornblende-biotite and biotite granite; minor non-porphyritic granite, aplite, pegmatite	Intrudes Plum Mountain Gneiss, Corella Formation; cut by metadolerite dykes
Wonga Granite	Series of deformed plutons on east side of Kalkadoon-Leichhardt Belt N of 21°S	Foliated to gneissic, porphyritic and even-grained biotite and hornblende-biotite granite; minor microgranite, aplite, pegmatite, metadolerite	Intrudes Argylla Formation, Corella Formation; cut by and forms net-veined complexes with metadolerite

TABLE 13 (Continued)

Name of unit	*Distribution*	*Lithology*	*Relationships*
Big Toby Granite	Crops out over about 22 km^2 in W of Leichhardt River Fault Trough (in MOUNT ISA), Western Fold Belt	Pale grey, massive to foliated, biotite granodiorite and granite, porphyritic in part, commonly xenolithic; minor aplite, pegmatite, net-veined complexes	Intrudes Yaringa Metamorphics (basement) and possible Eastern Creek Volcanics (cover sequence 2?)
Yeldham Granite	Crops out over about 12 km^2 in the Kamarga Dome, Lawn Hill Platform, Western Fold Belt	Pink to grey, equigranular, medium-grained muscovite granite; minor hornblende-bearing granite, pegmatite, greisen	Overlain by Kamarga Volcanics (cover sequence 2) and McNamara Group (cover sequence 3)
Nicholson Granite Complex	Forms part of Murphy Tectonic Ridge	Biotite and hornblende-biotite granite, commonly porphyritic, xenolithic; minor leucogranite, greisen, microgranite, muscovite granite, hornblende granodiorite	Intrudes Murphy Metamorphics (basement), Cliffdale Volcanics (cover sequence 1); overlain by Wire Creek Sandstone, Fickling Group, Tawallah Group (cover sequence 3)
EWEN BATHOLITH			
Ewen Granite	Major plutons in Ewen Block, Western Fold Belt	Pinkish non-foliated biotite and hornblende-biotite granite and granodiorite, xenolithic and porphyritic in parts; minor tonalite, foliated granite and microgranite, aplite, pegmatite	Intrudes Candover Metamorphics, Leichhardt Volcanics (cover sequence 1); overlain by Eastern Creek Volcanics (cover sequence 2); cut by metadolerite dykes
KALKADOON BATHOLITH	Kalkadoon-Leichhardt Belt		
Kalkadoon Granite	Series of plutons extending length of Kalkadoon-Leichhardt Belt	Grey biotite (±rare hornblende) granodiorite and tonalite, pink biotite granite, commonly foliated, porphyritic and xenolithic; minor leucogranite, muscovite granite, microgranite, porphyritic granophyre, porphyritic biotite-muscovite granite, monzonite, diorite, aplite, pegmatite; some net-veined complexes	Intrudes Kurbayia Migmatite, undivided Tewinga Group, Leichhardt Volcanics; overlain possibly by some Leichhardt Volcanics (cover sequence 1), by Bottletree Formation, Mount Guide Quartzite and Quilalar Formation (cover sequence 2), Surprise Creek Formation (cover sequence 3). Cut by mafic and felsic dykes
One Tree Granite	Body 40 km long, up to 10 km wide, in DAJARRA	Pinkish, massive to strongly foliated, medium to coarse biotite granite, grey, foliated, finer-grained biotite-rich granite and granodiorite, commonly porphyritic; minor tonalite, microgranite, aplite, pegmatite	Intrudes Plum Mountain Gneiss (basement); overlain by Leichhardt Volcanics (cover sequence 1); intruded by felsic dykes of Leichhardt type, metadolerite, and probably Wills Creek Granite
Wills Creek Granite	Several plutons up to 10 km long in DAJARRA	Pinkish, non-foliated, medium to coarse, generally leucocratic, biotite granite; minor aplite, rare porphyritic microgranite	Intrudes Leichhardt Volcanics, undivided Tewinga Group, and probably Kalkadoon Granite; overlain by Makbat Sandstone and probably Stanbroke Sandstone (cover sequence 2); cut by mafic dykes
Woonigan Granite	Several plutons up to 10 km long in DUCHESS REGION	Pinkish, non-foliated, medium to fine, leucocratic biotite granite; minor aplite, porphyritic microgranite	Intrudes Leichhardt Volcanics, undivided Tewinga Group; Kalkadoon Granite; cut by metadolerite and porphyritic granophyre dykes

microcline and in some cases plagioclase. The Mount Erle and Myubee Igneous Complexes include dolerite, gabbro, and hybrid dioritic rocks forming net-veined complexes with leucogranite. Similar net-veined complexes occur where the Burstall Granite and Lunch Creek Gabbro are in contact (in MARRABA), and in Wonga Granite 25 km northwest of Cloncurry (in PROSPECTOR, Fig. 38B). The leucogranite predominating in the Mount Erle and Myubee Igneous Complexes is similar in type and possibly also in age to that of the Burstall, Overlander, and Revenue Granites. The Burstall Granite east of Mary Kathleen has been dated at 1726 ± 8 Ma and 1745 $^{+17}_{-15}$ Ma, a rhyolite dyke associated with this granite has been dated at 1737 ± 15 Ma, and the Lunch Creek Gabbro has been dated at 1740 $^{+28}_{-20}$ Ma (U-Pb zircon data; Page, 1983b). Ages of 1671 $^{+8}_{-7}$ Ma and about 1740 Ma have been obtained on samples of Wonga Granite (U-Pb zircon data; Page, 1978, 1979). Hence, the Wonga Batholith ranges in age from about 1740 to 1670 Ma.

Sybella Batholith

The Sybella Batholith is a group of plutons, all mapped as *Sybella Granite,* extending for about 190 km from north to south in the southern part of the Leichhardt River Fault Trough, Western Fold Belt. The intrusions consist mainly of pinkish, weakly to strongly foliated and gneissic granitic rocks (Fig. 40) commonly containing phenocrysts or augen of feldspar (mainly microcline). They include several net-veined complexes (e.g., Fig. 38C), especially in the Kitty Plain area 20 km northwest of Mount Isa. Part of the Sybella Granite has been dated at about 1670 Ma (U-Pb zircon data; Page, 1981a), an age similar to that of the Mount Isa Group to the

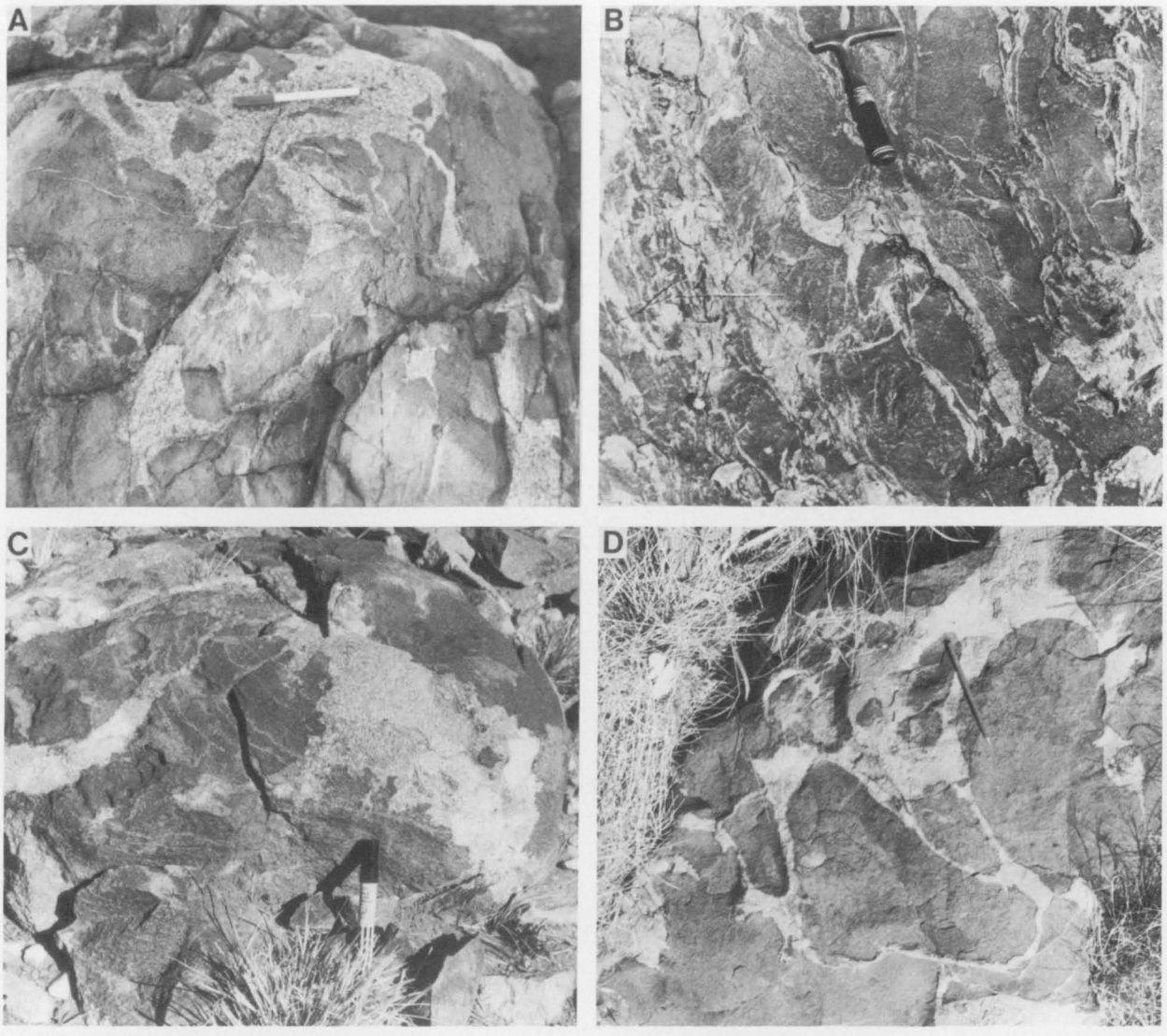


Fig. 38. Net-veined complexes in the Mount Isa Inlier. A, Tonalite pillows (dark grey) in leucocratic Kalkadoon Granite, Kalkadoon Batholith (MARY KATHLEEN GR 570941) — (M2686/14A). B, Deformed metadolerite pillows in leucocratic Wonga Granite, Wonga Batholith (PROSPECTOR GR 950480) — (M2699/58). C, Pillows of metadolerite in leucogranite; part of a small body of Sybella Granite or Big Toby Granite intruding Yaringa Metamorphics in MOUNT ISA (GR 126037) — (M2685/8). D, Dolerite pillows in Saxby Granite of the Williams Batholith (KURIDALA REGION GR 638758)—(M2625/18A)

east. The presence in basal pebbly beds of the McNamara Group in MOUNT ISA and KENNEDY GAP of clasts of porphyritic microgranite and quartz-tourmaline pegmatite, common rock types in the Sybella Batholith, and abundant grains of rounded blue quartz identical to that forming phenocrysts in one phase of Sybella Granite, has been taken to indicate that the McNamara Group and the correlative Mount Isa Group postdate the emplacement of the Sybella Batholith (Hill & others, 1975; Glikson & others, 1976; Wilson & others, 1979a). However, this age relationship has yet to be verified.

Naraku Batholith

The Naraku Batholith consists of several generally poorly exposed intrusions, mapped as *Naraku Granite,* in the northern part of the Quamby-Malbon and Cloncurry-Selwyn zones of the Eastern Fold Belt. The intrusions are formed mainly of pinkish granitic rocks containing either biotite or hornblende as the main mafic mineral. They range from non-foliated (post-tectonic) to strongly foliated (pretectonic or syntectonic). Most of the large body of Naraku Granite in central QUAMBY, west of the Quamby Fault Zone, is foliated. The batholith intrudes cover sequence 2, but is not seen in contact with any rocks assigned to cover sequence 3, or with the Late Proterozoic Quamby Conglomerate. Post-tectonic Naraku Granite 16 km north of Cloncurry has been dated at around 1500 Ma (U-Pb zircon; R. W. Page, personal communication, 1984).

Williams Batholith

The numerous plutons making up the Williams Batholith (Blake & others, 1984) crop out in the southern part of the Quamby-Malbon and Cloncurry-Selwyn zones of the Eastern Fold Belt. Two main types of granitic rocks are present. One type, which forms small intrusions in the southeast (*Blackeye, Cowie,* and *Maramungee Granites* and some unnamed granite) and also part of the *Gin Creek Granite* in the southwest, is recrystallised and foliated (as a result of metamorphism), leucocratic (pale pink to pale grey), texturally heterogeneous, and generally non-porphyritic. The foliation is concordant with that in adjacent country rocks, and intrusive contacts are partly of lit-par-lit or migmatitic

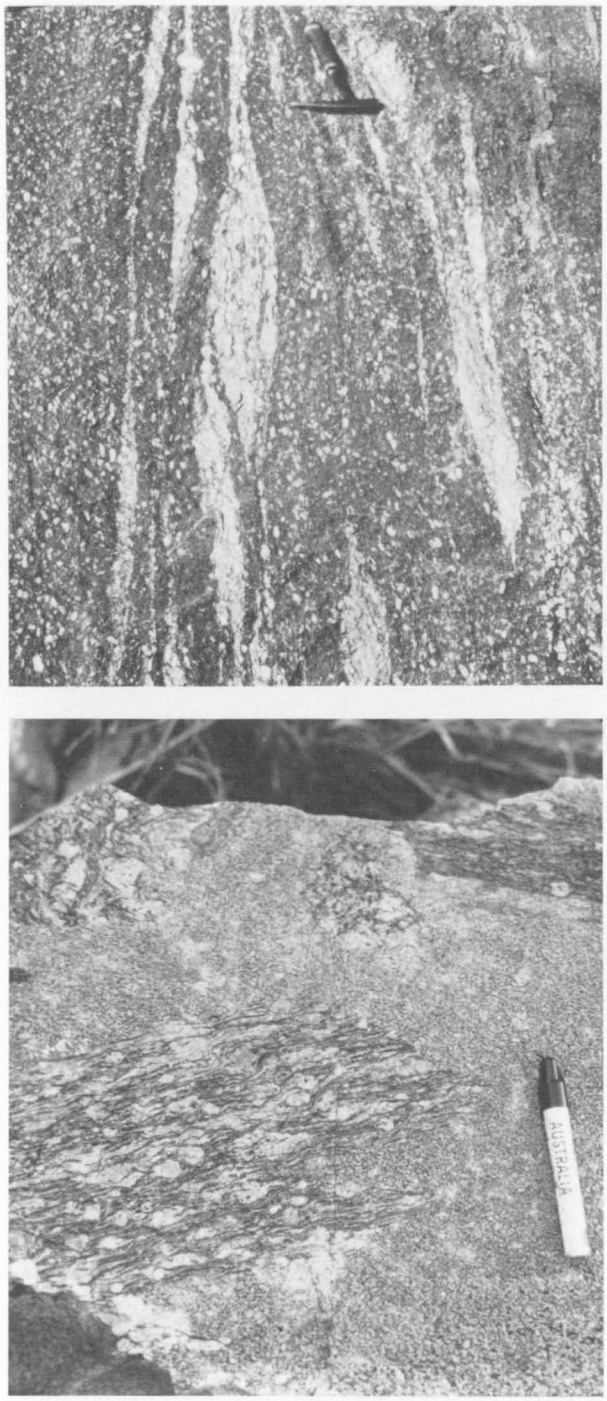


Fig. 39. Wonga Granite, Wonga Batholith. Top: Gneissic granite with feldspar augen and streaky bands of leucogranite (PROSPECTOR GR 940460) — T. A. Noon (GA8887). Bottom: Disoriented inclusions of augen gneiss in younger fine-grained leucogranite (MARRABA GR 975240). (M2684/41)

type. These intrusions may be either syntectonic or pretectonic. The other type, represented by the *Wimberu, Mount Dore, Yellow Waterhole, Mount Cobalt, Mount Angelay, Squirrel Hills,* and *Saxby Granites,* part of the *Gin Creek Granite,* and some unnamed granite, forms the larger intrusions of the Williams Batholith. This type, unlike the other, is mostly non-foliated, medium pink, and texturally homogeneous, commonly contains microcline and plagioclase phenocrysts up to 5 cm across, and typically has cross-cutting intrusive contacts. It postdates the main tectonism that affected the cover sequence 2 units that it intrudes and is inferred to be younger than the foliated granites. U–Pb zircon ages of around 1500 Ma have been obtained on the Wimberu and Yellow Waterhole Granites (R. W. Page, personal communication, 1984), and a Rb–Sr date of 1509±22 Ma is reported for the Mount Dore Granite by Nisbet & others (1983). Hence, most granite of the Williams Batholith, like parts of the Naraku Granite to the north, was probably emplaced at around 1500 Ma.

Other granites

Rocks of the *Nicholson Granite Complex* on the Murphy Tectonic Ridge are similar in lithology to those of the Kalkadoon and Ewen Batholiths, and may be similar in age (Page & others, 1984). K–Ar ages of about 1800 Ma determined by McDougall & others (1965) for the complex are minimum ages (Page & others, 1984). The Nicholson Granite Complex intrudes, and is probably comagmatic with, the Cliffdale Volcanics of cover sequence 1. It does not appear to be as deformed or as metamorphosed as most of the Kalkadoon Batholith.

The *Yeldham Granite,* which has been dated at about 1820 Ma (U–Pb zircon data of R. W. Page, personal communications, 1984), is the oldest unit exposed in the Lawn Hill Platform of the Western Fold Belt. It crops out in LAWN HILL REGION, where it is overlain by the Kamarga Volcanics, assigned to cover sequence 2, and the McNamara Group of cover sequence 3. It appears to be undeformed.

The *Big Toby Granite* crops out west of the Sybella Batholith in MOUNT ISA, on the western side of the Leichhardt River Fault Trough, and consists of two main phases. One phase, exposed in the north, is a grey fine-grained xenolithic granodiorite intruding the basement Yaringa Metamorphics and dated at about 1800 Ma (U–Pb zircon by Page, 1981a). The other phase, exposed to the south, is a pinkish porphyritic biotite granite which intrudes rocks mapped as possible Eastern Creek Volcanics (cover sequence 2) and hence may be a much younger phase, perhaps related to 1670 Ma-old Sybella Granite. Both phases are foliated.

The *Weberra Granite* intrudes rocks of cover sequence 2 in the northeast of the Lawn Hill Platform (in MOUNT OXIDE REGION). It consists of leucocratic even-grained granite which in places contains interstitial garnet, and does not appear to be either deformed or metamorphosed. The granite has been dated at around 1700 Ma (U–Pb zircon; R. W. Page, personal communication, 1985), and is regarded as possibly coeval with the Fiery Creek Volcanics of cover sequence 3. The country rocks are metamorphosed up to the hornblende hornfels facies in a contact aureole which in places is 4 km wide.

Mafic intrusions

Intrusive mafic rocks in the region form dykes, sills, pod-like bodies and also net-veined complexes with granite (Figs 38, 42). They are generally less resistant to erosion than the rocks they intrude, and typically form topographic depressions which have the characteristic smooth dark airphoto tones of mafic rocks. Hence, they can be readily identified on aerial photographs except where they intrude mafic volcanics or are too thin to be distinguished at photo-scale. Most have been metamorphosed and deformed to some extent, and consist of either metadolerite or amphibolite. Those of metadolerite commonly have some igneous textures evident (e.g., Fig. 41) and in a few cases some primary igneous minerals are present, whereas in amphibolite intrusions there are few, if any, primary igneous features preserved. The deformed intrusions typically have schistose margins and, where they are several metres thick, massive interiors. A few mafic intrusions are post-tectonic and are formed of

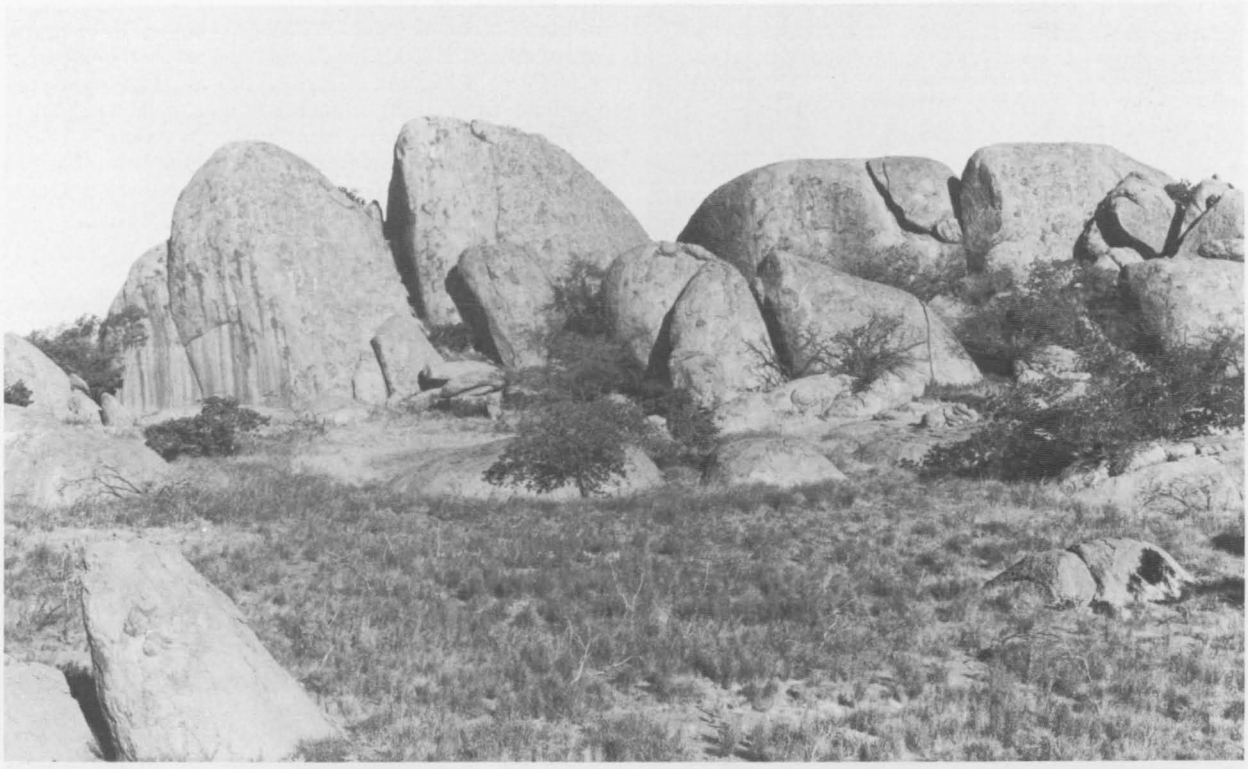


Fig. 40. Typical exposure of Sybella Granite west of Mount Isa (MOUNT ISA GR 285143) — R. M. Hill (M1337/9)

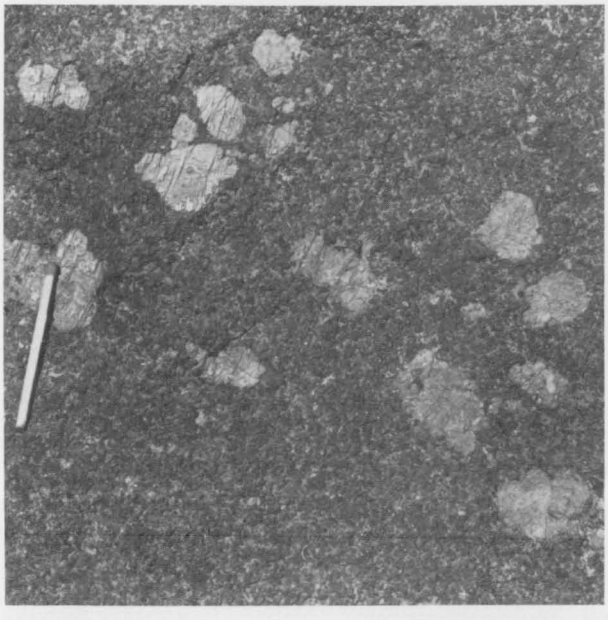


Fig. 41. Phenocrysts of altered plagioclase in metadolerite (MARRABA GR 197820) — G. M. Derrick (M929/6A)

unmetamorphosed (though commonly deuterically altered) dolerite. Two mafic intrusive units have been formally named: the Lunch Creek Gabbro and the Lakeview Dolerite (which is not distinguished on the accompanying 1:500 000 geological map).

Most, but not all, mafic intrusive rocks are markedly magnetic (e.g., Blake & others, 1984). Palaeomagnetic directions have been measured on some of them by Duff & Embleton (1976), including the Lunch Creek Gabbro and Lakeview Dolerite, but their meaning is not clear.

The *Lunch Creek Gabbro* crops out east of the Mary Kathleen uranium mine in the Mary Kathleen zone of the Eastern Fold Belt (in MARRABA), where it intrudes the Corella Formation, forms net-veined complexes with the Burstall Granite of the Wonga Batholith (Fig. 42), and is cut by a dyke of Lakeview Dolerite. It is a sill-like body about 500 m thick showing compositional banding (Fig. 43) and, although metamorphosed, commonly retains primary igneous textures and mineralogy. The main rock type, gabbro, contains orthopyroxene, clinopyroxene, biotite, plagioclase, opaque minerals, and rare olivine. Other rock types recorded include biotite diorite, hybrid diorite, tonalite, and hornblende-feldspar pegmatite (Derrick & others, 1978). Zircon from a gabbro pegmatoid in the Lunch Creek Gabbro has been dated at 1740^{+28}_{-20} Ma by Page (1983b).

The *Lakeview Dolerite* forms two large dykes, mainly between 10 and 50 m thick, in the southern central part of the Mount Isa Inlier (Fig. 44). The dykes have general north-northeasterly trends and hence are oblique to the prevailing northerly trending structures. They intrude cover sequences 2 and 3 and granites of the Wonga Batholith, and postdate the latest folding and metamorphism affecting the Mount Isa Inlier. Main constituents are plagioclase (labradorite cores), clinopyroxene, orthopyroxene, magnetite, and subordinate igneous hornblende and biotite (Ellis & Wyborn, 1984). The Lakeview Dolerite has been dated at 1116 ± 12 Ma (Rb–Sr; Page, 1983b). Petrographically similar unmetamorphosed dolerite forms east-west-trending dykes in the southeast of the Eastern Fold Belt (Fig. 44).

Dykes

Innumerable mafic dykes, many more than can be shown on the 1:100 000 geological maps or in Fig. 44, intrude the basement, cover sequences 1 and 2, and pre-1700 Ma old granite in the Western Fold Belt, Kalkadoon–Leichhardt Belt, and Eastern Fold Belt, but few have been reported cutting cover sequence 3 or post-1700 Ma old granite. None are

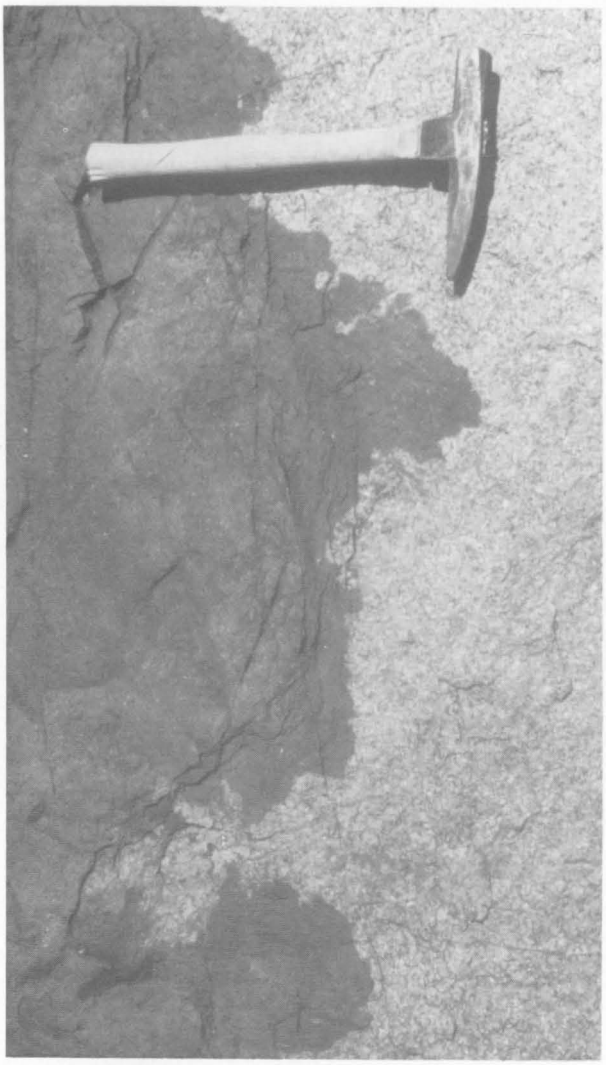


Fig. 42. Contact between Lunch Creek Gabbro and Burstall Granite of the Wonga Batholith (MARRABA GR 020070). The crenulate/cumulose contact suggests a liquid-liquid relationship, with mafic magma chilling against felsic magma—I. H. Wilson (GA2979)

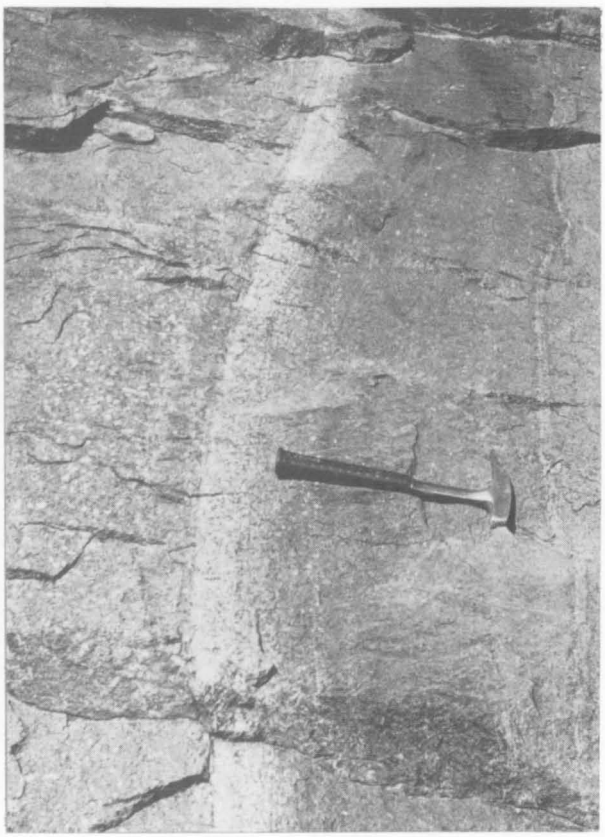


Fig. 43. Compositional banding in Lunch Creek Gabbro (MARRABA GR 030050) — G. M. Derrick (GA2798)

known in the Myally Shelf of the Western Fold Belt, or within the South Nicholson Basin. Some dolerite dykes cut the Nicholson Granite Complex and Cliffdale Volcanics (cover sequence 1) of the Murphy Tectonic Ridge: they trend northeast to east-northeast, and may be related to the Seigal Volcanics of the Tawallah Group in the McArthur Basin (cover sequence 3). Most mafic dykes are less than 10 m wide, although a few range up to 1 km or more in width.

Four main swarms of metamorphosed mafic dykes can be distinguished within the Mount Isa Inlier (Fig. 44). One swarm, formed of northerly trending dykes, occurs on the east side of the Leichhardt River Fault Trough and the western margin of the adjoining Kalkadoon–Leichhardt Belt. These dykes cut the Kalkadoon Granite and rocks intruded by this granite, and also the Bottletree Formation and Haslingden Group of cover sequence 2. Within the Haslingden Group, they are particularly abundant in the Mount Guide Quartzite and Leander Quartzite, but appear to be less numerous in the Eastern Creek Volcanics, especially in the upper part, and relatively few penetrate up into the Myally Subgroup. The dykes of this swarm were considered by Carter & others (1961) to be similar in age to the Eastern Creek Volcanics, but Glikson & others (1976) considered them to be much younger because, although generally parallel to regional structural trends, they cut across easterly striking bedding in the Haslingden Group northeast of Mount Isa, and hence appear to postdate a folding event affecting both the Haslingden Group and overlying Mount Isa Group. However, the interpretation of Carter & others (1961) may be valid, because the dykes, as might be expected, are aligned parallel to the margins of the fault trough thought to have existed at the time of Eastern Creek volcanism, and may not show any obvious effects of subsequent folding about northerly trending axes.

A second major swarm forms a conjugate system of dykes intruding the Kalkadoon and Ewen Batholiths, Leichhardt Volcanics (cover sequence 1) and Kurbayia Migmatite (basement) in the western part of the Kalkadoon–Leichhardt Belt and in the Ewen Block of the Western Fold Belt. Two main sets of dykes are present, one trending between north and northeast and the other trending between west-northwest and north-northwest. There are also a few dykes in this swarm which trend east-west. Most dykes of the conjugate system do not appear to penetrate up into the Magna Lynn Metabasalt (cover sequence 2), which overlies the Leichhardt Volcanics, and they are only weakly magnetic (Blake & others, 1984), unlike most mafic rocks of the Mount Isa Inlier, including those of the Magna Lynn Metabasalt and Eastern Creek Volcanics. They are, therefore, unlikely to be intrusive equivalents of these two formations and are probably older than them.

A third swarm, formed of northwesterly to northerly trending dykes, intrudes cover sequence 2 (mainly the Argylla Formation) and granites of the Wonga Batholith in the eastern part of the Kalkadoon–Leichhardt Belt. Some of the northwesterly trending dykes within the conjugate swarm to the west probably belong to this third swarm.

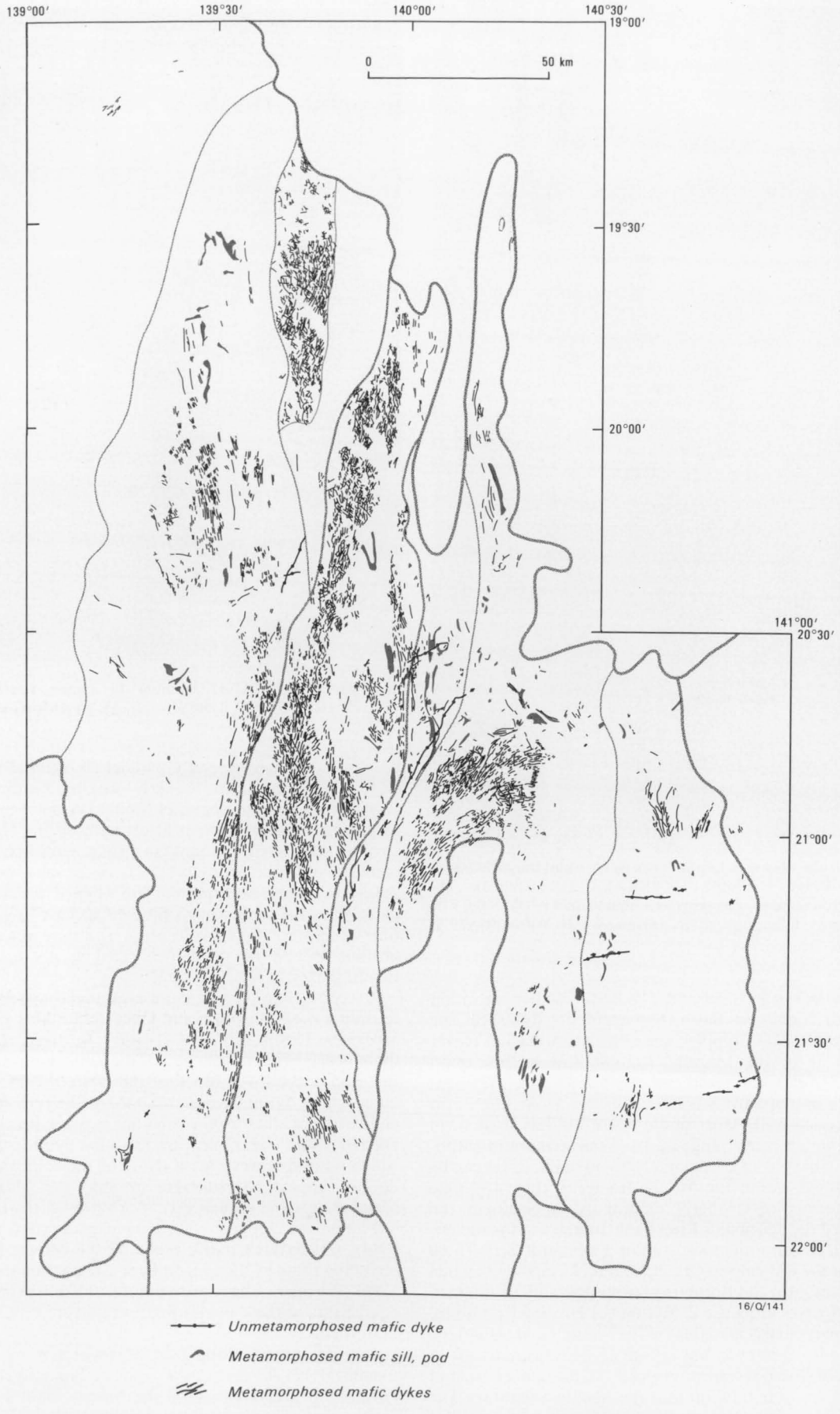


Fig. 44. Distribution of mafic intrusions in the Mount Isa Inlier.

The fourth main dyke swarm intrudes the Argylla Formation and Malbon Group of cover sequence 2 in the central and southern parts of the Quamby-Malbon zone in the Eastern Fold Belt. The dykes of this swarm have trends which swing from northerly in the southwest to northeasterly in the north and easterly in the northeast, roughly parallel to the axial planes of the Bulonga Anticline, Wakeful Syncline, and Duck Creek Anticline, and may have been intruded during the development of these folds.

Less extensive and less intense swarms include (1) northerly trending metadolerite dykes in the Soldier's Cap Group southeast of Cloncurry and in the Kuridals Formation southeast of Selwyn, in the Eastern Fold Belt, and (2) northeast to east-northeast-trending little-metamorphosed dykes (felsic as well as mafic) cutting the Haslingden Group and Weberra Granite in the Lawn Hill Platform (MOUNT OXIDE REGION) of the Western Fold Belt. The latter dykes may be related to the Fiery Creek Volcanics of cover sequence 3. The metamorphosed dykes southeast of Cloncurry cut major folds in the Soldier's Cap Group, and hence postdate a folding event.

Two main sets of widely spaced unmetamorphosed dolerite dykes are present in the southern half of the Mount Isa Inlier. These are the northeasterly trending Lakeview Dolerite dykes and an east-west-trending set which is best exposed in the southeast, cutting cover sequence 2 and plutons of the Williams Batholith.

Sills

Sills are locally common within cover sequence 2 in the Mount Isa Inlier. They range up to 250 m or more in thickness, and some extend laterally for many kilometres. Many are multiple intrusions, with individual sills being separated from one another by thin concordant screens of country rock. Several sills intrude the Haslingden Group in the Leichhardt River Fault Trough (especially the Myally Subgroup), the Mary Kathleen Group (mainly the Corella Formation) in the Kalkadoon-Leichhardt Belt, and the Malbon and Mary Kathleen Groups in the Eastern Fold Belt. However, some of the mafic bodies mapped as sills within the Corella Formation in the Kalkadoon-Leichhardt Belt (for example, in the central part of the Rosebud and Little Beauty Synclines in MARY KATHLEEN) and in the Mary Kathleen zone of the Eastern Fold Belt, may be extrusions.

Pod-like bodies

Pod-like mafic intrusions, mostly less than 1 km across, are a characteristic feature of the Cloncurry-Selwyn zone in the Eastern Fold Belt, especially in the outcrop areas of the Doherty and Corella Formations (Mary Kathleen Group). There are also some in other parts of the Mount Isa Inlier, mainly in the south.

Ages of mafic intrusions

The Proterozoic mafic intrusions of the Mount Isa Inlier are clearly of several ages (e.g., Carter & others, 1961; Ellis & Wyborn, 1984). Many intrusions are probably related to the mafic lavas of the Inlier, which are particularly extensive in cover sequence 2, and hence may be between about 1790 and 1760 Ma old. Other mafic intrusions appear to have had no extrusive equivalents, or at least none preserved or exposed. Such intrusions include the main dyke swarms in the Kalkadoon-Leichhardt Belt and Eastern Fold Belt, sills in the Myally Subgroup and Mary Kathleen Group of cover sequence 2, dolerite and metadolerite forming net-veined complexes with granites of the Sybella, Wonga, and Williams Batholiths, and the post-tectonic dolerite dykes. The oldest mafic intrusions are amphibolite bodies in the Kurbayia Migmatite and other basement units; these were deformed before the eruption of the Leichhardt Volcanics and are therefore older than 1875 Ma. The only two mafic intrusions isotopically dated are the Lunch Creek Gabbro at about 1740 Ma and the post-tectonic Lakeview Dolerite at about 1116 Ma (Page, 1983b).

Mafic intrusive events evident or postulated in the Mount Isa Inlier, together with the age groupings distinguished by Carter & others (1961) and Ellis & Wyborn (1984), are shown in Table 14.

Felsic minor intrusions

Felsic minor intrusions are common locally within the Mount Isa Inlier, but are much less numerous than mafic minor intrusions. Most can be related to nearby felsic volcanic and plutonic units (e.g., Fig. 45). The oldest felsic dykes may be those of dark grey fine-grained tonalite which intrude the basement Kurbayia Migmatite in the Kalkadoon-Leichhardt Belt and are cut by leucogranite veins of possibly rheomorphic origin—perhaps formed by partial melting of the country rocks by the tonalite. These tonalite dykes may be similar in age to the 1860 Ma-old Kalkadoon Granite, or somewhat older. The Kurbayia Migmatite is also cut by younger felsic dykes, formed of grey fine-grained feldspar porphyry, which are similar in chemistry and probably age to felsic volcanics of the 1790 Ma-old Bottletree Formation (cover sequence 2) exposed to the west. Felsic dykes related to the Leichhardt Volcanics of cover sequence 1 intrude the One Tree Granite of the Kalkadoon Batholith in the south of the Kalkadoon-Leichhardt Belt. Some intrusions of Argylla-type (pinkish prophyry), and hence probably about 1780 Ma old, occur within the Leichhardt Volcanics in MARY KATHLEEN (Fig. 45). Felsic and also some mafic dykes, probably related to the Fiery Creek Volcanics (cover sequence 3), intrude rocks of the Haslingden Group (cover sequence 2) and Weberra Granite in the Lawn Hill Platform, in MOUNT OXIDE REGION.

In MARRABA, rocks assigned to the Corella Formation within the Quamby-Malbon zone of the Eastern Fold Belt are reported to be intruded by a series of felsic sills about 400 m thick, mapped as Tommy Creek Microgranite (Derrick,

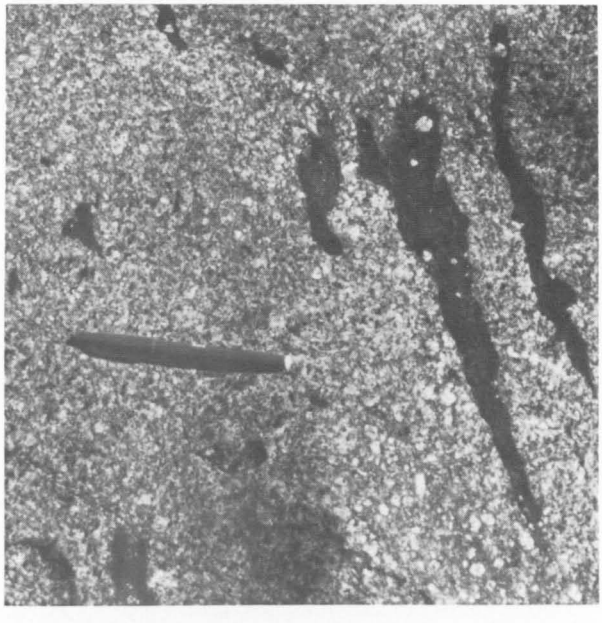


Fig. 45. Intrusive felsic porphyry of Argylla type containing streaky mafic inclusions which may have been liquid when incorporated in the felsic magma (MARY KATHLEEN GR 762894). (M2657/35)

TABLE 14. MAFIC INTRUSIONS OF THE MOUNT ISA INLIER

Age (Ma)	*Description*	*Age Grouping of*	
		Carter & others (1961)	*Ellis & Wyborn (1984)*
Post-1500	Unmetamorphosed dolerite dykes post-dating folding of cover sequences and emplacement of granite in the Mount Isa Inlier; include dykes of Lakeview Dolerite, dated at 1116±12 Ma	VI, VIII	W3, B2, E4
~1500	Dolerite forming net-veined complexes with granites of the Williams Batholith in the Eastern Fold Belt	—	—
~1600	Metadolerite dyke swarm associated with development of the Bulonga Anticline, Wakeful Syncline, and Duck Creek Anticline in the Quamby-Malbon zone, Eastern Fold Belt	IV	E2
~1600?	Metadolerite dykes cutting folds in the Soldiers Cap Group southeast of Cloncurry, Eastern Fold Belt	IV	E2
~1670	Dolerite forming net-veined complexes with Sybella Granite west of Mount Isa, Western Fold Belt	—	W2
~1680	Intrusive equivalents of mafic Fiery Creek Volcanics (cover sequence 3)	—	—
<1740	Metadolerite dyke swarm intruding cover sequence 2 (Argylla Formation, Ballara Quartzite) and granites of the Wonga Batholith in the eastern part of the Kalkadoon-Leichhardt Belt	III	B1
~1740	Metadolerite and gabbro forming net-veined complexes with granites of the Wonga Batholith in the Mary Kathleen zone of the Eastern Fold Belt. Includes Lunch Creek Gabbro	—	E3
?	Metadolerite sills intruding the Corella Formation (cover sequence 2) in the Kalkadoon-Leichhardt Belt	III	E2
?	Metadolerite sills, dykes and plugs intruding the Mary Kathleen Group (cover sequence 2) in the Eastern Fold Belt	III, IV	E3
?	Metadolerite sills in the Myally Subgroup (cover sequence 2) in the Leichhardt River Fault Trough of the Western Fold Belt	V	W1
?	Metadolerite and amphibolite sills in the Soldiers Cap Group (cover sequence 2), in the Cloncurry-Selwyn zone of the Eastern Fold Belt	IV	E1
~1780	Intrusive equivalents of Eastern Creek Volcanics, Jayah Creek Metabasalt, Oroopo Metabasalt, and Kamarga Volcanics in the Western Fold Belt, Magna Lynn Metabasalt in the Kalkadoon-Leichhardt Belt, and Malbon and Soldiers Cap Groups in the Eastern Fold Belt (all cover sequence 2); may include all or part of dyke swarm in eastern part of the Leichhardt River Fault Trogh and western part of the adjoining Kalkadoon-Leichhardt Belt	II	W1, E2
~1790	Intrusive equivalents of mafic lavas of the Bottletree Formation (cover sequence 2) in the Leichhardt River Fault Trough, Western Fold Belt	—	—
Between 1800 and 1840	Weakly magnetic mafic dykes forming conjugate swarm in the western part of the Kalkadoon-Leichhardt Belt and in the Ewen Block of the Western Fold Belt, intruding Kalkadoon and Ewen Batholiths and Leichhardt Volcanics (cover sequence 1)	II	B1
~1860	Metadolerite forming net-veined complexes with Kalkadoon Granite in the Kalkadoon-Leichhardt Belt	—	—
~1870	Intrusive equivalents of metabasalt lavas in the Leichhardt Volcanics and Candover Metamorphics in the Kalkadoon-Leichhardt Belt and Ewen Block of the Western Fold Belt	—	—
Pre-1880	Intrusive amphibolite bodies in basement units (Kurbayia Migmatite, Sulieman Gneiss, Saint Ronans Metamorphics, Double Crossing Metamorphics)	I	—

1980). The sills are pale pink, fine-grained, foliated quartzofeldspathic rocks which in places contain small phenocrysts of quartz and feldspar. At least some, and possibly most, of these rocks are now considered by many geologists to be rhyolitic metavolcanics (e.g., Derrick, 1980; Blake, 1983; see Wilson, 1983b, for alternative view). One sample of Tommy Creek Microgranite, described as leucocratic microgranite, has been dated at 1600^{+15}_{-11} Ma by Page (1983a), who has interpreted this age as dating sill emplacement. Alternatively, the 1600 Ma date could be a metamorphic rather than an igneous age.

Only one felsic minor intrusion is shown on the 1:500 000 geological map. This is the *Garden Creek Porphyry*, a subvertical sheet up to 250 m thick intruding, in the main more or less concordantly, the Mount Guide Quartzite (cover sequence 2) in the southeast of the Leichhardt River Fault Trough. It contains abundant phenocrysts of andesine, microcline, and quartz in a microgranitic groundmass, and is almost invariably flanked on both sides by metadolerite, indicating that it may be a composite intrusion. Some small dykes of porphyritic and non-porphyritic rhyolite less than 20 m thick, which cut Jayah Creek Metabasalt (cover sequence 2) to the southwest (in ARDMORE), may be related to the Garden Creek Porphyry.

Most of the granite plutons in the Mount Isa Inlier have associated dykes, sills, and veins of leucogranite, pegmatite, even-grained to porphyritic microgranite, granophyre, and rhyolite, which cut the adjacent country rocks. Dykes of porphyritic rhyolite emanating from the Burstall Granite (Wonga Batholith) into the Corella Formation (cover sequence 2), in the Mary Kathleen zone of the Eastern Fold Belt, have been genetically related by some authors to the uranium mineralisation at Mary Kathleen (e.g., Derrick, 1977; Cruikshank & others, 1980). One of these dykes has been dated at 1737±15 Ma (Page, 1983b). To the southeast, in the Quamby-Malbon zone in SELWYN REGION, the Staveley Formation (cover sequence 2) is cut by one or more thin sheets of unmetamorphosed felsic porphyry possibly related to non-foliated granite of the Williams Batholith.

In the Murphy Tectonic Ridge, dykes of feldspar and quartzfeldspar porphyry, ranging in composition from rhyolite to dacite, are associated with the Cliffdale Volcanics (cover sequence 1) and Nicholson Granite Complex. They form a conjugate set with west to west-northwest and north to north-northeast trends (Sweet & others, 1981).

Mount Philp Breccia

Bodies of Mount Philp Breccia (shown as Mount Philip Agglomerate on the MARY KATHLEEN map) cut the Corella Formation in the central and southern part of the Mary Kathleen zone of the Eastern Fold Belt. They consist of disoriented fragments, ranging in shape from angular to rounded and in size from less than one centimetre to several

tens of metres, dispersed in a pink to red groundmass. The fragments are of metasediments (especially calc-silicate rocks), metabasalt, metadolerite, quartz–feldspar pegmatite, and possible leucogranite, all of which can be matched with rocks found within the adjacent Corella Formation. The groundmass of the breccia has an igneous-type texture, and contains stubby euhedral phenocrysts of tremolitic amphibole enclosed in a pink fine-grained mosaic of interlocking albite laths with many small and irregular miarolitic cavities lined with inward-growing euhedral albite crystals. The breccia bodies postdate the main deformation and metamorphism affecting the adjacent Corella Formation, and may fill pipes and fissures formed by explosive releases of pressure during intrusion of magma into calc-silicate rocks at depth (Blake & others, 1982a).

PHANEROZOIC

The Proterozoic rocks of the Mount Isa Inlier and environs are overlain unconformably by unmetamorphosed Palaeozoic, Mesozoic, and Cainozoic sedimentary sequences.

The *Palaeozoic* sequence forms part of the Georgina Basin succession described by Shergold & Druce (1980). It crops out extensively west of the Mount Isa Inlier, and is also exposed to the south. Scattered exposures within the Inlier indicate that the Palaeozoic sequence may originally have covered most or all of the present Proterozoic outcrops. It consists predominantly of shallow-marine clastic, calcareous, dolomitic, cherty, and phosphatic sedimentary rocks of early Cambrian to early Ordovician age (Table 15). These rocks are flat-lying to gently dipping except near some faults (e.g., along the southern part of the Pilgrim Fault Zone). The Georgina Basin succession also includes a late Adelaidean glacial unit, the Little Burke Tillite (de Keyser, 1972), which is exposed near Duchess in DUCHESS REGION (outcrop too small to show on the 1:500 000 map).

The *Mesozoic* is represented by flat-lying sedimentary rocks which extend northwards and westwards across the Proterozoic outcrops from the Eromanga Basin in the southeast (Senior & others, 1978) and the Carpentaria Basin in the northeast (Smart & others, 1980). Named Mesozoic units mapped in the 1:100 000 sheet areas (Table 16) range in age from late Jurassic to early Cretaceous, comprise fluvial and shallow-marine deposits, and typically form mesas and partly dissected low plateaus.

The *Cainozoic* sediments (i.e., Tertiary and Quaternary) present within and around the margins of the Proterozoic outcrop areas are non-marine. Alluvial and colluvial sediments predominate, but aeolian sand, inorganic limestone, ferricrete, silcrete, and residual deposits are also widespread. Ferruginous and siliceous duricrusts are a characteristic feature of much of the region.

TABLE 15. LOWER PALAEOZOIC UNITS

Name	*Distribution* [1]	*Age*	*Dominant Lithology*
Beetle Creek Formation	AR, DA, DUR, MMR, MI	Cambrian	Chert, mudstone, siltstone, shale, sandstone, limestone, phosphorite
Blazen Shale	AR	Cambrian	Shale, siltstone, chert, bituminous limestone
Border Waterhole Formation	CRR, LHR	Cambrian	Chert, siltstone, phosphorite
Bukalara Sandstone	SE	Cambrian	Sandstone, conglomerate
Camooweal Dolomite	CRR	Cambrian	Dolomite
Chatsworth Limestone	DA, SER	Cambrian	Limestone, marl
Currant Bush Limestone	CRR	Cambrian	Limestone, marl, dolomite
Devoncourt Limestone	DA, DUR	Cambrian	Limestone, bituminous limestone, marl
Inca Formation	DA, MMR, MI	Cambrian	Siltstone, shale, sandstone, chert, limestone
Kjabbi Formation	QU	Cambrian	Limestone, sandstone, grit
Mount Birnie beds	DA, DUR, KUR, SER	Cambrian	Sandstone, conglomerate, shale
Mount Henry Formation	MMR	Cambrian	Conglomerate, sandstone, siltstone
Ninmaroo Formation	(Duchess–Urandangi Region 1:250 000 Sheet)	Ordovician	Calcareous sedimentary rocks
O'Hara Shale	DA, DUR, SER	Cambrian	Siltstone
Pomegranate Limestone	SER	Cambrian	Limestone, marl, breccia
Quita Formation	AR	Cambrian	Bituminous limestone, marl, mudstone
Riversdale Formation	AR	Cambrian	Sandstone, dolomite, siltstone
Roaring Siltstone	DA, DUR, SER	Cambrian	Siltstone, shale, sandstone
Selwyn Range Limestone	DUR	Cambrian	Calcilutite, marl
Steamboat Sandstone	AR	Cambrian	Sandstone, siltstone
Swift Formation	DA	Ordovician	Siltstone, sandstone, chert
Thorntonia Limestone	AR, DA, DUR, KUR, LHR, MMR, MOR	Cambrian	Chert, breccia, dolomite, limestone
Undivided Cambrian	KG	Cambrian	Siltstone, shale, dolomite

(1) 1:100 000 geological map sheets; for key to abbreviations see Table 2

TABLE 16. MESOZOIC UNITS

Name	*Distribution* [1]	*Age*	*Dominant Lithology*
Mullaman Beds	CRR, HC, LHR, SE	Cretaceous	Sandstone, conglomerate, claystone, siltstone
Normanton Formation	CO, MY	Cretaceous	Sandstone, siltstone, mudstone
Allaru Mudstone	CL, CO, MY, SER	Cretaceous	Mudstone
Toolebuc Formation	CL, CO, MY, QU, SER	Cretaceous	Calcareous bituminous shale, limestone
Wallumbilla Formation	CL, CO, MY, SER	Cretaceous	Mudstone, sandstone, siltstone
Gilbert River Formation	CO, KUR, LHR, MOR, MY, SER	Jurassic	Sandstone, conglomerate
Undivided Mesozoic	AL, AR, DA, DUR, KG, MA, MMR, MI, MOR, MY, PR, QU	—	Sandstone, conglomerate

(1) 1:100 000 geological map sheets; for key to abbreviations see Table 2

STRUCTURE

Details of structures recognised within the region before 1982 are given in the BMR Records and map commentaries for the 1:100 000 geological maps and in BMR Bulletins 193 and 219. Results of structural investigations currently in progress (1985) will be published in the future.

Mount Isa Inlier

The Proterozoic rocks forming the Mount Isa Inlier are in general more intensely deformed in the south than in the north. Those of the basement were first deformed before the Proterozoic cover sequences were laid down. The first recognised period of region-wide folding and faulting to affect the cover sequences was from about 1620 Ma to 1550 Ma (Page & others, 1984).

Western Fold Belt

Lawn Hill Platform

The rocks of the Lawn Hill Platform in the northwest of the Western Fold Belt show basin-and-dome folding of concentric style. Most of the folds are elongate, and have mainly northeasterly trends in the north and northerly trends in the south. Folds in the east, near the north-northeast-trending Mount Gordon Fault Zone, are aligned parallel to this zone (e.g., the Valparaisa Syncline in MOUNT OXIDE REGION). The Mount Caroline Anticline (Fig. 46), which is cut by small quartz-filled faults possibly related to changes in plunge of the fold, and the Ploughed Mountain Anticline in the north have steep to overturned limbs (Sweet & Hutton, 1982). Steep dips also occur in a northerly trending zone up to 10 km wide in the western part of MAMMOTH MINES REGION and MOUNT OXIDE REGION, where an axial plane cleavage is developed in isoclinally folded rocks of the McNamara Group (cover sequence 3).

Several broad circular structures are present within the Lawn Hill Platform. These include the Kamarga Dome in LAWN HILL REGION and the Fiery Creek and Sandy Creek Domes in MOUNT OXIDE REGION, around which dips are mainly less than 20°. A much younger feature is an annular outcrop of Cambrian rocks, which are locally folded and brecciated, surrounding a slightly lower Proterozoic core (upper McNamara Group) in LAWN HILL REGION. A suggestion that this circular structure may represent a crypto-explosion feature was considered unlikely by Sweet & Hutton (1982), but is supported by a recent finding of shatter cones and possible melt-rock within the central core (Stewart & Mitchell, in prep.).

Four major faults displace rocks of the Lawn Hill Platform (see 1:500 000 geological map):

(1) The north-northeasterly trending Mount Gordon Fault, with a right lateral strike-slip displacement of up to 10 km. It is part of a fault zone up to 7 km wide marking the boundary between the Lawn Hill Platform and Leichhardt River Fault Trough to the east.

(2) The northwesterly trending Termite Range Fault, which has a possible vertical displacement of up to 1000 m.

(3) The north-northwest-trending May Downs Fault in the south. Tight to isoclinal mesoscopic folds along this fault indicate a sinistral strike-slip movement.

(4) The northeast-trending Fiery Creek Fault in the north. This fault, which appears to terminate against the Termite Range Fault to the southwest, may have been active during extrusion of the Fiery Creek Volcanics and also during deposition of the lower part of the McNamara Group (Hutton & Wilson, 1984).

Fig. 46. Oblique aerial photograph, looking southwest, of part of the Mount Carolina Anticline, Lawn Hill Platform (LAWN HILL REGION). (M2686/4)

Leichhardt River Fault Trough

Rocks of cover sequences 2 and 3 exposed in the Leichhardt River Fault Trough are generally more intensely deformed and metamorphosed than those in the Lawn Hill Platform.

Folds with north to north-northwest trends and steep to vertical axial planes predominate. Most folds in the north plunge south, whereas northerly plunges predominate in the south. Some folds are doubly plunging. An axial plane cleavage is commonly developed, especially in pelitic units. Three deformation events can be recognised. The first, D_1, mainly resulted in easterly oriented folds. The predominantly northerly trending major folds originated during the second event, D_2. During the third event, D_3, which is apparent only locally (e.g., at Mount Isa mine), some north-northwesterly oriented folds were developed (Bell, 1983). A pronounced foliation present in much of the Sybella Granite may be related to either D_1 or D_2.

The basement units exposed in the southern part of the Leichhardt River Fault Trough have a well-developed foliation which, at least in some areas, predates deposition of the cover sequences and subsequent D_2 folding. The foliation in the Yaringa Metamorphics, west of Mount Isa, for example, was formed before the overlying McNamara Group of cover sequence 3 was deposited. It has easterly trends in southern exposures and mainly north-northwesterly to northerly trends to the north, perhaps as a result of later folding. The Saint Ronans Metamorphics to the south have a foliation that is folded by southerly plunging south-southeast-trending folds of probably D_2 age. Some minor folds (but no major folds) related to the early foliation have been found in these basement units.

The complex system of faults in the Leichhardt River Fault Trough includes faults associated with the folding events that affected cover sequences 2 and 3 as well as younger faults. There are also some faults which may have been active during deposition of the cover sequences, as indicated by abrupt lateral changes in thickness and lithology (e.g., Smith, 1969; Derrick & others, 1977c; Derrick, 1982; Hutton & Wilson, 1984).

Many faults were probably formed during folding. These include those that are parallel to bedding, cleavage, or foliation, and are displaced by later faults. Other possible examples are the series of mainly easterly trending major faults which repeat parts of cover sequence 2 and cover sequence 3 north of Mount Isa. These were termed "spoon faults" by Dunnett (1976), who regarded them as listric normal faults, mainly downthrown to the south, which curved onto a decollement horizon at depth. Derrick (1982) considered that one of these faults, the Investigator Fault in PROSPECTOR, was active during deposition of the lower McNamara Group. Bell (1983), however, has reinterpreted the spoon faults as northerly dipping thrusts which are part of a major thrust duplex involving tectonic transport from the north, this duplex being formed during D_1, and subsequently folded during D_2.

A prominent system of conjugate strike-slip faults with northeasterly and northwesterly trends cuts across folds and hence postdates the folding events. The northeast-trending faults are dextral and those trending northwest are sinistral. Faults with similar trends and sense of displacement are present to the east, in the Kalkadoon-Leichhardt Belt and Eastern Fold Belt.

Major north-northeast- to north-northwest-trending faults with considerable post-folding movements include those of the Hero-Mount Isa-Mount Annable-Rufus Fault zone; the Mount Gordon Fault and related faults to the northwest; the May Downs Fault in the west; the Gorge Creek Fault in the east; the Mount Remarkable Fault to the northeast; and the Wonomo Fault in the southeast. Small-scale folds are commonly developed in the vicinity of these faults. Some post-Cambrian displacement is evident in places, as along the Rufus Fault Zone, where Cambrian units have been down-faulted to form the Ardmore Outlier.

Ewen Block

The Ewen Block is inferred to be a broad open anticlinal structure because it consists mainly of cover sequence 1 and Ewen Granite. In the south the Eastern Creek Volcanics immediately to the west, in the Leichhardt River Fault Trough, and to the east, in the Myally Shelf, dip west and east, respectively. No folds have been identified in the unstratified Leichhardt Volcanics of cover sequence 1 and the comagmatic Ewen Granite, but in the south the Eastern Creek Volcanics (cover sequence 2) form a broad anticline plunging at up to 20° north. Underlying Candover Metamorphics (possible cover sequence 1) exposed in the core of this anticline appear to be more deformed, and also more metamorphosed, than the Eastern Creek Volcanics. They commonly show a well-developed steeply dipping foliation or fracture cleavage trending between north-northeast and north-northwest, subparallel to bedding. In the centre of the Ewen Block, units of cover sequences 2 and 3 are exposed in a northwest-trending offshoot from the Myally Shelf. This offshoot, the Mount Fox Outlier, is a syncline bounded by a fault on its northeast side. Numerous northeasterly and northwesterly trending faults within the Ewen Block are probably part of the same conjugate system that cuts the Leichhardt River Fault Trough. Major faulting along the western and eastern margin of the Ewen Block has caused extensive shearing, especially in the west.

Myally Shelf

Cover sequences 2 and 3 in the Myally Shelf show complex tight to isoclinal folding in the west and more open folding in the east. The folds have northerly trends and most plunge to the north, although some doubly plunging and southerly plunging folds are also present. An axial plane cleavage is developed in pelitic rocks.

The main fault displacing the cover sequences is the Saint Paul Fault, which forms the eastern boundary of the Myally Shelf. Other faults include those of the northwest and northeast-trending conjugate system present in other parts of the Mount Isa Inlier, some north-trending faults, and several faults with general easterly trends and a main movement sense of north-block-up.

Kalkadoon-Leichhardt Belt

The oldest structures identified in the Kalkadoon-Leichhardt Belt are small folds and a related axial plane foliation developed in the basement Kurbayia Migmatite (Fig. 47). These predate emplacement of the Kalkadoon Batholith and deposition of the cover sequences, and hence were formed long before the D_1 event recognised in the Leichhardt River Fault Trough. Similar structures developed in the Plum Mountain Gneiss to the southeast are possibly of comparable age, but may be much younger, as the prominent foliation in this unit is parallel to the foliation developed in adjacent granite of the Kalkadoon and Wonga Batholiths.

No folds have been identified within the Leichhardt Volcanics of cover sequence 1. However, cover sequences 2 and 3 form several major synclines. These range from open to tight, have steep to vertical axial planes, and trend between north and northwest. Most are doubly plunging: examples include the Rosebud and Little Beauty Synclines in MARY KATHLEEN. No comparable anticlines have been mapped. A pronounced foliation or cleavage also trending between north and northwest is widespread in the cover sequences, in the granites of the Kalkadoon and Wonga Batholiths, and in the basement Plum Mountain Gneiss (Fig. 48). Large open drag folds in the latter unit, immediately south of the northwest-trending Plum Mountain Fault, may be related to

Fig. 47. Folds in Kurbayia Migmatite (basement) predating intrusion of Kalkadoon Granite, DUCHESS REGION (GR 525535). (M2624/30A)

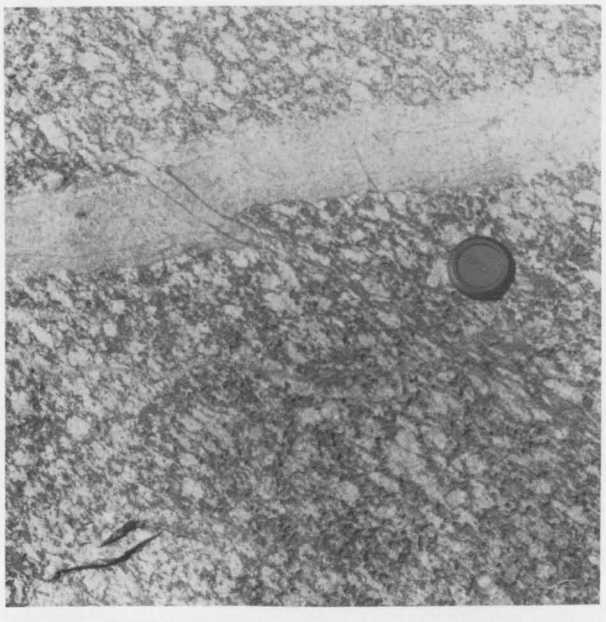


Fig. 48. Foliated augen gneiss and aplite vein, Plum Mountain Gneiss (basement) (DAJARRA GR 770110). (M2624/4A)

movement which took place along this fault after the main folding event (Blake & others, 1984).

The major synclines and associated foliation and cleavage are not the oldest structures affecting the cover sequences in the Kalkadoon–Leichhardt Belt, because recent studies (e.g., BMR, 1985; C. Passchier, pers. comm., 1984) have shown that extensive thrusting (D_1) preceded the main folding event (D_2). Repetitions of stratigraphic units in fault-bounded outcrops of Western Fold Belt rocks in the west of the Kalkadoon–Leichhardt Belt and occurrences to the east of Mount Albert Group overlying Mary Kathleen Group, mainly in MARY KATHLEEN, may be attributed to D_1 thrusting. Another result of such thrusting may be the northerly trending bands of eastward-dipping cover sequences 1 and 2 exposed in the central part of the Kalkadoon–Leichhardt Belt. Faults on the east side of each band may be either part of an imbricate stack (BMR, 1985) formed during the D_1 thrusting event and possibly steepened by subsequent folding, or they may be normal or high-angle reverse faults formed during folding (D_2). Both interpretations were suggested by Derrick & others (1977c).

The eastern margin of the Kalkadoon–Leichhardt Belt is a zone of intensely deformed rocks assigned to cover sequence 2 (mainly Argylla and Corella Formations) and the Wonga Batholith. This zone—the Wonga Belt of Derrick (1980) and the western part of the Duchess Belt of Blake & others (1984)—is characterised by steeply dipping to vertical, northerly trending foliations (Fig. 49), transposed bedding, mylonitic layering with intrafolial folds, tight to isoclinally folded veins of quartz and leucocratic microgranite, and a variety of lineations. The deformation is due to east-west compression, resulting in east-west shortening of 65–80% in places, according to Holcombe & Fraser (1979), who have discussed aspects of the structure, stratigraphy and intrusive relationships in this zone in MARY KATHLEEN. Holcombe & Fraser (1979) and Holcombe (1981) showed that the main deformation took place after granite emplacement. They also concluded that felsic metaporphyries previously regarded as extrusive in the zone are intrusive and postdate rather than predate a suite of mafic dykes; this interpretation was refuted (correctly, in the author's view) by Derrick & Wilson (1981a).

Faults which postdate the main folding event (D_2) include northeast and northwest-trending sets of the conjugate system that characterises much of the Mount Isa Inlier. Several of the faults trending northeast extend eastwards to cut across the Eastern Fold Belt; they show considerable horizontal displacements and postdate at least some of the northwest-trending faults. Examples include, from north to south, the Saint Paul Fault, marking the eastern boundary of the Myally Shelf; the Mount Remarkable Fault, which has a dextral displacement of about 25 km in PROSPECTOR and joins up with the Gorge Creek Fault to the southwest; the Wonga Fault with a dextral displacement about 3 km; the Cameron Fault, dextral displacement 1–2 km; and the Fountain Range Fault (Fig. 50), with a dextral displacement up to 25 km. The north-trending Dajarra Fault in the southwest of the Kalkadoon–Leichhardt Belt is a possible extension of the

Fig. 49. Northerly trending subvertical mylonitic felsic gneiss (metavolcanics) of the Argylla Formation (cover sequence 2) on the eastern margin of the Kalkadoon–Leichhardt Belt in DUCHESS REGION (GR 755512). (M2627/22A)

Fig. 50. Southwest-trending quartz ridge up to 140 m high along the Fountain Range Fault in southeast MARY KATHLEEN and northeast DUCHESS REGION. (M2695/77A)

Fountain Range Fault. It may have major vertical and horizontal displacements; in the south, for example, it separates greenschist facies cover sequence 1 (Leichhardt Volcanics) to the east from amphibolite facies cover sequence 2 (Argylla Formation) to the west.

Eastern Fold Belt

Mary Kathleen zone

This zone consists predominantly of thinly banded, generally plastically deformed, calc-silicate rocks of the Corella Formation, and strongly foliated granitic plutons of the Wonga Batholith. Structural trends range from north-northwest to north-northeast. Deformation is most intense in the west of the zone, adjacent to the Wonga Belt and its extension to the south, along the eastern margin of the Kalkadoon-Leichhardt Belt.

Major and minor folds in the Corella Formation are typically tight to isoclinal and generally have subvertical axial planes, shallow and variable plunges, and high amplitude to wave-length ratios. Disharmonic folds, intrafolial folds, refolded folds, tectonic transposition banding, and metamorphic differentiation banding are common (e.g., Blake & others, 1984). At least two main episodes of folding about north-south axes are apparent, one predating and the other postdating granite emplacement (Blake, 1982, 1983; Blake & others, 1984). Foliations parallel to axial planes are well developed in pelitic units within the Corella Formation, but generally not in calc-silicate rocks, except in some fold hinges.

A series of major fault systems, those of the Pilgrim, Ballara-Corella River and Mount Rosebee Fault Zones, mark the eastern boundary of the Mary Kathleen zone. These probably represent deep crustal structures which were active during the Phanerozoic as well as in the Proterozoic. In the case of the Pilgrim Fault Zone, Proterozoic units exposed to the east cannot be directly correlated with units exposed to the west (Blake & others, 1984), and Cambrian units show vertical displacements of up to 100 m or more along parts of the zone, thus indicating major Precambrian and significant post-Cambrian fault movements. Other major faulting displacing the Proterozoic rocks of the zone include (1) some with north-south trends, such as the Pinnacle Fault in the north and the Mary Kathleen 'shear' at the Mary Kathleen uranium mine; (2) several northwest-trending faults, the main example being the Plum Mountain Fault south of Duchess; and (3) the northeasterly trending Mount Remarkable Fault, Fountain Range Fault (which merges with the Ballara-Corella River Fault Zone to the northeast), Overlander Fault (dextral displacement about 2 km), Saint Andrews Fault (dextral displacement possibly about 5 km), and Railway Fault (at Duchess, apparent dextral displacement of about 2 km).

Quamby-Malbon zone

The main structures in the Quamby-Malbon zone are the broad northerly to northeasterly plunging Bulonga and Duck Creek Anticlines and the intervening Wakeful Syncline, which form the Malbon Block of Plumb & others (1980). Complex patterns of smaller open to tight folds, some of which are of elongate basin-and-dome type, are present to the north and east of the main structures. Trends of the smaller folds range from north-south (especially south of Cloncurry) to east-west. The cover sequence 2 units in the zone commonly have a cleavage or foliation parallel to the axial planes of these folds. Part of the eastern limb of the Duck Creek Anticline in southern MARRABA and northern KURIDALA REGION forms a series of spectacular northeast-plunging tight to isoclinal folds which are outlined by ridge-forming Mitakoodi Quartzite (Fig. 57 in Blake & others, 1984). Farther east, the Roxmere Quartzite (tentatively assigned to cover sequence 3) is broadly folded; in places it occurs upside down in fault blocks partly or entirely surrounded by breccia. These fault blocks may be parts of nappe structures (Blake & others, 1984).

The northern part of the zone comprises the Boomarra Horst, which consists mainly of intensely deformed northerly trending rocks assigned to the Corella Formation and Soldiers Cap Group of cover sequence 2. Some northerly plunging and doubly plunging synclines are present in the north of the horst. The large Naraku Granite pluton to the south, northwest of Quamby, is strongly foliated, and evidently predates the main deformation (Wilson & others, 1979b). The Coolullah Fault along the west side of the Boomarra Horst was active up to late Mesozoic times, as Palaeozoic and Mesozoic strata in the general vicinity (but not Cainozoic sediments) are mildly deformed (Wilson & Grimes, 1986).

The late Proterozoic Quamby Conglomerate exposed in the central part of the Quamby-Malbon zone forms two tight synclines: one in the Fedral Graben, situated along the north-northeast trending Quamby Fault Zone, and the other to the north, in a smaller graben within the north-trending Mount Rosebee Fault Zone. Presumably, the synclines were formed during the development of these fault zones sometime after the main deformation of cover sequences 1-3. Most other faults mapped in the Quamby-Malbon zone also probably postdate the main deformation affecting cover sequence 2, as they cut previously folded rocks. They include the northeast to north-northeast-trending Martin Creek and Big Mick Faults that form part of the eastern boundary of the zone south of Cloncurry. These faults separate greenschist facies rocks to the west from amphibolite facies rocks of the Cloncurry-Selwyn zone to the east.

Cloncurry-Selwyn zone

This zone consists almost entirely of strongly deformed rocks of cover sequence 2 (assigned to the Soldiers Cap Group and the Corella, Doherty, and Kuridala Formations of the

Mary Kathleen Group) and plutons of the Williams Batholith; most of the plutons postdate the main deformation event. Structural trends are typically between north-northwest and north-northeast in the southern and central parts of the zone, and close to east-west in the northern part, east of Cloncurry.

At least three phases of folding have been recognised in the zone (Donchak & others, 1983; Nisbet & others, 1983; Blake & others, 1984). First and second-generation folds are mostly tight to isoclinal, and later folds are generally more open. Axial planes and associated cleavages and foliations are mainly steep to vertical. Small to large-scale refolded folds, basin-and-dome interference folds, and crenulated cleavages are common features. Intrafolial folds occur in migmatitic gneiss of the Soldiers Cap Group; some of the compositional banding in the gneiss probably results from transposition of original bedding (Blake & others, 1984). Most major folds in the southern part of the zone are second or third-generation structures. The large elongate basin (doubly plunging syncline) outlined by metadolerite sills at Kuridala, for example, is probably a second-generation structure, as it folds the first-generation cleavage in the Kuridala Formation (Blake & others, 1984). In CLONCURRY, however, the Snake Creek Anticline, Toole Creek Syncline, Weatherly Creek Syncline and other major folds appear to be mainly first-generation structures modified by later folding. The north-trending Toole Creek Syncline and east-trending Weatherly Creek Syncline may be parts of a single refolded syncline, as implied by GSQ (1983a).

The bulk of the widespread calc-silicate breccias of the Cloncurry-Selwyn zone are considered to be tectonic in origin (e.g., Glikson, 1972; Blake & others, 1984; Ryburn & others, in preparation). They were formed after the deposition of both the Soldiers Cap and Mary Kathleen Groups, and may either predate or be synchronous with the emplacement of the non-foliated granites of the William's Batholith.

The main fault in the zone is the north-northwest-trending Cloncurry Fault (the 'Cloncurry overthrust' of Honman, 1939), which in places separates the Soldiers Cap Group from the Doherty Formation. This fault has displaced granites of the Williams Batholith, but not overlying Mesozoic strata. Another major fault, the northwest-trending Straight Eight Fault, separates the Kuridala Formation from the Doherty Formation northeast of Kuridala.

Murphy Tectonic Ridge Area

The Murphy Tectonic Ridge in the northwest represents a broad anticline arch. Here the Cliffdale Volcanics of cover sequence 1 are only gently folded but, together with the penecontemporaneous Nicholson Granite Complex, are intensely faulted. To the north the unconformably overlying Tawallah Group of cover sequence 3 in the McArthur Basin dips generally northwards at up to 60°. To the south, the Wire Creek Sandstone, Peters Creek Volcanics, and Fickling Group of cover sequence 3 (Lawn Hill Platform) have general southerly dips of around 10°. Tight folding is restricted to fault zones.

The northwest-trending Calvert Fault cuts the McArthur Basin and South Nicholson Basin, as well as the Murphy Tectonic Ridge. It was active during Cliffdale Volcanics–Nicholson Granite Complex magmatism, and later major horizontal movements took place along it before the deposition of cover sequence 3. Subsequent vertical movements along this fault, and also along the Tin Hole Hinge Zone and Fish River Fault Zone on the north and south sides of the Murphy Tectonic Ridge, postdate cover sequence 3. Several other faults, mainly with west-northwest and northeast to east-northeast trends, cut cover sequence 3 and older rocks.

South Nicholson Basin

The late Proterozoic South Nicholson Group and underlying rocks of cover sequence 3 exposed within the South Nicholson Basin have been folded into a series of elongate basins and domes. The folding is most intense in the southwest, in CARRARA RANGE REGION. Trends of folds and faults are variable in the east and are mainly east-northeast in the west. Folds in the South Nicholson Group are more open than those in cover sequence 3, indicating that cover sequence 3 was folded before as well as after deposition of the South Nicholson group. A major fault in the southwest, the Little Range Fault, may have a vertical displacement of up to 5 km; the main movement along this fault probably predates deposition of the South Nicholson Group. The South Nicholson Basin is cut by several other faults, most of which have vertical displacement of less than 200 m.

REGIONAL METAMORPHISM

All the early and middle Proterozoic rocks of the Mount Isa Inlier and environs have probably been affected by low to medium-grade regional metamorphism. However, most of those in the northwest, apart from the basement, cover sequence 1, and granite of the Murphy Tectonic Ridge, show no obvious metamorphic effects, and have been described as unmetamorphosed. Such rocks are tentatively regarded as belonging to the subgreenschist facies by the author. Most of the Williams Batholith and part of the Naraku Batholith in the southeast may also belong to this facies. Mineral assemblages elsewhere in the Mount Isa Inlier generally indicate metamorphism ranging from lower greenschist to upper amphibolite facies. The regional metamorphism is of low-pressure/high-temperature type, with pressures ranging up to 4 kb and temperatures up to about 660°C. Details are given by Derrick & others (1977c), Bultitude & Wyborn (1982), Jaques & others (1982), Wyborn & Page (1983), Blake & others (1984), and in the map commentaries and BMR Records for the 1:100 000 geological maps.

There is evidence locally of polymetamorphism. For example, the basement Yaringa Metamorphics west of Mount Isa and part of the Kurbayia Migmatite to the east have greenschist facies mineral assemblages (e.g., chlorite + muscovite + quartz), but were almost certainly metamorphosed to upper amphibolite facies, and partially melted, before any of the cover sequences were deposited. Also, retrograde assemblages marking relatively late low-grade regional metamorphic events are widespread. Geochronological studies show that regional metamorphism of the cover sequences and granitic intrusions took place between about 1620 Ma and 1500 Ma (Page & others, 1984), and caused the resetting of igneous K-Ar and Rb-Sr ages (e.g., Page, 1978, 1983a; Wyborn & Page, 1983). Rocks of the basement, however, were first metamorphosed before the cover sequences were laid down, perhaps at around 1900 Ma (Page, in Blake & others, 1983b).

Distribution of metamorphic facies

The distribution of prograde regional metamorphic facies is shown on the 1:500 000 geological map sheet. It is based on thin-section studies—including microprobe mineral analyses—of mainly mafic, calc-silicate, and pelitic rocks.

Many of the Proterozoic rock types, such as granites, felsic volcanics, and most sandstones, do not contain useful metamorphic indicator minerals, but are cut by mafic dykes or are spatially associated with lithologies which do contain such minerals. Textural changes have also been used as indicators of metamorphic grade, particularly in granites, as documented by Wyborn & Page (1983).

Subgreenschist facies rocks are presumed to predominate in the Lawn Hill Platform, and also in the McArthur Basin and South Nicholson Basin. The cover sequence 1 volcanics and associated granite of the Murphy Tectonic Ridge appear to be metamorphosed mainly to either subgreenschist or lower greenschist facies, but may locally include some higher-grade rocks (L. A. I. Wyborn, pers. comm., 1985).

Rocks regionallly metamorphosed to the greenschist facies include the basement Murphy Metamorphics in the far northwest, most of cover sequence 2 and locally part of cover sequence 3 in the Lawn Hill Platform, and most or all of the rocks exposed in the Ewen Block and Myally Shelf. In the Leichhardt River Fault Trough, Kalkadoon-Leichhardt Belt, and Eastern Fold Belt, greenschist and amphibolite facies rocks alternate in both east-west and north-south directions. The highest-grade rocks, those of the upper amphibolite facies, are exposed in the Leichhardt River Fault Trough on the east side of the Sybella Batholith west of Mount Isa (Hill & others, 1975), in the Kalkadoon-Leichhardt Belt in northern MARY KATHLEEN and southern PROSPECTOR (Wyborn & Page, 1983), and in the Mary Kathleen zone (e.g., Derrick, 1980), and the eastern part of the Cloncurry-Selwyn zone (Jaques & others, 1982) of the Eastern Fold Belt. In contrast, the Makbat Sandstone and underlying Leichhardt Volcanics in the far south of the Kalkadoon-Leichhardt Belt (in DAJARRA) have only been metamorphosed to lower greenschist or possibly subgreenschist facies. Most of the granites of the Williams Batholith, and also some granite of the Naraku Batholith, postdate the main prograde metamorphism that affected the early and middle Proterozoic cover sequences, but were probably metamorphosed to the subgreenschist or lower greenschist facies during a subsequent retrograde event.

Description of metamorphic facies

In *subgreenschist facies* or 'unmetamorphosed' rocks, delicate primary igneous and sedimentary textures are evident. Recrystallisation effects are minor, and are restricted to limestone and dolomite. Such changes, as well as any secondary minerals present (e.g., quartz as a cement in sandstone or replacing carbonates to form chert) can alternatively be attributed to diagenetic or deuteric effects.

In *greenschist facies,* some primary igneous and sedimentary textures are commonly well preserved. Typical mineral assemblages are quartz ± alkali feldspar ± chlorite ± greenish brown biotite ± sericite/muscovite ± tremolite-actinolite ± epidote/clinozoisite in felsic igneous rocks and non-calcareous sedimentary rocks; tremolite-actinolite + albite + calcite or dolomite in calcareous rocks; and albite ± chlorite ± actinolite ± epidote/clinozoisite ± biotite ± quartz ± K-feldspar ± sphene ± calcite in mafic rocks. Quartz grains in sandstones are commonly partly recrystallised. In mafic igneous rocks, remnants of primary clinopyroxene and calcic plagioclase are present locally, but most clinopyroxene is replaced by chlorite, actinolite, epidote and sphene, and primary plagioclase is generally altered to albite, epidote, sericite, and calcite. In granite, K-feldspar is typically perthitic throughout the greenschist facies; igneous hornblende may be preserved in the lower greenschist facies, as in some Ewen Granite of the Ewen Block, but is pseudomorphed by biotite and epidote in upper greenschist facies Kalkadoon Granite in the Kalkadoon-Leichhardt Belt (Wyborn & Page, 1983). Late retrogression is indicated by alteration of biotite to chlorite.

Lower amphibolite facies rocks are generally more intensely recrystallised and foliated, and most primary igneous and sedimentary textures are either poorly preserved or obliterated. Typical assemblages are quartz ± feldspar (albite and/or microcline) ± red-brown biotite ± muscovite ± garnet ± hornblende in felsic igneous rocks, the same minerals ± andalusite ± cordierite ± staurolite in non-calcareous sedimentary rocks (Fig. 51), green hornblende (chlorine-bearing) ± sodic plagioclase ± clinopyroxene (generally salitic) ± garnet ± scapolite ± quartz ± K-feldspar in calc-silicate rocks; and green hornblende + oligoclase/andesine ± clinopyroxene ± garnet in mafic rocks. Cordierite-anthophyllite rocks are developed locally (e.g., in DUCHESS REGION, MARY KATHLEEN), and kyanite has been recorded west of Mary Kathleen and between Mary Kathleen and Cloncurry. Metamorphic hornblende includes tschermakitic, edenitic, hastingsitic, actinolitic, and magnesian varieties. Garnet, when present, may be mainly almandine, andradite, grossular or spessartine. Where mafic igneous rocks are not foliated or obviously metamorphosed, as in parts of the Mount Erle and Myubee Igneous Complexes in DUCHESS REGION, amphibolite facies metamorphism is indicated by coronas of fine-grained magnetite and orthopyroxene around primary olivine, and symplectic intergrowths of hornblende and spinel between primary olivine and plagioclase grains. K-feldspar in granite metamorphosed to lower amphibolite facies is typically non-perthitic (Wyborn & Page, 1983). On these criteria, particularly the presence of hornblende + oligoclase-andesine in metabasalt and metadolerite, rocks regarded as upper greenschist facies by Derrick & others (1977c) in MARY KATHLEEN are assigned by the author to the lower amphibolite facies.

Fig. 51. Porphyroblasts of andalusite in mica schist of the Kuridala Formation (cover sequence 2), Cloncurry–Selwyn zone, Eastern Fold Belt (SELWYN GR 595605). (M2301/30)

Scapolite is widespread in the Kalkadoon-Leichhardt Belt and Eastern Fold Belt, occurring in some metamorphosed mafic rocks (Fig. 52) and granites, as well as in calcareous metasediments (Fig. 21). It is thought to have mainly formed during amphibolite facies regional metamorphism of halite-bearing beds, as suggested by Ramsay & Davidson (1970), rather than resulting from regional soda-metasomatism accompanied by the introduction of chlorine, as proposed by Edward & Baker (1954).

Rocks metamorphosed to the *upper amphibolite facies* are strongly recrystallised, typically to coarsely porphyroblastic

Fig. 52. Rounded scapolite porphyroblasts in biotite schist, Corella Formation (cover sequence 2), Mary Kathleen zone, Eastern Fold Belt (MARRABA GR 988142) — G. M. Derrick (GA2704)

schist or granoblastic gneiss, and few, if any, primary igneous and sedimentary textures are evident. Sillimanite occurs in some schist and gneiss, calc-silicate rocks contain andradite garnet and calcic plagioclase, and amphibolite is characterised by the presence of clinopyroxene + andradite or almandine garnet ± pargasitic hornblende + calcic plagioclase (Jaques & others, 1982). Local partial melting is indicated by abundant veins of leucogranite and pegmatite and the presence of migmatite. In granite, primary microcline is recrystallised to form polygonal aggregates (Wyborn & Page, 1983a).

CONTACT METAMORPHISM

Metamorphic aureoles are developed around many of the granite plutons. They are most marked adjacent to plutons postdating the main metamorphism and deformation, such as those of the Williams Batholith in the southeast, or where regional metamorphism is only low grade, as around the Weberra Granite in the Lawn Hill Platform (in MOUNT OXIDE REGION) and around part of the Wills Creek Granite (Kalkadoon Batholith) in the south of the Kalkadoon–Leichhardt Belt (in DAJARRA). The highest-grade contact rocks, metamorphosed to the hornblende hornfels facies, are generally restricted to within 100 m of plutons. Metamorphic aureoles, mostly less than a few metres wide, are also developed adjacent to some mafic intrusions.

In the inner parts of the contact aureoles, sandstone and felsic volcanics are recrystallised to granoblastic rocks in which tourmaline needles are commonly present. Pelitic rocks form hornfels containing andalusite, cordierite, garnet and/or fibrolitic sillimanite.

Skarns are commonly developed in calcareous units, especially in the Corella Formation adjacent to plutons of the Wonga Batholith in the Mary Kathleen zone of the Eastern Fold Belt (e.g., Derrick, 1977, 1980; Bultitude & others, 1982; Page, 1983b), where wollastonite and vesuvianite have been recorded.

Some metasomatic effects may be related to contact metamorphism. These include the formation of 'red rock', resulting from alkali feldspar (albite or K-feldspar) and hematite metasomatism, widespread in the eastern part of the Kalkadoon–Leichhardt Belt and in the Eastern Fold Belt. Two main metasomatic events were recognised by Derrick (1977) in the vicinity of the Mary Kathleen uranium mine, within the Mary Kathleen zone of the Eastern Fold Belt: (1) a higher temperature first event, thought to be associated with the intrusion of the Burstall Granite (1720–1740 Ma), during which K-feldspar-rich and scapolite–pyroxene bands were formed; and (2) a later event, considered to be related to rhyolite dykes emplacement (~ 1737) Ma), which resulted in garnetisation, skarns and uraninite–allanite mineralisation. However, according to Page (1983b), the uraninite–allanite mineralisation formed at 1550 ± 15 Ma, probably during regional metamorphism, and much if not all the K-feldspar and scapolite metasomatism and skarn formation is younger than this, being no older than about 1200 Ma.

DEFORMATIONAL HISTORY

Two major periods of deformation accompanied by regional metamorphism can be recognised in the Proterozoic of the Mount Isa Inlier, and a later period of mild deformation is evident to the northwest, in the South Nicholson Basin. Only basement units were deformed during the first period, which preceded the Leichhardt volcanism of cover sequence 1 (e.g., Blake, 1980, 1981b). Following Page & others (1984), this period of deformation took place about 1900 Ma ago, when the Yaringa Metamorphics west of Mount Isa were metamorphosed (Page, in Blake & others, 1983b). The second period of deformation postdates cover sequence 3 and predates deposition in the South Nicholson Basin. A third period of deformation caused gentle basin-and-dome-type folding of the South Nicholson Group.

Between the first two deformation periods, there were several episodes of granite emplacement and accompanying contact metamorphism, and also local tilting, uplift, and erosion. However, no region-wide folding or metamorphism took place. This is indicated by: (a) the presence of disconformities rather than angular unconformities at most non-tectonic contacts between and within cover sequences 1 to 3; (b) the absence of abrupt changes in metamorphic grade or deformation at such contacts; (c) structural data, which shows that the Mount Isa Group of cover sequence 3 has had the same structural history as underlying rocks of cover sequence 2 and nearby rocks of cover sequence 1 (e.g., Blake & others, 1984); and (d) geochronological data indicating that the earliest deformation and regional metamorphic event to affect the cover sequences took place about 50 Ma after 1670 Ma (Page, 1978), the time when the Mount Isa Group was deposited (Page, 1981b).

The second major period of regional deformation, and the

first to affect cover sequences 1 to 3, appears to have consisted of three main phases. According to Bell (1983), the earliest phase, D_1, causing the development of east-west-oriented folds and the formation of a major thrust duplex, involved tectonic transport from north to south over distances exceeding 200 km, in the Leichhardt River Fault Trough. This phase was followed by D_2, during which the major north-south-oriented folds of the Mount Isa Inlier were formed. Recent structural studies (e.g., BMR, 1985) show that D_1 thrusts are also widespread in the Kalkadoon–Leichhardt Belt and Eastern Fold Belt. Both D_1 and D_2 were accompanied by regional metamorphism up to the amphibolite facies. Faults commonly present along contacts between contrasting rock types may have formed during either D_1 or D_2. A third phase of deformation, D_3, is represented by some northwesterly and possibly also northeasterly trending structures, but was not associated with major regional metamorphism.

The first phase, D_1, of the second deformation period took place at about 1610 Ma; the second phase, D_2, was at about 1550 Ma, shortly before the emplacement (at around 1500 Ma) of post-tectonic granites of the Williams and Naraku Batholiths in the east; the third phase, D_3, is dated at about 1480 Ma.

The younger mild deformation evident in the South Nicholson Basin and probably of much wider extent, though not recognised at present elsewhere in the region, occurred after the deposition of the South Nicholson Group but before that of the overlying Cambrian beds, which are flat-lying.

The major faults and fault zones identified in the region probably represent long-acting deep-seated crustal discontinuities along which both horizontal and vertical movements have taken place. Some are thought to have been active during deposition of cover sequences 1, 2 and 3; all were active between the second deformation period and the end of the Proterozoic, and some displace Palaeozoic and Mesozoic strata, so were active during the Phanerozoic as well as the Proterozoic. Movements along faults may account for folding of the late Proterozoic Quamby Conglomerate in the Eastern Fold Belt and for local folding and tilting of younger units, such as those of Cambrian age in the Pilgrim Fault Zone.

GEOCHEMISTRY OF IGNEOUS ROCKS

The geochemistry of igneous rocks in the Mount Isa Inlier has been discussed by Glikson & others (1976), Derrick & others (1977c), Wilson (1978b, 1983a), Derrick (1980), Bultitude & Wyborn (1982), Wyborn & Page (1983a), Blake & others (1983a), Donchak & others (1983), Ellis & Wyborn (1984), and Wyborn (in Blake & others, 1984). More than 1000 igneous rocks have been chemically analysed for major and trace elements (Wyborn, in prep.). Variation diagrams for felsic rocks are shown in Figs 53 and 54. Most of the analysed rocks have been regionally metamorphosed and many are extensively recrystallised. However, generally consistent trends for most elements on variation diagrams indicate that the majority of the analysed samples are probably close to their original compositions, rather than being extensively modified by metamorphism and metasomatism.

The chemical data indicate that the igneous rocks have a marked bimodal distribution in terms of silica content. Silica values plotted against frequency (Fig. 55) show prominent peaks at 50 and 72% SiO_2. The rare rocks of intermediate composition may be (1) hybrids, such as those found in intrusive net-veined complexes, (2) much altered volcanic rocks which were probably of less silicic composition originally, (3) the more fractionated parts of dolerite suites, and (4) the more mafic parts of granitic suites.

Felsic rocks

Four widespread suites of felsic volcanics have been identified in the Mount Isa Inlier. These are the Leichhardt suite, represented by the Leichhardt Volcanics of cover sequence 1; the Bottletree and Argylla suites, represented by the felsic volcanics of the Bottletree and Argylla Formations, respectively, of cover sequence 2; and the Carters Bore suite, represented by the Carters Bore Rhyolite and the felsic Fiery Creek Volcanics of cover sequence 3. The geochemical distinction between the Leichhardt and Argylla suites was first documented by Derrick & others (1977c), and has been substantiated by later workers, especially Bultitude & Wyborn (1982) and Wilson (1983a). The Bottletree and Carters Bore suites were first described as such by Bultitude & Wyborn (1982), who also distinguished a fifth suite, the Duchess–Corella suite, which appears to be restricted to the Corella Formation in DUCHESS REGION. Each suite is thought to be derived from a chemically unique source (Wyborn, in Blake & others, 1984).

The Leichhardt suite has higher Al and Sr and lower Zr, Nb, and Y contents than the Argylla suite. The Bottletree suite is generally similar to the Argylla suite, but has higher CaO, Sr, Zn, and Pb contents. High K values and relatively high Ti and Mg contents characterise the Carters Bore suite. The Duchess–Corella suite differs from these suites in having relatively high Nb and Y and low Sr and Zr contents.

Analysed felsic rocks from the Plum Mountain Gneiss and Kurbayia Migmatite (basement) and undivided Tewinga Group (basement or cover sequence 1) in the south of the Kalkadoon–Leichhardt Belt are chemically similar to the Leichhardt suite, as probably also are the Cliffdale Volcanics (cover sequence 1) of the Murphy Tectonic Ridge. Analysed felsic volcanics from the Mitakoodi Quartzite belong to the Argylla suite. Those from the Saint Ronans Metamorphics and Sulieman Gneiss in the southwest, the Corella Formation west of Cloncurry, and the Soldiers Cap Group in the southeast are of uncertain affinities.

The older granites of the Mount Isa Inlier, those of the Kalkadoon and Ewen Batholiths (1840–1870 Ma), are geochemically as well as geochronologically similar to the felsic volcanics of the Leichhardt suite, and are considered to be cogenetic with this suite (e.g., Wyborn & Page, 1983). Similarly, the granites of the Nicholson Granite Complex in the Murphy Tectonic Ridge are probably cogenetic with the Cliffdale Volcanics and chemically similar to the Leichhardt suite (L. A. I. Wyborn, personal communication, 1985). The Yeldham and Big Toby Granites may be part of the same suite. The younger granites of the Mount Isa Inlier, those of the Sybella Batholith (~1670 Ma), Wonga Batholith (1670–1740 Ma), and Williams and Naraku Batholiths (~1500 Ma), and the Weberra Granite (~1700 Ma), generally have lower Al and Sr contents than the granites of the Kalkadoon Batholith, and higher levels of incompatible elements, especially Nb, Ti, Th, and U.

According to Wyborn (in Blake & others, 1984; also Wyborn & Page, 1983a, 1983b, and pers. comm., 1985), almost all the felsic igneous rocks are I-type, derived from infracrustal sources which have never been exposed to surface weathering. The felsic volcanics of the Leichhardt suite and the cogenetic granites are classified as typical I-types, derived from first-stage melting of an igneous source in the lower crust, this source being formed during continent-wide differentiation from the mantle between about 1900 and 2100 Ma ago. The Bottletree and Argylla suites are considered

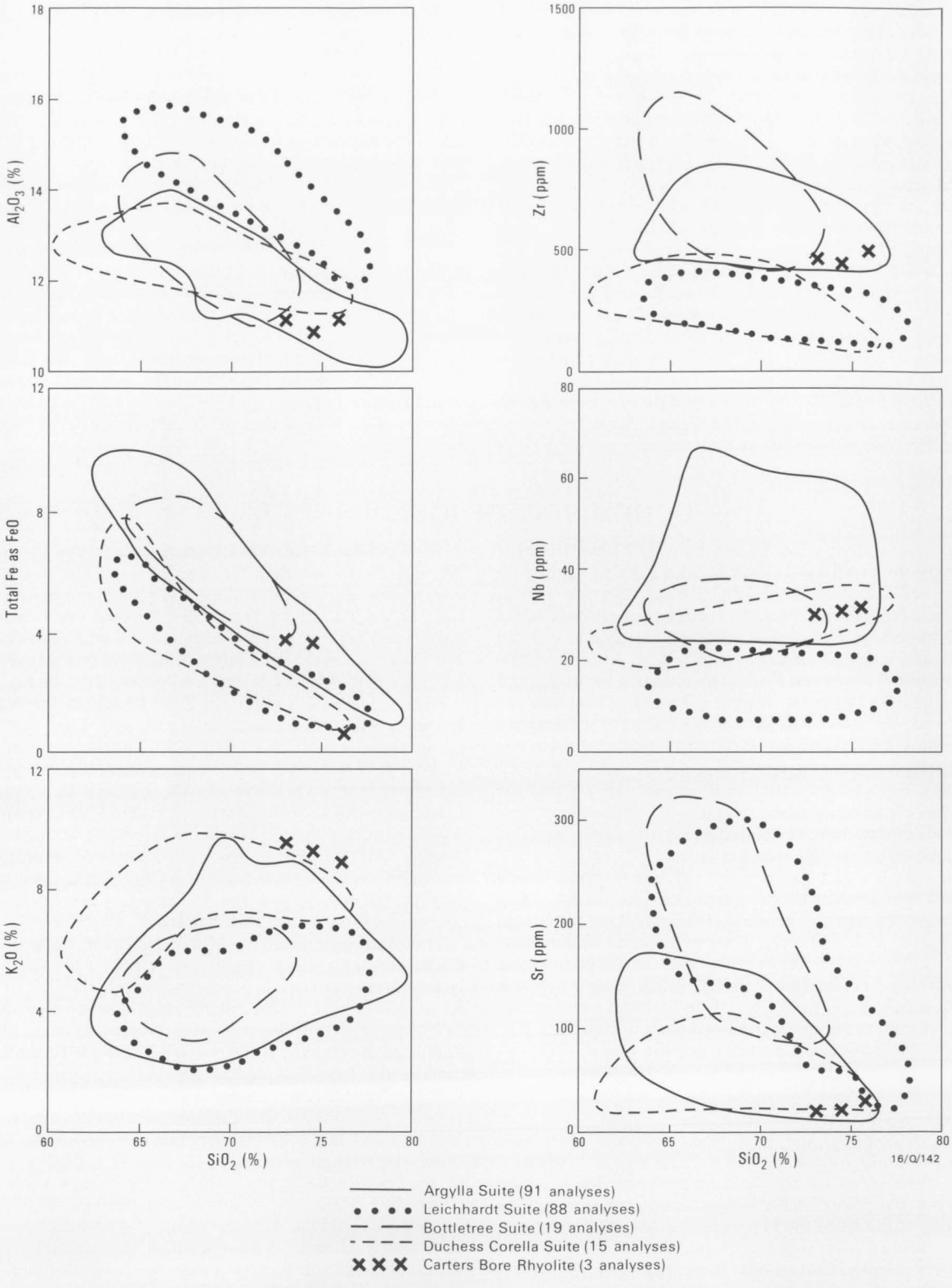


Fig. 53. Variation diagrams of selected major oxides and trace elements showing fields of main felsic volcanic suites exposed in the Mount Isa Inlier and environs. Based on data from Wyborn (in preparation and personal communication, 1985).

to be A-types in the sense of Collins & others (1982), derived from a near-anhydrous source that remained in the lower crust after the formation of the earlier I-type felsic melt. Some of the granites of the Wonga, Sybella and Williams Batholiths may also be A-types. No S-type felsic volcanics or major granite plutons have been identified.

Mafic rocks

In spite of their wide range in age and spatial distribution, most of the Proterozoic mafic volcanics and intrusions in the Mount Isa Inlier are of uniform chemical composition, and are classified as continental tholeiites, although they have lower contents of incompatible elements such as Ti, P, Zr,

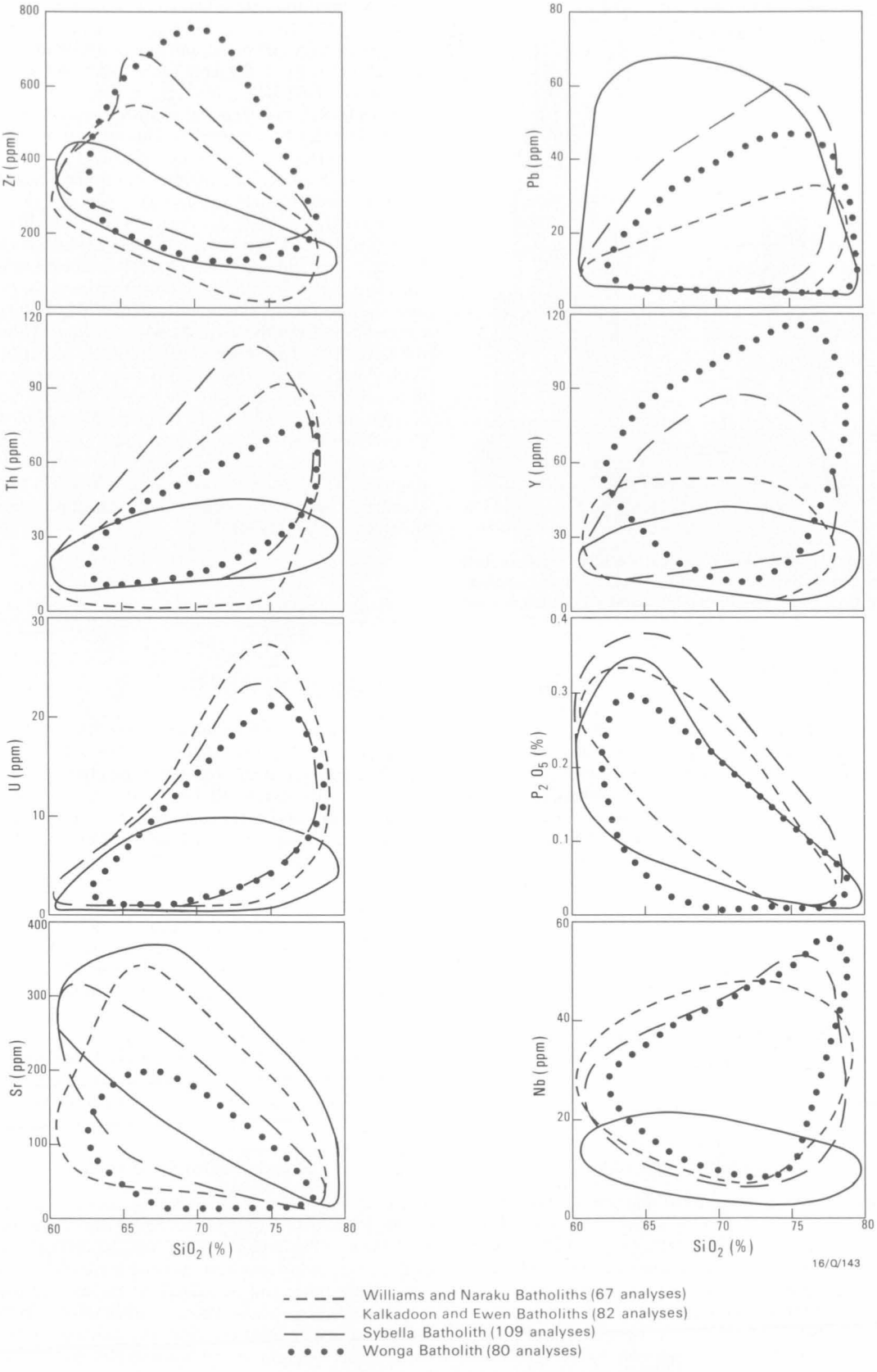


Fig. 54. Variation diagrams of selected major oxides and trace elements showing fields for granites of the Mount Isa Inlier and environs. Data from Wyborn (in preparation and personal communication, 1985).

and Y than most continental tholeiites. Most analyses plot in the subalkaline field on the conventional total alkalies–silica diagram, and show a trend of iron-enrichment on an AFM diagram (Ellis & Wyborn, 1984). Glikson & others (1976) and Glikson & Derrick (1978) recorded an eastward change in mafic volcanics of cover sequence 2: from basalts

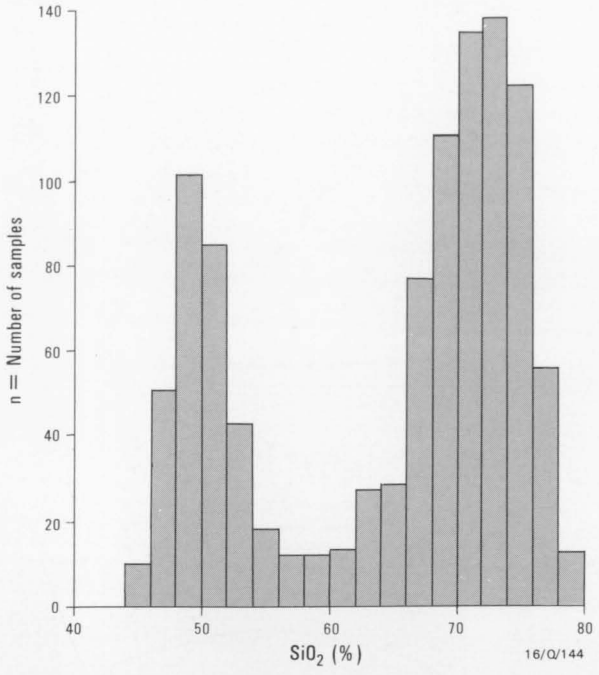


Fig. 55. Frequency-distribution diagram for SiO_2 based on 1040 analyses of igneous rocks from the Mount Isa Inlier and environs. Data from Wyborn (in preparation and personal communication, 1985).

of continental tholeiite affinities with high values of Ti, P, K, Zr, and Y in the Eastern Creek Volcanics of the Western Fold Belt, to basalts of ocean-floor tholeiite affinities with low values for these elements in the Soldiers Cap Group of the Eastern Fold Belt. However, as shown by Bultitude & Wyborn (1982), the chemical characteristics of the Eastern Creek Volcanics documented by Glikson & others (1976) and Glikson & Derrick (1978) apply only to the Cromwell Metabasalt Member of this formation, and possibly result from a local strong downwarping during the basaltic volcanism (Carmichael & others, 1974). Analysed samples from the Pickwick Metabasalt Member of the Eastern Creek Volcanics, undivided Eastern Creek Volcanics, and probable correlatives of this formation in the southwest (Jayah Creek and Oroopo Metabasalts) are not significantly different in composition from those of the Magna Lynn Metabasalt in the Kalkadoon-Leichhardt Belt and the Soldiers Cap Group farther east. All analysed samples from intrusions regarded as possibly comagmatic with the Eastern Creek Volcanics are compositionally similar to the Pickwick Metabasalt Member (Ellis & Wyborn, 1984). However, some mafic intrusions in the Eastern Fold Belt, including both metamorphosed and unmetamorphosed dykes, are like the Cromwell Metabasalt Member in being relatively enriched in incompatible elements (Ellis & Wyborn, 1984).

TECTONIC SETTING

As a result of the broad reconnaissance survey of the 1950s, Carter & others (1961) concluded that the Mount Isa Inlier did not develop at the margin of the Australian craton, thereby implying an intracratonic setting. Similarly, Rutland (1973, 1976) considered that the eastern edge of the Proterozoic craton lay well to the east of Mount Isa. In contrast, Plumb & Derrick (1975), Dunnet (1976), Glikson & others (1976), Glikson & Derrick (1978), and especially Wilson (1978b) have suggested that the Mount Isa Inlier represents a middle Proterozoic continental margin on the east side of the Australian craton. This view has become widely accepted (for example, Glikson, 1980; Rossiter & Ferguson, 1980; Plumb & others, 1980, 1981; Piper, 1982; Condie, 1982), but is considered unlikely by Wyborn & Blake (1982) and Blake (1986), who favour an intracratonic setting for the Mount Isa Inlier.

These two contrasting models are based on four main lines of evidence:

Geochemical evidence

In support of the continental margin setting, mafic volcanics of cover sequence 2 in the western part of the Mount Isa Inlier (Eastern Creek Volcanics) are reported by Glikson & others (1976) and Glikson & Derrick (1978) to be of continental tholeiite-type, whereas those of comparable age in the east (Soldiers Cap Group) are more similar to ocean floor tholeiites. Felsic volcanics of the Leichhardt and Argylla suites are considered to be comparable to the Cainozoic volcanics of the Andes, and to have K_2O/SiO_2 values which decrease eastwards (oceanwards) (Wilson, 1978b).

However, chemical data now available, as discussed by Bultitude & Wyborn (1982), Ellis & Wyborn (1984) and Wyborn (in Blake & others, 1984), show that most mafic volcanics and intrusives in the east as well as in the west of the Mount Isa Inlier are uniform in composition, and can be classified as continental tholeiites with relatively low contents of incompatible elements. More fractionated types with higher levels of such elements are characteristic of the Cromwell Metabasalt Member of the Eastern Creek Volcanics, and also form some dykes in the east and west, but none have been recorded from the Pickwick Metabasalt Member and other parts of the Eastern Creek Volcanics or from probable correlatives in the southwest (Jayah Creek Metabasalt and Oroopo Metabasalt). Of the four widespread felsic volcanic suites—the Leichhardt suite of cover sequence 1, Bottletree and Argylla suites of cover sequence 2, and the Carters Bore suite of cover sequence 3—none appear to show an eastward decrease in K_2O/SiO_2 values. Rocks with between 55 and 63% SiO_2 are rare, and no orogenic andesites of Andean-type are known.

The igneous rocks of the Mount Isa Inlier are markedly bimodal with respect to silica content, a typical feature of intracratonic rifting, but not of active continental margins.

Palaeogeographic evidence

According to Wilson (1978b), no rocks older than the middle Proterozoic cover sequences of the Mount Isa Inlier are known to the east, implying that the detrital sediments of the cover sequences were derived from either within or west of the Inlier and deposited on the eastern edge of a Proterozoic continent. A Proterozoic landmass to the east, though, cannot be ruled out. Scattered outcrops and borehole data indicate that granite and metamorphic rocks of probably Proterozoic age, but not ocean-floor-type rocks, extend eastwards beneath the Mesozoic Eromanga Basin to the Precambrian Georgetown Inlier (Fig. 56). Some rocks exposed in the Georgetown Inlier are possibly at least as old as most rocks of the Mount Isa Inlier (Black & McCulloch, 1984), and may have formed part of a large landmass during much of the middle Proterozoic.

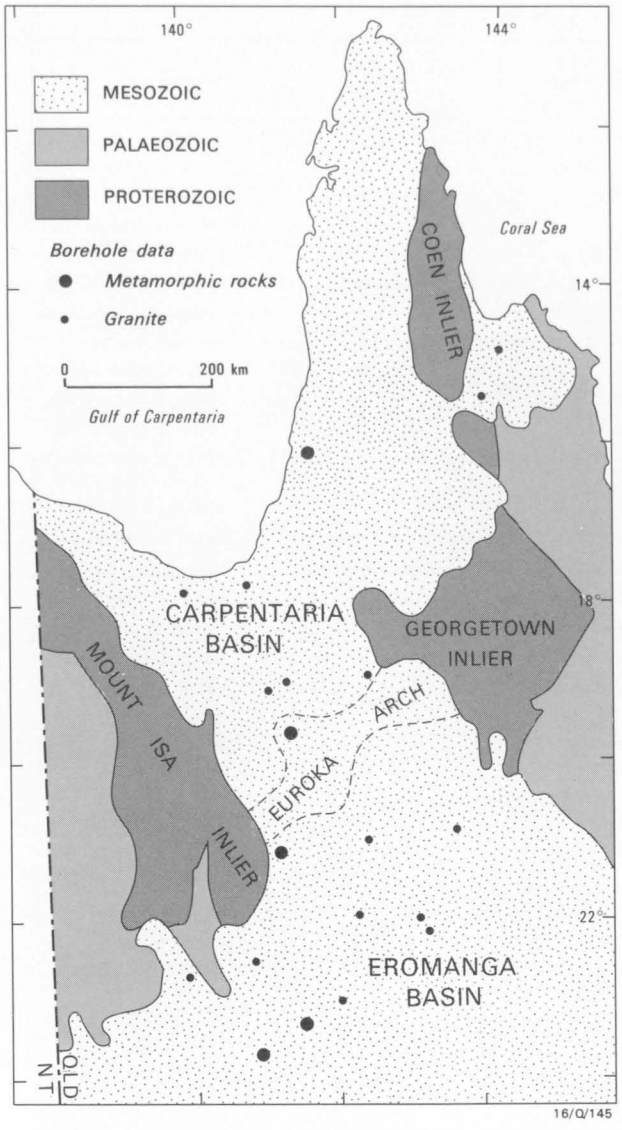


Fig. 56. Outcrops and borehole intersections of Proterozoic rocks in north Queensland.

Sedimentological evidence

Glikson & others (1976) reported that voluminous deep-water sedimentary rocks were present only in the most eastern part of the Mount Isa Inlier, where they are represented by turbidites in the Soldiers Cap Group, indicating open-marine conditions to the east but not to the west. Turbidites also make up most of the Kuridala Formation which crops out to the east of the Soldiers Cap Group in SELWYN REGION and is a probable correlative of this group (Blake & others, 1984). As the turbidites of the Kuridala Formation appear to be generally finer grained and less feldspathic than those of the Soldiers Cap Group, an eastern source may be more likely than a source to the west.

Evidence for crustal thinning

In the continental margin model, a general increase in regional metamorphism from west to east, and a change in structural style from faulting-dominant in the west to folding-dominant in the east (Plumb & Derrick, 1975; Glikson & others, 1976), and also the regional gravity (Dunnet, 1976), are taken to indicate that during the deposition of the middle Proterozoic cover sequences the crust beneath the Mount Isa Inlier thinned eastwards. None of this evidence may be valid, though, for the following reasons:

A. Regional metamorphism to amphibolite facies is as widespread in the western part of the Inlier as in the east (see inset on 1:500 000 map).
B. In the west as well as in the east, folding is prevalent where well-layered rocks are exposed and faulting is most apparent where massive units, such as granite and thick felsic volcanics, were involved in the deformation.
C. The regional gravity map of Australia (BMR, 1976, and Fig. 2B) shows that the Mount Isa Inlier corresponds to a general gravity high flanked to the east and west by gravity lows. Whether the gravity indicates thinner crust to the east than to the west, or vice versa, is open to interpretation (Dooley, 1980).

ECONOMIC GEOLOGY

The Mount Isa Inlier is a major producer of copper, lead, zinc and silver, and has also produced substantial amounts of gold, uranium and cobalt, and minor manganese, cadmium, bismuth, tungsten, beryl and mica. In addition, considerable tonnages of calcite and silica have been mined for use as flux in smelting operations by Mount Isa Mines Ltd. Mining has been a major activity in the Inlier since the discovery of copper and gold near Cloncurry in the 1860s. Some uranium has been recovered from the Proterozoic Murphy Tectonic Ridge, but no mining has been carried out in the South Nicholson Basin, or in the part of the McArthur Basin covered by the 1:500 000 map. Several large deposits of sedimentary phosphorite are known in Middle Cambrian rocks of the Georgina Basin, and one of these, at *Phosphate Hill*, DAJARRA, was mined between 1976 and 1978, producing over 1 million tonnes of phosphate rock.

The history of exploration and mining in the Mount Isa Inlier is described by Carter & others (1961), Derrick & others (1977c), and Blake & others (1984). Mineral exploration surveys in the standard 1:250 000 sheet areas are summarised by Noon (1974, 1976, 1977), Hutton (1977), and Wilson (1977, 1978a, 1980).

Reviews of the mineralisation in the Mount Isa Inlier have been given by Carter & others (1961), Wilson & others (1972), Williams (1980), and Blake & others (1984), and are also included in reports accompanying the 1:100 000 geological maps. Brief descriptions of many of the mines and prospects in the Inlier, and references to more detailed studies, are given in these publications. Gossans associated with lead-zinc deposits have been studied by Taylor & Scott (1982). The general classification of mineral deposits adopted by Williams (1980) is used in the following summary. Production figures for all mines mentioned are listed in Table 17. The distribution of mineral deposits is shown in Fig. 57.

Shale-hosted stratiform lead-zinc-silver deposits

Examples of this type include the Mount Isa, Hilton and Lady Loretta lead-zinc-silver deposits in the Western Fold Belt and the Dugald River deposit of the Eastern Fold Belt.

TABLE 17. MAJOR MINES AND PROSPECTS

Name	*Location (1:100 000 geological Sheet area)*	*Recorded production (t = tonnes, g = grams)*	*Principal references*
Answer mine	SELWYN REGION	1023t Cu, 11090g Au	Blake & others (1984)
Big Beryl mine	MOUNT ISA	71.8t Beryl	Brooks & Shipway (1960)
Blockade mine	MARY KATHLEEN	1228t Cu	Derrick & others (1977c)
Dingo prospect	KURIDALA REGION	(Cu–Pb–Zn deposit)	Donchak & others (1983)
Dobbyn mine	ALSACE	2834t Cu	Caster & others (1961)
Duchess mine	DUCHESS REGION	25155t Cu, 76141g Au, 331560g Ag	Carter & others (1961)
Dugald River prospect	QUAMBY	(Pb–Zn deposit)	Connor & others (1982)
Fairmile prospect	KURIDALA REGION	(Pb–Zn–Cu deposit)	Donchak & others (1983)
Federal mine	MARRABA	977t Cu	Carter & others (1961)
Gilded Rose mine	CLONCURRY	194042g Au	Carter & others (1961)
Great Australia mine	CLONCURRY	2693t Cu	Carter & others (1981)
Hampden mine	KURIDALA REGION	15114t Cu, 376096g Au, 173619g Ag	Carter & others (1961) Blake & others (1984)
Hilton prospect	MOUNT ISA	(Pb–Zn–Ag deposit)	Mathias & others (1973)
Kalkadoon mine	ALSACE	3495t Cu	Carter & others (1961)
Lady Annie mine	MAMMOTH MINES REGION	1393t Cu[1]	Lewis (1975)
Lady Fanny mine	DUCHESS REGION	460t Cu, 1676g Au	Krosch & Sawers (1974)
Lady Loretta prospect	MAMMOTH MINES REGION	(Pb–Zn deposit)	Louden & others (1975)
Lillimay mine	PROSPECTOR	339t Cu	Carter & others (1961)
Magnet mine	QUAMBY	736t Cu	Carter & others (1961)
Mammoth mine	MAMMOTH MINES REGION	5485lt Cu[2]	Scott & Taylor (1982)
Manxman mine	PROSPECTOR	216t Cu	—
Mary Kathleen mine	MARRABA	8894t U_3O_8[3]	Hawkins (1975), Scott & Scott (1985)
Mighty Atom mine	ALSACE	1165t	Carter & others (1961)
Mount Cobalt mine	SELWYN REGION	777t Co	Nisbet & others (1983)
Mount Cuthbert mine	ALSACE	4403t Cu	Carter & others (1961)
Mount Elliott mine	SELWYN REGION	24862t Cu, 1054698g Au	Carter & others (1961)
Mount Hope mine	DUCHESS REGION	637t Cu, 109g Au	Brooks (1977)
Mount Isa mine	MOUNT ISA	2934417t Cu, 4090728t Pb, 2887895t Zn, 10700t (approx.) Ag[4]	Mathias & Clarke (1975), Swager (1985)
Mount Mascotte mine	DUCHESS REGION	890t Cu, 7637g Au	Carter & others (1961)
Mount McNamara mine	MARRABA	609t Cu, 4260g Au	Carter & others (1961)
Mount Olive mine	PROSPECTOR	290t Cu	Carter & others (1961)
Mount Oxide mine	MOUNT OXIDE REGION	12674t Cu	Hutton & Wilson (1984)
Orphan mine	COOLULLAH	2871t Cu, 18715g Au, 51097g Ag	Carter & others (1961)
Pandanus mine	SEIGAL	26t U_3O_8	Sweet & others (1981)
Pegmont prospect	SELWYN REGION	(Pb–Zn deposit)	Stanton & Vaughan (1979) Blake & others (1983)
Phosphate Hill mine	DAJARRA	1290000t phosphate rock[5]	Russell & Trueman (1971)
Referee mine	PROSPECTOR	550t Cu	Carter & others (1961)
Revenue mine	DUCHESS REGION	302t Cu, 311g Au	Krosch & Sawers (1974)
Rosebud mine	MARY KATHLEEN	565t Cu	Derrick & others (1977c)
Saint Mungo mine	DAJARRA	1561t Cu	Carter & others (1961)
Silver King mine	LAWN HILL REGION	>2600t Pb	Sweet & Hutton (1982)
Silver Phantom mine	KURIDALA REGION	435587g Ag	Donchak & others (1983)
Skal prospect	KENNEDY GAP	(U deposit)	Brooks (1960)
Trekalano mine	DUCHESS REGION	20472t Cu, 423236g Au, 338560g Ag	Carter & others (1961)
Wee MacGregor mine	MARY KATHLEEN	2776t Cu, 43509g Au	Derrick & others (1977c)
Winston Churchill mine	MARY KATHLEEN	647t Cu	Derrick & others (1977c)
Young Australia mine	KURIDALA REGION	3911t Cu	Donchak & others (1983)

1. J. Kay, GSQ, personal communication 1986
2. D. J. Perkin, BMR, personal communication 1986
3. J. L. Liebelt, Chairman's address, 18 April 1983
4. Total production to 31.12.85, D. J. Perkin, BMR, personal communication 1986
5. Resource Assessment Division, BMR, 1986

All occur in metamorphosed pyritic and dolomitic shale and siltstone, and are generally considered to be syngenetic or early diagenetic in origin. The *Mount Isa* and *Hilton* deposits (e.g., Mathias & Clark, 1975; Mathias & others, 1973) are in the Urquhart Shale of the Mount Isa Group (cover sequence 3) within the Leichhardt River Fault Trough, whereas the *Lady Loretta* deposit (Loudon & others, 1975) is in the Lady Loretta Formation of the lower McNamara Group in the Lawn Hill Platform. The Lady Loretta Formation is considered to be slightly younger than the

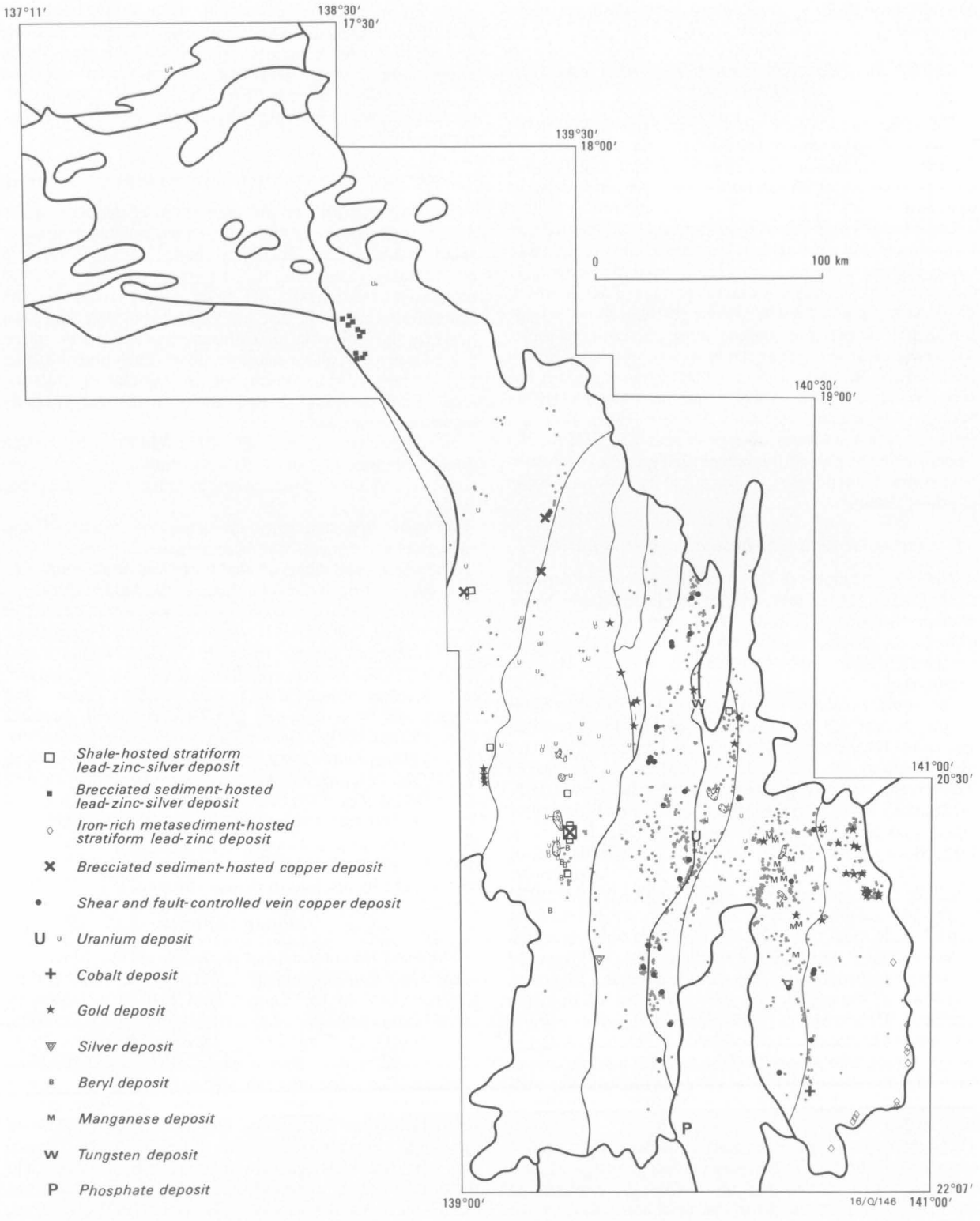


Fig. 57. Distribution of mineral deposits in the Mount Isa Inlier and environs.

Urquhart Shale. The host rocks for the *Dugald River* deposit (Connor & others, 1982) are assigned to the Corella Formation (cover sequence 2). Cadmium has been obtained as a by-product from the Mount Isa Pb–Zn–Ag ore, and is also present in the Lady Loretta deposit.

Brecciated sediment-hosted lead–zinc–silver deposits

Mineral deposits of this type occur in the Lawn Hill Formation of the McNamara Group (cover sequence 3) in the Lawn Hill Platform of LAWN HILL REGION. They consist of breccia, localised along northeast to east-northeast-trending tensional faults, which contains galena, sphalerite and minor pyrite and chalcopyrite in a gangue of quartz and siderite. The main deposit is at the *Silver King* mine. Three possible sources for the mineralisation have been suggested (Sweet & Hutton, 1982): hydrothermal solutions from an unknown igneous intrusion, migration of metal-bearing connate waters from underlying or adjacent strata, and

remobilisation from a larger concealed deposit yet to be discovered.

Iron-rich metasediment-hosted stratiform lead-zinc deposits

This mineralisation-type was discovered during 1971 in the Cloncurry-Selwyn zone of the Eastern Fold Belt. Examples include the deposits at the *Pegmont, Dingo* and *Fairmile* prospects. None of the deposits have yet proved to be economic.

The mineralisation occurs in metamorphosed banded iron formation within the Kuridala Formation and Soldiers Cap Group of cover sequence 2, and is considered to be essentially syngenetic and possibly of exhalative origin (Blake & others, 1984). As first pointed out by Derrick (1976), it shows striking similarities in ore and gangue minerals, country rocks, metamorphism, and age to the lead-zinc mineralisation at Broken Hill, New South Wales. The Pegmont deposit has been investigated by Löcsei (1977), Stanton & Vaughan (1979), Stanton (1982), and Vaughan & Stanton (1984). Both the Pegmont-type and Mount Isa-type of lead-zinc deposits can be considered as part of the same broad group of sediment-hosted stratiform deposits, as suggested by Perkin (in Blake & others, 1984).

Brecciated sediment-hosted copper deposits

The main examples of this type are the copper deposits at Mount Isa, Mammoth, Mount Oxide and Lady Annie mines in the Western Fold Belt. Brecciation is at least partly tectonic in origin, but whether the mineralisation is syngenetic/diagenetic or epigenetic is a matter of some controversy.

The *Mount Isa* copper deposit occurs in the Urquhart Shale of the Mount Isa Group, like the spatially associated lead-zinc-silver deposit, but is hosted in the discordant silica-dolomite. It has been regarded as an essentially sedimentary deposit (e.g., Stanton, 1963; Mathias & Clark, 1975) closely linked with the formation of the lead-zinc-silver ores (e.g., Finlow-Bates & Stumpfl, 1979, 1985; Robertson, 1982; McGoldrick, 1985), and also as an epigenetic deposit unrelated to the lead-zinc-silver mineralisation. An epigenetic origin for the copper was proposed by Smith & Walker (1971) on geochemical grounds, with the copper being derived from nearby mafic rocks of the Eastern Creek Volcanics (see also Wilson & others, 1985). Gulson & others (1983, 1985) reached the same conclusion from lead isotope data, and suggested that some of the copper may have been derived from the Leichhardt Metamorphics (=Volcanics). An epigenetic origin is supported by the structural evidence of Perkins (1984) and Swager (1984), who have related the formation of the copper ore bodies and the host silica dolomite to a deformation event which postdated deposition of the Mount Isa Group by at least 50 Ma.

The *Mammoth* copper deposit is hosted by brecciated sandstone of the Myally Subgroup (cover sequence 2), and is located within the Mount Gordon Fault Zone separating the Lawn Hill Platform from the Leichhardt River Fault Trough. It is considered by Scott & Taylor (1982) to be epigenetic, with the copper being leached from the nearby Pickwick Metabasalt Member of the Eastern Creek Volcanics and transported along a fault system to the site of the deposit.

At *Mount Oxide* mine, the copper ore occurs in carbonaceous shale at the top of the Gunpowder Creek Formation, McNamara Group, and is described as stratiform (e.g., Hutton & Wilson, 1984).

The *Lady Annie* copper deposit occurs in the Paradise Creek Formation of the McNamara Group in the Lawn Hill Platform, 3 km west-southwest of the apparently unrelated Lady Loretta Pb-Zn deposit. The primary copper ore, which is too low in grade to be economic, is in veins of dolomite and less commonly quartz cutting mainly dolomitic siltstone and dolomite. As in the other deposits of this type, mafic rocks of the Eastern Creek Volcanics have been suggested as a possible source for the copper, although contemporaneous volcanic exhaltations are not ruled out (Lewis, 1975).

Shear and fault-controlled vein-copper deposits

The vast majority of the many copper deposits in the Mount Isa Inlier are of this type, which is characterised by small tonnages but relatively high grades. They are particularly common in the more deformed and metamorphosed parts of cover sequence 2 in the Kalkadoon-Leichhardt Belt and Eastern Fold Belt. The main hosts for these deposits are carbonaceous and pyritic slates, calc-silicate rocks, and metabasalt, all of which probably have high primary base-metal contents, but similar deposits are also found in felsic igneous rocks; many are spatially associated with metadolerite.

In addition to copper, many of the vein deposits contain appreciable amounts of gold, some have significant silver contents, and a few contain minor bismuth (Carter & others, 1961).

At most deposits, only the zones of oxidation and supergene enrichment have been mined.

The more productive of the shear and fault-controlled vein-copper deposits include those at the *Mount Cuthbert, Kalkadoon, Dobbyn* and *Mighty Atom* mines, ALSACE; *Orphan* mine, COOLULAH; *Referee, Lillimay, Mount Olive,* and *Manxman* mines, PROSPECTOR: *Magnet* mine, QUAMBY; *Wee MacGregor, Blockade, Winston Churchill,* and *Rosebud* mines, MARY KATHLEEN; *Federal* and *Mount MacNamara* mines, MARRABA; *Great Australia* mine, CLONCURRY; *Duchess, Trekalano, Mount Mascotte, Mount Hope, Lady Fanny,* and *Revenue* mines, DUCHESS REGION; *Hampden* and *Young Australia* mines, KURIDALA REGION; *Saint Mungo* mine, DAJARRA; and *Mount Elliott* and *Answer* mines, SELWYN REGION. All these mines have produced more than 200 t Cu. Since mid-1970, copper has been recovered from several deposits of this type by leaching methods (Brooks, 1977, 1979b).

Uranium deposits

The main uranium deposit in the Mount Isa Inlier, that at the *Mary Kathleen* mine (Fig. 58), is situated in the Mary Kathleen zone of the Eastern Fold Belt. It is hosted by garnetiferous calc-silicate rocks of the Corella Formation, and consists of disseminated uraninite in allanite (e.g., Hawkins, 1975). According to Derrick (1977) and Cruikshank & others (1980), the host calc-silicate rocks are skarns and the uranium + rare earth mineralisation is epigenetic, both skarn formation and mineralisation being formed during metasomatism related to intrusion of nearby Burstall Granite and, in particular, associated uranium-rich rhyolite dykes into the Corella Formation; the rhyolite dykes are regarded as the main source of the uranium. Hawkins (1975), however, suggested that the uranium may have been remobilised from within the sedimentary pile during metamorphism. In contrast, Scott & Scott (1985) consider that the Mary Kathleen deposit is syngenetic; in their interpretation the calc-silicate host rocks have an appreciable basaltic and felsic tuff content and are interlayered with some mafic lavas, and both garnet formation and uranium-rare earth concentrations are related to the basaltic volcanism. Page (1983b) has dated the uraninite ore at 1550 ± 15 Ma, a U-Pb age which is about 90 Ma younger than that of the rhyolite dykes and Burstall Granite and is synchronous with the regional metamorphism (although the uranium protore could be as old as the granite);

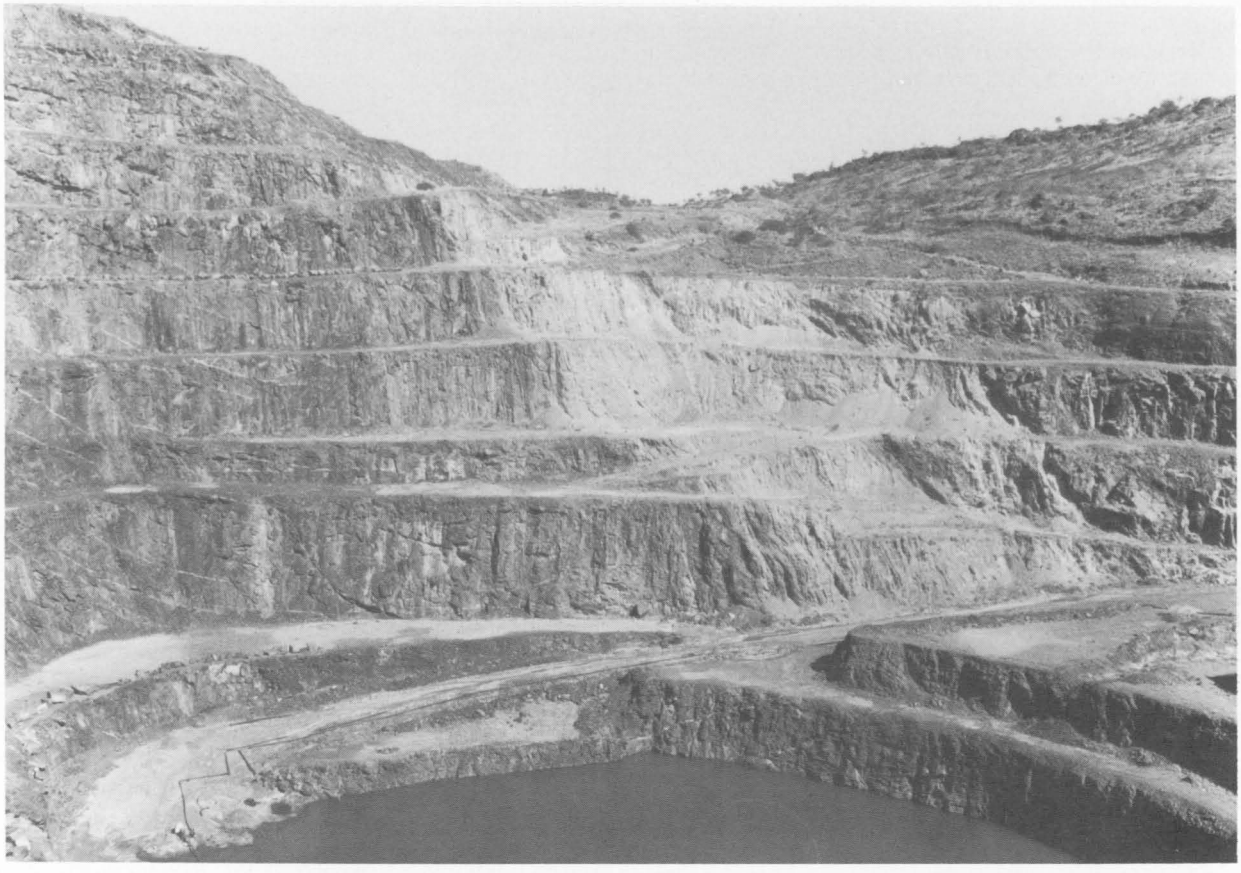


Fig. 58. South side of the open cut at the abandoned Mary Kathleen uranium mine, June 1985. The uranium ore was hosted by brecciated garnetiferous calc-silicate rocks which are exposed to the left (east) of the pale-coloured zone marking the position of the Mary Kathleen shear. (M2684/39)

he has also obtained Rb-Sr data which indicates that skarn formation took place much later, at around 1200 Ma.

Numerous small uranium deposits occur within the region (Brooks, 1960, 1975), two of which, Skal and Pandanus, are shown on the 1:500 000 geological map. *Skal*, the first uranium deposit found in the Mt Isa area (in 1954), is hosted by metasediments and metabasalt of the Eastern Creek Volcanics in the Leichhardt River Fault Trough. Its genesis is uncertain. In the *Pandanus* deposit, located in the Murphy Tectonic Ridge, the uranium minerals occur in shear zones cutting altered Cliffdale Volcanics, and are possibly related to nearby granite of the Nicholson Granite Complex (Sweet & others, 1981).

Cobalt deposits

The only significant deposit consisting predominantly of cobalt ore is at the *Mount Cobalt* mine, in the southwest of the Cloncurry-Selwyn zone of the Eastern Fold Belt. This deposit occurs in a shear zone between a metadolerite sill and steeply dipping metasediments of the Kuridala Formation (Nisbet & others, 1983). Total production, about 778 t metallic cobalt, was obtained between 1919 and 1934. Several minor cobalt occurrences in the region are noted in Brooks (1979a).

Gold deposits

Most of the 3100 kg of gold produced from the Mount Isa Inlier has come as a by-product from shear and fault-controlled vein-copper deposits in the Eastern Fold Belt; the main producers being the *Mount Elliott, Trekelano*, and *Hampden* deposits (Table 16). The largest mine worked solely for gold is the *Gilded Rose* southeast of Cloncurry, in the Cloncurry-Selwyn zone of the Eastern Fold Belt. The deposit here consists of auriferous quartz veins cutting schist and quartzite of the Soldiers Cap Group.

Gold has also been obtained from alluvial deposits, mainly near Cloncurry, and from the late Adelaidean Quamby Conglomerate, where epigenetic (hydrothermal?) gold occurs with hematite in the conglomerate matrix (Carter & others, 1961). Some potentially economic gold deposits are contained in massive, banded and locally brecciated quartz-hematite bodies anomalously rich in gold, and also copper, near Selwyn, in the Eastern Fold Belt. The origin of these bodies is uncertain—although generally concordant with bedding, they are considered to be epigenetic by Blake & others (1983a, 1984).

Silver deposits

A few small silver deposits have been mined. The largest is the *Silver Phantom* deposit, which is in a roof pendant of Mitakoodi Quartzite (Malbon Group) within the Wimberu Granite, in the Quamby-Malbon zone of the Eastern Fold Belt. The deposit consists mainly of cerargyrite, native silver, and naumannite in a gangue of barite, jasper, chalcedonic and opaline silica, and dark clayey material.

Beryl and mica deposits

Small amounts of beryl and mica have been obtained from pegmatites west of Mount Isa. Most of the beryl produced has come from the *Big Beryl* deposit. The pegmatites, which are related to the Sybella Granite, intrude amphibolite mapped as Eastern Creek Volcanics (Brooks & Shipway, 1960).

Manganese deposits

Several small manganese deposits, some of which have been mined, occur within the Overhang Jaspilite of the Mary Kathleen Group in the Quamby–Malbon zone of the Eastern Fold Belt.

GEOLOGICAL HISTORY

Interpretations of the geological history of the Mount Isa region (e.g., Carter & others, 1961; Plumb & Derrick, 1975; Derrick & others, 1977c; Derrick, 1980; Plumb & others, 1980; Blake, 1980; Blake & others, 1984; and commentaries for the 1:100 000 geological maps) need to be continually revised as new stratigraphic, structural, and geochronological data come to light. The sequence of events outlined below is based on data available in 1984, and no doubt will require minor modifications and some major changes in the future.

Pre-1900 Ma

The *basement* to the Proterozoic cover sequences of the region consists partly or entirely of rocks older than 1900 Ma.

Sedimentation and igneous activity

Quartzofeldspathic, quartzose, pelitic, and calcareous sediments were deposited over much or all of the region sometime before 1900 Ma. Felsic and minor mafic volcanism and intrusive activity accompanied some sedimentation in the south. The sediments and igneous rocks form the *Murphy Metamorphics, Yaringa Metamorphics, Kurbayia Migmatite*, and *Plum Mountain Gneiss*; probably the *Sulieman Gneiss, Kallala Quartzite, Saint Ronans Metamorphics, May Downs Gneiss Member* of the Mount Guide Quartzite, and part of the undivided *Tewinga Group*; and possibly the *Double Crossing Metamorphics* and part of the *Corella Formation*. Source areas for the sediments may have included late Archaean granitic terrane.

From ~1900–1875 Ma

Deformation and metamorphism

The basement rocks were tightly folded and regionally metamorphosed during this period. The metamorphism reached the amphibolite facies, with some partial melting to form migmatite, in the south, but the basement Murphy Metamorphics of the Murphy Tectonic Ridge and in the most western part of the Lawn Hill Platform only appear to have been metamorphosed to the greenschist facies. The tectonism resulted in uplift and erosion, and by 1875 Ma most of the region was probably a land area where large tracts of metamorphic rocks were exposed.

From ~1875–1800 Ma

Widespread felsic volcanic activity together with minor mafic volcanism and local clastic sedimentation took place during the early part of this period to form *cover sequence 1.*

Volcanism

Extensive felsic and minor mafic volcanism, represented by the *Leichhardt Volcanics*, took place in the Kalkadoon–Leichhardt Belt and Ewen Block. It probably began at about 1875 Ma in the south, and persisted until about 1850 Ma in the north. The bimodal volcanism and associated sedimentation, represented by the *Candover Metamorphics* in the south of the Ewen Block and the felsic volcanism that formed the *Cliffdale Volcanics* of the Murphy Tectonic Ridge, may also have taken place between 1875 and 1850 Ma. The abundance of ignimbritic deposits and paucity of associated bedded sedimentary rocks indicate that the eruptions were predominantly, if not entirely, subaerial.

Intrusive activity

Granites of the *Kalkadoon Batholith, Ewen Batholith*, and the *Nicholson Granite Complex*, comagmatic with felsic volcanics, were emplaced before, during, and after the volcanism. A suite of mafic dykes were intruded at about the same time. Some of these formed net-veined complexes where they intersected Kalkadoon Granite and some were feeders for basalt lavas. Younger dykes, formed of weakly magnetic dolerite, were intruded as a conjugate swarm into the Kalkadoon–Leichhardt Belt and Ewen Block after 1840 Ma but probably before 1800 Ma. No weakly magnetic extrusive equivalents of these dykes are known. The *Yeldham Granite* was emplaced in the Lawn Hill Platform at about 1820 Ma, and the basement Yaringa Metamorphics were intruded by the *Big Toby Granite* at about 1800 Ma.

Deformation and metamorphism

Some contact metamorphism and local folding, tilting, and faulting accompanied granite emplacement and volcanism, but no major region-wide deformation or regional metamorphism took place during this period.

Palaeogeography

Most of the region was probably a land area subjected to denudational processes throughout the period. By 1800 Ma, parts of some granite plutons had become unroofed and metamorphic basement rocks were exposed.

From ~1800–1680 Ma

Most of the sedimentation and volcanism represented by *cover sequence 2* of the Western Fold Belt, Kalkadoon–Leichhardt Belt, and Eastern Fold Belt took place after 1800 Ma, but before 1740 Ma, when some granites of the Wonga Batholith were emplaced. No rocks of this period are known on the Murphy Tectonic Ridge or in the far west of the Lawn Hill Platform.

Sedimentation

Subsidence to the west of the Kalkadoon–Leichhardt Belt resulted in sedimentation commencing at about 1790 Ma in a linear depression—the Leichhardt River Fault Trough of Glikson & others (1976) and Derrick (1982)—which may have been a half-graben (Sweet, 1983a; Derrick, 1983). The first sediments laid down in this depression, those of the *Bottletree Formation* and the lower parts of the *Mount Guide* and *Leander Quartzites* of the *Haslingden Group*, were immature fluvial and shallow-water deposits derived from cover sequence 1 volcanics, granite, and basement rocks which were exposed mainly to the east, and also from contemporaneous volcanics. The more mature sediments forming the upper parts of the Mount Guide and Leander Quartzites were probably deposited in shallow water offshore. Fluvial, lacustrine, and/or shallow-marine sedimentation continued within the Leichhardt River Fault Trough during the remainder of Haslingden Group time. Detritus continued to be derived from the landmass to the east, and some probably

also came from sources to the north and west. Fluvial sediments present in the *Magna Lynn Metabasalt* and *Argylla Formation* were deposited within the Kalkadoon-Leichhardt Belt, which was part of the extensive landmass to the east of the Leichhardt River Fault Trough. These sediments may be contemporaneous with those of the Bottletree Formation, as suggested by Derrick & Wilson (1981b), or with those of the upper part of the Haslingden Group, as suggested by Blake (1980, 1981b).

A subsequent relative rise in sea level resulted in a marine transgression, during which mainly shallow-water sediments probably covered most of the Mount Isa Inlier. These sediments form the *Quilalar Formation* in the Western Fold Belt, the *Ballara Quartzite, Corella Formation, Stanbroke Sandstone*, and probably the *Makbat Sandstone* of the Kalkadoon-Leichhardt Belt, and the upper part of the *Argylla Formation*, much of the overlying *Malbon Group* and *Mary Kathleen Group*, and possibly most of the *Soldiers Cap Group* of the Eastern Fold Belt. Syngenetic iron-rich metasediment-hosted stratiform lead-zinc deposits were formed during sedimentation of the Soldiers Cap Group and Kuridala Formation (Mary Kathleen Group) in the southeast, possibly from exhalations associated with contemporaneous subaqueous volcanism.

Volcanism

Mafic and felsic volcanism accompanied the earliest sedimentation in the Leichhardt River Fault Trough: that of the *Bottletree Formation*, at around 1790 Ma. After a period of quiescence, mafic volcanism recommenced in the Leichhardt River Fault Trough with the voluminous outpouring of the basaltic lavas forming the bulk of the *Eastern Creek Volcanics* of the *Haslingden Group* and probably the *Jayah Creek Metabasalt* and *Oroopo Metabasalt*. Local sporadic mafic volcanism continued during the deposition of the *Myally Subgroup* and *Quilalar Formation*.

Basalt flows of the *Magna Lynn Metabasalt* were erupted on the landmass to the east, within the Kalkadoon-Leichhardt Belt, at about the same time as either the Bottletree Formation (e.g., Derrick & Wilson, 1981b) or the Eastern Creek Volcanics (e.g., Blake & others, 1984), and were succeeded by subaerial felsic eruptions, represented by the volcanics of the *Argylla Formation*, dated at about 1780 Ma. The mafic and felsic volcanism partly overlapped in time, and appears to have continued on a very minor scale during deposition of the overlying *Ballara Quartzite* and *Corella Formation*. Farther east, in the Quamby-Malbon zone of the Eastern Fold Belt, an early phase of felsic volcanic activity, represented by the *Argylla Formation*, was followed by the emission of the basalt lavas of the *Marraba Volcanics*. These lavas may be correlatives of the Eastern Creek Volcanics (e.g., Carter & others, 1961; Glikson & others, 1976; Plumb & others, 1980), or they may be younger than most or all of the Haslingden Group (e.g., Blake, 1980). The abundance of intercalated sedimentary rocks indicates that the Argylla and Marraba eruptions here may have been largely subaqueous. Felsic and mafic volcanism persisted on a much smaller scale in the Eastern Fold Belt during deposition of the *Mitakoodi Quartzite* and the *Corella Formation*. Possibly contemporaneous basaltic and minor felsic volcanics were erupted, probably underwater, during sedimentation of the *Soldiers Cap Group* and *Mary Kathleen Group* in the Cloncurry-Selwyn zone. The youngest such activity in this zone may be represented by rhyolite, date at 1720 Ma, in the *Doherty Formation* (Mary Kathleen Group).

Intrusive activity

Many mafic and some felsic dykes and other minor intrusions were emplaced between 1790 Ma and about 1750 Ma. They include feeders for the numerous extrusions of cover sequence 2 and also for sills in the Haslingden, Mary Kathleen, and Soldiers Cap Groups. Most plutons of the *Wonga Batholith* were probably intruded between 1740 Ma and 1720 Ma into units assigned to cover sequence 2 in the east of the Kalkadoon-Leichhardt Belt and in the Mary Kathleen zone of the Eastern Fold Belt. Some mafic intrusions, including the *Lunch Creek Gabbro* east of Mary Kathleen, were intruded at about the same time as the Wonga granites, and in places formed net-veined complexes with granite.

Tectonism

Faulting and local tilting and folding probably accompanied igneous activity, and contact metamorphism, metasomatism and skarn formation were associated with granite emplacement. The plutonism at 1740 Ma may have been accompanied by uplift, resulting in local or widespread subaerial erosion and cessation of sedimentation. In parts of the Western Fold Belt (e.g., in northwest MOUNT OXIDE REGION), units of cover sequence 2 were steeply tilted and/or folded before 1680 Ma (when they were overlain unconformably by cover sequence 3). Much of the Corella Formation in the Mary Kathleen zone of the Eastern Fold Belt was tightly folded either before or during the early stages of granite emplacement. This deformation, if it predates granite emplacement, may predate cover sequence 1, in which case part of the Corella Formation may belong to the early Proterozoic basement (Blake, 1980, 1982, 1983).

Palaeogeography

The depositional area in the west, the Leichhardt River Fault Trough, was probably bounded initially to the east by a large landmass with considerable relief. This landmass was the main source of at least the early detritus. To the west there was probably a lower land area. Subsidence in the Leichhardt River Fault Trough more or less kept pace with sedimentation. With time, the depositional area was enlarged, and younger units of cover sequence 2 overlapped eastwards onto basement and cover sequence 1 rocks of the Kalkadoon-Leichhardt Belt and south-westwards onto probable basement.

By middle or late Haslingden Group time, the eastern landmass had been denuded to a broad plain with some residual hills. It may then have become largely covered by extensive sheets of basaltic and felsic volcanics—those of the Magna Lynn Metabasalt and Argylla Formation.

A relative rise in sea level at the end of Haslingden Group time caused most of the Mount Isa Inlier to become an extensive depositional area—perhaps forming part of a broad shelf—which became covered by sediments of the Quilalar Formation in the west and the correlative Mary Kathleen Group to the east. By about 1750 Ma the sediments and volcanics of cover sequence 2 had reached thicknesses of probably more than 12 000 m in the Western and Eastern Fold Belts, and more than 5000 m in the Kalkadoon-Leichhardt Belt. Some time after 1750 Ma in the west and possibly somewhat later in the east, relative uplift resulted in sedimentation giving way to subaerial erosion, as the region once more became a landmass.

The Murphy Tectonic Ridge may have been a land area throughout this period.

From ~1680–1670 Ma

Cover sequence 3 was laid down during this period.

Sedimentation and volcanism

In the eastern part of the Western Fold Belt, fluvial sedimentation (forming the *Bigie Formation*) was followed by subaerial and possibly shallow-water felsic and mafic volcanism (1680 Ma old *Carters Bore Rhyolite* and contemporaneous *Fiery Creek Volcanics*). Similar sedimentation and volcanism to the northwest and west is represented by the *Wire Creek Sandstone* and *Peters Creek Volcanics* on the south side of the Murphy Tectonic Ridge, the *Tawallah Group* on the north side, and the *Carrara Range Group* in the far west of the Lawn Hill Platform. The volcanism in the east of the Western Fold Belt was followed, after a short period of erosion, by the deposition of the shallow-water sediments which form the *Surprise Creek Formation*. The area to the northwest appears to have remained land at this time. After another short time interval, during which some local deformation and erosion took place, the sediments of the *Mount Isa Group* were deposited, mainly in shallow water. The sediments extended westwards across the Lawn Hill Platform and northwards onto the Murphy Tectonic Ridge, where they are represented by the lower parts of the *McNamara Group* and *Fickling Group*, respectively. The shale-hosted stratiform lead–zinc–silver deposits at Mount Isa, Hilton, and Lady Loretta were formed at this time. Contemporaneous felsic volcanism is indicated by the occurrence of numerous tuff beds in the Native Bee Siltstone and Urquhart Shale of the Mount Isa Group and in the correlative Paradise Creek Formation of the McNamara Group. Deeper-water sedimentation prevailed over most of the Lawn Hill Platform during the deposition of the upper parts of the McNamara and Fickling Groups. The *Mount Albert Group* sediments were deposited in the Kalkadoon–Leichhardt Belt and Eastern Fold Belt, probably in shallow-marine environments, either during this period or earlier—perhaps at the same time as the Mary Kathleen Group of cover sequence 2.

Intrusive activity

The *Weberra Granite* was intruded into the Lawn Hill Platform at about 1700 Ma. Most granite of the *Sybella Batholith* was emplaced at about 1670 Ma, either shortly before (e.g., Hill & others, 1975; Wilson & others, 1979) or shortly after (Blake & others, 1984) the Mount Isa Group was deposited. At least one pluton of *Wonga Granite* was also intruded at about 1670 Ma (Page, 1978). The *Garden Creek Porphyry* intruding the Mount Guide Quartzite of the Haslingden Group may be of similar age. A number of mafic dykes were intruded between about 1680 and 1670 Ma. A few of these were probably feeders for lava flows in the Western Fold Belt, and some formed net-veined complexes where they intersected plutons of Sybella Granite.

From ~1670–1450 Ma

The cover sequences and basement were regionally deformed and metamorphosed during this period.

Sedimentation and volcanism

U–Pb zircon ages of around 1600 Ma on felsic metavolcanics and microgranite in the Quamby–Malbon zone of the Eastern Fold Belt west of Cloncurry (the Tommy Creek area of Page, 1983a) indicate that some volcanism and associated sedimentation may have taken place at this time. Alternatively, 1600 Ma may be the age of metamorphism rather than volcanism. No evidence indicating possible sedimentation or volcanism between 1670 Ma and 1450 Ma has been found elsewhere in the region.

Tectonism

Major tectonism, involving thrusting, folding, faulting, and regional metamorphism to upper amphibolite facies, affected the entire region between about 1620 and 1550 Ma. Two main phases of deformation, D_1 and D_2, have been recognised (e.g., Bell, 1983; BMR, 1985). These were the first widespread deformations to affect the cover sequences. D_1 resulted in extensive thrusting and nappe formation, whereas D_2 was characterised by tight folding about northerly trending, steeply dipping to vertical axial planes. A later phase of deformation, D_3, resulted in the formation of north-northwest and north-northeast-trending shear zones at around 1480 Ma. Some retrogressive regional metamorphism may have accompanied this phase. Most of the epigenetic mineral deposits in the region were probably formed during the deformation events of this period.

Intrusive activity

The foliated granites of the *Williams* and *Naraku Batholiths* were emplaced in the Eastern Fold Belt during or before the main deformation. Mafic dykes intruded the Soldiers Cap Group of the Cloncurry–Selwyn zone and the Argylla Formation and Malbon Group of the Quamby–Malbon zone in the Eastern Fold Belt between 1620 and 1550 Ma, and were subsequently metamorphosed. The non-foliated granites of the Williams and Naraku Batholiths were emplaced at around 1500 Ma, after the main deformation. Some mafic dykes were intruded at about the same time as these plutons, and in places formed net-veined complexes with granite. The *Mount Philp Breccia* bodies, which intrude the Corella Formation of the Mary Kathleen zone in the Eastern Fold Belt, were formed after the Corella Formation had been strongly deformed during D_2 but they may predate D_3.

Palaeogeography

The region may have been a land area for all or most of this period.

From ~1450–570 Ma

Sedimentation

Some time after tectonism at 1550 Ma and probably after 1450 Ma, but before 1200 Ma, shallow-water sediments of the *South Nicholson Group* were deposited in the South Nicholson Basin northwest of the Mount Isa Inlier. At about the same time, or later in the Proterozoic, the probably fluvial *Quamby Conglomerate* was laid down in fault-bounded depressions within the Quamby–Malbon region of the Eastern Fold Belt. Towards the end of the Proterozoic, glacial sediments were deposited near Duchess.

Igneous activity

Some post-metamorphic mafic intrusions were emplaced during this period. North-northeast-trending dykes of *Lakeview Dolerite* were intruded at around 1115 Ma, and the east-trending dolerite dykes in the southeast may be of similar age. No extrusive equivalents of these intrusions are known.

Tectonism

K–Ar isotope systems in felsic igneous rocks became stabilised between 1450 Ma and 1350 Ma, when the high heat flow prevailing during the major deformation, regional

metamorphism and granite emplacement between 1620 Ma and 1470 Ma was followed by regional cooling. Vertical and lateral movements took place along the major faults of the region during the late Proterozoic, and gentle basin-and-dome folding affected the South Nicholson Group in the South Nicholson Basin. This folding may have extended southeastwards to affect much of the Mount Isa Inlier. Metamorphism and metasomatism at around 1200 Ma resulted in skarn formation in the Mary Kathleen zone of the Eastern Fold Belt (Page, 1983b). These skarns may be related to concealed igneous intrusions or to an as yet unrecognised deformation event (perhaps the event which caused basin-and-dome folding in the South Nicholson Basin).

Palaeogeography

As far as is known, the region was a land area throughout this period, and became eroded to form a low-lying plain.

From ~570 Ma to present

Sedimentation and palaeogeography

After prolonged erosion, shallow-marine sedimentation recommenced in the middle Cambrian and continued into the Ordovician. The early Palaeozoic sediments extended eastwards from the present Georgina Basin to blanket the region. Following relative uplift and further erosions, during which much of the early Palaeozoic sedimentary blanket was removed, the region was largely covered by fluvial and shallow-marine sediments of the late Jurassic and early Cretaceous Eromanga and Carpentaria Basin sequences.

Since the Mesozoic, the region has been part of a continental landmass. It was planated and subjected to deep weathering during the early Tertiary, and has been affected by subaerial erosional and depositional processes throughout the Tertiary and Quaternary. The present dissected landscape can be attributed to late Tertiary and Quaternary changes in climate, to relative rises and falls in sea level, and to broad gentle warping.

Tectonism

Many of the major faults in the region were active during the Palaeozoic and Mesozoic, but not, apparently, in the Cainozoic. Late Proterozoic, early Palaeozoic and Mesozoic sediments were tilted and folded in the vicinity of some faults. However, the early Palaeozoic and younger strata are generally flat-lying, indicating that the region has been essentially stable tectonically throughout the Phanerozoic.

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APPENDIX 1
PROTEROZOIC ROCK UNITS OF THE MOUNT ISA INLIER AND ENVIRONS

Name of unit	*Distribution* [1]	*Reference to definition*	*General lithology*	*Remarks*
Agate Downs Siltstone	KUR, SER	Blake & others (1981a)	Siltstone, phyllite, quartzite	Part of Mary Kathleen Group
Alsace Quartzite[2]	AL, KG, MMR, MK, MOR, MY, PR	Derrick & others (1976b)	Quartz and feldspathic sandstone	Part of Myally Subgroup, Haslingden Group
Answer Slate	KUR, SER	Carter & others (1961), Blake & others (1981a)	Slate, siltstone, phyllite	Part of Mary Kathleen Group
Aquarium Formation	SE	Roberts & others (1963)	Siltstone, sandstone	Part of Tawallah Group
Argylla Formation	AL, CL, CO, DA, DUR, KUR, MA, MK, PR, QU, SER	Carter & others (1961), Derrick & others (1976a)	Felsic volcanics, sandstone	Part of Tewinga Group; dated at ~1780 Ma (U-Pb)
Ballara Quartzite	AL, CO, DUR, MA, MK, PR, QU	Carter & others (1961), Derrick & others (1977a)	Sandstone, arkose	Part of Mary Kathleen Group
Bigie Formation	AL, MMR, MOR, MY, PR	Hutton & others (1981)	Sandstone, Conglomerate	Correlated with Carters Bore Rhyolite (1678 Ma); assigned to cover sequence 3
Big Toby Granite	MI	Derrick & others (1978)	Xenolithic granite, commonly foliated	Dated at ~1800 Ma (U-Pb)
Billicumidji Rhyolite Member	HC, SE	Sweet (1981)	Rhyolite lava	Part of Cliffdale Volcanics
Birds Well Granite	DA?, DUR	Blake & others (1981a)	Foliated biotite and hornblende-bearing granite	Part of Wonga Batholith
Blackeye Granite	SER	Blake & others (1981a)	Foliated leucocratic granite	Part of Williams Batholith
Bortala Formation	AL, KG, MMR, MK, MOR, MY, PR	Derrick & others (1976b)	Feldspathic, lithic and micaceous sandstone, siltstone	Part of Myally Subgroup, Haslingden Group
Bottletree Formation	AR, DA, DUR, (MK)	Blake & others (1981a)	Greywacke, conglomerate, felsic and mafic volcanics	Dated at ~1790 Ma (U-Pb); assigned to cover sequence 2
Bowlers Hole Granite	DUR	Blake & others (1981a)	Foliated biotite-hornblende granite	Part of Wonga Batholith
Bowthorn Siltstone Member	HC	Sweet (1981)	Micaceous siltstone	Part of Constance Sandstone, South Nicholson Group
Breakaway Shale	Al, KG, MMR, MK, MI, MOR, MY, PR	Bennett (1965); Derrick & others (1976c)	Siliceous and carbonaceous siltstone and shale	Part of Mount Isa Group
Buddawadda Basalt Member	HC, SE	Sweet (1981)	Basalt lava	Part of Peters Creek Volcanics
Bulmung Sandstone Member	LHR	Hutton & others (1981)	Micaceous, lithic, and conglomeratic sandstone	Part of Lawn Hill Formation, McNamara Group
Burstall Granite	MA, QU	Derrick & others (1978)	Leucocratic biotite ± hornblende granite	Dated at 1720–1750 Ma (U-Pb); part of Wonga Batholith
Bushy Park Gneiss	DUR	Blake & others (1981a)	Hornblende-biotite granitic gneiss	Part of Wonga Batholith
Candover beds	AL		see Candover Metamorphics	Informal name
Candover Metamorphics	(AL), (PR)	Wilson & Derrick (1983)	Schist, quartzite, felsic and mafic volcanics	Tentatively assigned to cover sequence 1
Carolina Sandstone Member	SE	Roberts & others (1963)	Sandstone, siltstone	Part of Seigal Volcanics, Tawallah Group
Carrara Range Group	CRR	Sweet (1982)	Sandstone, conglomerate, felsic and mafic volcanics	Correlated with Carters Bore Rhyolite (1678 Ma). Comprises Don Creek Sandstone, Mitchiebo Volcanics, Top Rocky Rhyolite; assigned to cover sequence 3
Carters Bore Rhyolite	DA? DUR, KG, MI	Derrick & others (1978)	Felsic volcanics	Dated at 1678 Ma (U-Pb); assigned to cover sequence 3
Charley Creek Formation	(MK)	Carter & others (1961)		Rocks of unit now assigned to Ballara Quartzite, Corella Formation and Deighton Quartzite

1. 1:100 000 geological map sheets; for key to abbreviations see Table 2. Unit is present in map sheet, but not named, if abbreviation is in parentheses
2. Names in italics are of units not distinguished on the 1:500 000 geological map

Name of unit	*Distribution*	*Reference to definition*	*General lithology*	*Remarks*
Chumvale Breccia	MA	Carter & others (1981); Derrick & others (1977a)	Calcareous, quartzitic, and jaspilitic breccias	Part of Mary Kathleen Group. Not distinguished from Overhang Jaspilite on 1:500 000 map
Cliffdale Volcanics	HC, SE	Carter & others (1961)	Felsic volcanics	Minimum age 1730 Ma (Rb-Sr); includes Billicumidji Rhyolite Member; assigned to cover sequence 1
Cloncurry Complex		Carter & others (1961)		Comprises all Proterozoic rocks of Mount Isa Inlier
Cone Creek Metabasalt Member	DUR, KUR, MA	Derrick & others (1976d)	Basalt, mafic schist	Part of Marraba Volcanics, Malbon Group
Constance Sandstone	CRR, HC, LHR, SE	Carter & others (1961)	Sandstone, conglomerate	Part of South Nicholson Group; includes Pandanus Creek, Wallis, and Bowthorn Siltstone Members
Coocerina Formation	(QU)	Wilson (1984)	Black shale, siltstone, schist	Assigned to Mount Albert Group
Corella Formation	AL, CL, DA, DUR, MA, MK, PR, QU	Carter & others (1961), Derrick & others (1977a)	Calc-silicate, pelitic and psammitic rocks, mafic and felsic volcanics	Part of Mary Kathleen Group; includes Dugald River Shale and Lime Creek Metabasalt Members
Cowie Granite	SER	Blake & others (1981a)	Leucocratic granite, granodiorite and tonalite	Part of Williams Batholith
Cromwell Basalt Member	KG		See Cromwell Meta-Member	Informal name
Cromwell Metabasalt Member	AL, MMR, MK, MI, MY, PR	Derrick & others (1976b)	Metabasalt, metasediments	Part of Eastern Creek Volcanics, Haslingden Group
Deighton Quartzite	MK, PR	Carter & others (1961)	Feldspathic, lithic and quartzose sandstone	Part of Mount Albert Group
Doherty Formation	KUR, SER, (CL)	Blake & others (1981a)	Banded and brecciated calc-silicate rocks, quartz sandstone	Part of Mary Kathleen Group; dated at 1720 Ma (U-Pb)
Don Creek Sandstone	CRR	Sweet (1982)		Part of Carrara Range Group
Doomadgee Formation	HC, SE	Sweet (1981)	Conglomerate, siltstone, shale, dolomite	Part of Fickling Group
Double Crossing Metamorphics	SER	Blake & others (1981a)	Felsic gneiss, migmatite, quartzite, schist	Assigned to basement?
Dugald River Shale Member	(QU)	Wilson (1984)	Black shale, schist	Assigned to Corella Formation, Mary Kathleen Group
Dynamite Creek Member	AL, MY	Wilson & Derrick (1983)	Conglomerate, sandstone	Part of Eastern Creek Volcanics, Haslingden Group
Eastern Creek Volcanics	AL, AR, DA, DUR, KG, MMR, MK, MI, MOR, MY, PR	Carter & others (1961), Derrick & others (1976b)	Metabasalt, metasediments	Part of Haslingden Group; includes Dynamite Creek, Cromwell Metabasalt, Lena Quartzite and Pickwick Metabasalt Members
Eastern (sedimentary) succession	AL, MA, MK, PR		Metasediments, metavolcanics	Cover sequences of Kalkadoon-Leichhardt Belt and Eastern Fold Belt
Esperanza Formation	KG, MOR, LHR, MMR	Hutton & others (1981)	Stromatolitic chert; sandstone, siltstone	Part of McNamara Group
Ewen Batholith	Al, MY		Granitic rocks	Comprises Ewen Granite
Ewen Granite	AL, MY	Carter & others (1961)	Medium-grained granitic rocks	Forms Ewen Batholith
Fickling Group	HC, SE	Sweet (1981)	Dolomite, chert, siltstone, sandstone	Comprises Fish River Formation, Doomadgee Formation, Mount Les Siltstone, Walford Dolomite; assigned to cover sequence 3
Fiery Creek Volcanics	AL, MMR, MOR, MY	Hutton & others (1981)	Mafic and felsic volcanics	Assigned to cover sequence 3
Fish River Formation	HC, SE	Sweet (1981)	Sandstone, siltstone shale	Part of Fickling Group
Garden Creek Porphyry	DA, DUR	Blake & others (1981a)	Porphyritic microgranite	Intrudes Mount Guide Quartzite
Gin Creek Granite	SER	Blake & others (1981a)	Massive and foliated biotite granite	Part of Williams Batholith

Name of unit	*Distribution*	*Reference to definition*	*General lithology*	*Remarks*
Gunpowder Creek Formation	DUR, KG, LHR, MMR, MI, MOR, MY	Carter & others (1961), Hutton & others (1981)	Siltstone, shale, sandstone	Part of McNamara Group
Hardway Granite	MK	Derrick & others (1978)	Granite, tonalite, granodiorite, diorite	Part of Wonga Batholith
Haslingden Group	AL, AR, DA, DUC, LHR, MMR, MK, MI, MOR, MY, PR	Derrick & others (1976b)	Quartz sandstone, feldspathic sandstone, metabasalt	Comprise Mount Guide and Leander Quartzites, Eastern Creek Volcanics and Myally Subgroup, assigned to cover sequence 2
Hampden State Member			Graphitic and commonly pyritic slate	Top part of Kuridala Formation according to White (1957)
Jayah Creek Metabasalt	AR, (DUR)	Blake & others (1981a)	Metabasalt, sandstone	Assigned to cover sequence 2
Judenan beds	DUR, KG, MI	Carter & others (1961)	Sandstone, siltstone	Synonymous with Myally Subgroup
Kalkadoon Batholith	(AL, DA, DUR, MK, PR)	Blake & others (1984)	Granite, granodiorite, tonalite	Includes Kalkadoon, One Tree, Wills Creek, and Woonigan Granites
Kalkadoon Granite	AL, DA, DUR, MK, PR	Carter & others (1961)	Granodiorite, granite, tonalite	Part of Kalkadoon Batholith; dated at ~1860 Ma (U-Pb)
Kalkadoon Granodiorite		Wyborn & Page (1983)		Revision of Kalkadoon Granite
Kallala Quartzite	AR	Blake & others (1981a)	Quartzite	Tentatively assigned to basement
Kamarga Volcanics	LHR	Hutton & Sweet (1980)	Metabasalt, sandstone	Assigned to cover sequence 2
Kennedy Siltstone	MK, MI	Bennett (1965); Derrick & others (1976c)	Dolomitic siltstone	Part of Mount Isa Group
Knapdale Quartzite	(MK), QU	Carter & others (1961)	Feldspathic and quartz sandstones	Assigned to Mount Albert Group
Kurbayia Migmatite	(DUR, MK)	Blake (this Bulletin)	Migmatitic metasedimentary and meta-igneous rocks	Assigned to basement
Kuridala Formation	KUR, SER	Carter & others (1961)	Schist, metagreywacke, black slate	Assigned to Mary Kathleen Group
Lady Clayre Dolomite	(QU)	Wilson (1984)	Dolomitic siltstone	Assigned to Mount Albert Group
Lady Loretta Formation	LHR, MMR, MOR	Hutton & others (1981)	Laminated and stromatolitic dolomite	Part of McNamara Group
Lakerview Dolerite	MA, MK	Derrick & others (1978)	Dolerite	Dated at 1116±12 Ma (Rb-Sr); post-tectonic
Lawn Hill Formation	CRR, LHR	Carter & others (1961), Hutton & others (1981)	Shale, siltstone, sandstone, dolomite	Part of McNamara Group: includes Bulmung Sandstone and Widdallion Sandstone Members
Leander Quartzite	KG, MMR, PR	Carter & others (1961)	Quartz and feldspathic sandstones, greywacke	Part of Haslingden Group
Leichhardt Metamorphics	AL, CO, MK, MY, PR	Carter & others (1961), Derrick & others (1976a)	Felsic volcanics, gneiss	Mainly equivalent to Leichhardt Volcanics
Leichhardt Volcanics	DA, DUR	Blake & others (1981a)	Felsic volcanics	Assigned to cover sequence 1; part of Tewinga Group dated at ~1875-1850 Ma (U-Pb)
Lena Quartzite Member	AL, KG, MMR, MI, MOR, PR	Derrick & others (1976b)	Feldspathic and quartz sandstone	Part of Eastern Creek Volcanics, Haslingden Group
Lime Creek Metabasalt Member	MA	Derrick & others (1977a)	Metabasalt lava, pillow lava, amphibolite	Part of Corella Formation Mary Kathleen Group
Little Burke Tillite	DUR	de Keyser (1972)	Tillite, dolomite	Late Adelaidean unit at base of Georgina Basin succession
Llewellyn Creek Formation	CL, KUR	Derrick & others (1976c)	Phyllite, schist, metagreywacke	Part of Soldiers Cap Group
Lochness Formation	AL, MMR, MOR, MY, PR	Derrick & others (1976b)	Feldspathic and dolomitic sandstone, siltstone	Part of Myally Subgroup, Haslingden Group; includes Police Creek Siltstone Member
Lunch Creek Gabbro	MA	Derrick & others (1978)	Gabbro, dolerite	Dated at 1740 Ma (U-Pb)
Magazine Shale	MI	Bennett (1965); Derrick & others (1976a)	Siliceous, pyritic and carbonaceous shale	Part of Mount Isa Group
Magna Lynn Metabasalt	AL, CO, DA, DUR, MK, PR	Derrick & others (1976a)	Metabasalt	Part of Tewinga Group

Name of unit	*Distribution*	*Reference to definition*	*General lithology*	*Remarks*
Mairindi Creek Granite	DUR	Blake & others (1981a)	Foliated biotite granite	Part of Wonga Batholith
Makbat Sandstone	DA	Carter & others (1961)	Feldspathic to quartzose sandstone	Assigned to cover sequence 2
Malbon Group	CL, DUR, KUR, MA, MK, SER	Derrick & others (1976d)	Metabasalt, feldspathic sandstone	Comprises Marraba Volcanics and Mitakoodi Quartzite; assigned to cover sequence 2
Mammoth Formation	KG	Informal name		Now assigned to Torpedo Creek Quartzite, McNamara Group
Maramungee Granite	SER	Blake & others (1981a)	Foliated leucocratic granitic rocks	Part of Williams Batholith
Marraba Volcanics	DUR, KUR, MA, MK, SER	Carter & others (1961), Derrick & others (1976b)	Metabasalt, siltstone	Part of Malbon Group; includes Cone Creek Metabasalt, Mount Start, and Timberoo Members
Marimo Shale	CL, KUR, MA	Carter & others (1961), Derrick & others (1977a)	Carbonaceous slate, shale, siltstone	Part of Mary Kathleen Group. Two members—Mick Creek Sandstone and Toby Barty Sandstone Members—now assigned to Roxmere Quartzite (GSQ, 1983)
Mary Kathleen Group	AL, CL, CO, DA, DUR, KUR, MA, MK, PR, QU, SER	Derrick & others (1977a)	Quartzose, calcareous and carbonaceous metasediments	Comprises Ballara Quartzite, Corella Formation, Answer Slate, Overhang Jaspilite, Chumvale Breccia, Staveley Formation, Marimo Slate, Agate Downs Siltstone, Kuridala Formation, Doherty Formations; assigned to cover sequence 2
May Downs Gneiss Member	MI	Derrick & others (1976b)	Gneiss, schist	Assigned to Mount Guide Quartzite, Haslingden Group, but may be basement
McDermott Formation	SE	Roberts & others (1963)	Dolomite, sandstone, siltstone	Part of Tawallah Group
McNamara Group	CRR, DUR, KG, LHR, MMR, MI, MOR, MY	Hutton & others (1981), Sweet (1982)	Dolomitic sandy and pelitic sedimentary rocks	Comprises Esperanza, Lady Loretta, Lawn Hill, Musselbrook, Paradise Creek and Plain Creek Formations, Riversleigh Siltstone, Shady Bore Quartzite, Termite Range Formation, Torpedo Creek Quartzite; assigned to cover sequence 3
Mick Creek Sandstone Member	MA	Derrick & others (1977a)	Feldspathic sandstone	Part of Marimo Slate, Mary Kathleen Group; now mapped as Roxmere Quartzite (GSQ, 1983)
Middle Creek Sandstone Member	CRR		Sandstone; siltstone, shale	Part of Mullera Formation, South Nicholson Group
Mingera beds		Carter & others (1961)		Now mapped as formations of McNamara Group
Mitakoodi Quartzite	CL, DUR, KUR, MA, MK, SER	Carter & others (1961), Derrick & others (1976d)	Feldspathic sandstone	Part of Malbon Group; includes Wakeful Metabasalt Member
Mitchiebo Volcanics	CRR	Sweet (1982)	Basalt/trachyte, sandstone	Part of Carrara Range Group
Moondarra Siltstone	AL, AR, DA, DUR, MMR, MK, MI, MOR, MY, PR	Bennett (1965), Derrick & others (1976c)	Siltstone, shale	Part of Mount Isa Group
Mount Albert Group	CL, CO, KUR, MA, MK, PR, QU	Derrick & others (1977c)	Sandstone, schist, dolomite	Comprises Coocerina Formation, Deighton Quartzite, Knapdale Quartzite, Lady Clayre Dolomite, Roxmere Quartzite, White Blow Formation; tentatively assigned to cover sequence 3
Mount Angelay Granite	KUR	Blake & others (1981a)	Non-foliated granite	Part of Williams Batholith
Mount Cobalt Granite	SER	Blake & others (1981a)	Biotite granite	Part of Williams Batholith

Name of unit	*Distribution*	*Reference to definition*	*General lithology*	*Remarks*
Mount Dore Granite	SER	Blake & others (1981a)	Biotite ± hornblende granite	Part of Williams Batholith; dated at ~1510 Ma (Rb-Sr)
Mount Elliott Slate Member			Carbonaceous black slate	Basal part of Kuridala Formation according to White (1957)
Mount Erle Igneous Complex	DUR	Blake & others (1981a)	Leucogranite, dolerite, hybrid rocks	Part of Wonga Batholith
Mount Guide Quartzite	AR, DA, DUR, MK, MI, PR	Carter & others (1961), Derrick & others (1976b), Blake & others (1981a)	Sandstone, greywacke	Includes Yappo Member; part of Haslingden Group
Mount Isa Group	AL, AR, DA, DUR, KG, MMR, MK, MI, MOR, MY, PR	Bennett (1965), Derrick & others (1976c)	Siltstone, shale	Comprises Warrina Park Quartzite, Moondarra Siltstone, Breakaway Shale, Native Bee Siltstone, Urquhart Shale, Spear Siltstone, Kennedy Siltstone, Magazine Shale; dated at 1670 Ma (U-Pb); assigned to cover sequence 3
Mount Isa Shale		Carter & others (1961)	Shale, siltstone	Now Mount Isa Group
Mount Les Siltstone	HC, SE	Sweet (1981)	Dolomitic siltstone, shale	Part of Fickling Group
Mount Norna Quartzite	CL, KUR	Derrick & others (1976c)	Sandstone, greywacke	Part of Soldiers Cap Group
Mount Oxide Chert Member	KG, LHR, MMR, MOR	Hutton & others (1981)	Bedded chert	Part of Paradise Creek Formation, McNamara Group
Mount Philp Agglomerate	MK	Carter & others (1961), Derrick & others (1977a)		Revised as Mount Philp Breccia; was assigned to Mary Kathleen Group
Mount Philp Breccia	DUR, (MK)	Blake & others (1981a)	Intrusive breccia	Intrudes Corella Formation
Mount Start Member	MA	Derrick & others (1976d)	Sandstone, shale	Part of Marraba Volcanics, Malbon Group
Mullera Formation	CRR, LHR, SE	Carter & others (1961)	Siltstone, shale, sandstone	Part of South Nicholson Group; includes Train Range Ironstone Member and Middle Creek Sandstone Member
Murphy Metamorphics	CRR, SE	Roberts & others (1963)	Schist, gneiss, phyllite	Part of basement
Musselbrook Formation	CRR	Sweet (1982)	Sandstone, siltstone, claystone, chert	Part of McNamara Group
Myally beds		Carter & others (1961)		Replaced by Myally Subgroup of Haslingden Group
Myally Subgroup	AL, KG, MMR, MK, MI, MOR, MY, PR	Derrick & others (1976b)	Feldspathic sandstone, siltstone	Comprises Alsace Quartzite, Bortala Formation, Whitworth Quartzite, Lochness Formation; part of Haslingden Group
Myubee Igneous Complex	DUR	Blake & others (1981a)	Granite, gabbro	Part of Wonga Batholith
Naraku Batholith	(CL, MA, QU)		Granitic rocks	Consists of Naraku Granite
Naraku Granite	CL, MA, QU	Carter & others (1961)	Foliated and non-foliated granite	Makes up Naraku Batholith; dated at ~1500 Ma (U-Pb)
Native Bee Siltstone	AL, DUR, KG, MK, MI, MOR, MY, PR	Bennett (1965), Derrick & others (1976c)	Siltstone, shale	Part of Mount Isa Group
Nicholson Granite		Carter & others (1961)		Now part of Nicholson Granite Complex
Nicholson Granite Complex	HC, SE	Sweet (1981)	Granite, granodiorite, diorite	Oldest dated phase ~1800 Ma (Rb-Sr)
Norris Granite		Roberts & others (1963)		Now part of Nicholson Granite Complex
One Tree Granite	DA	Blake & others (1981a)	Biotite granite and granodiorite	Part of Kalkadoon Batholith
Oroopo Metabasalt	AR, (DUR)	Blake & others (1981a)	Metabasalt, metasediments	Assigned to cover sequence 2
Overhang Jaspilite	DUR, KUR, MA, MK	Derrick & others (1977a)	Siltstone, chert, jaspilite	Part of Mary Kathleen Group
Overlander Granite	DUR	Blake & others (1981a)	Leucocratic granite	Part of Wonga Batholith
Paradise Creek Formation	KG, LHR, MMR, MI, MOR	Carter & others (1961), Hutton & others (1981)	Dolomite, chert, sandstone	Includes Mount Oxide Chert Member; part of McNamara Group

Name of unit	*Distribution*	*Reference to definition*	*General lithology*	*Remarks*
Peters Creek Volcanics	HC, SE	Carter & others (1961)	Basalt, rhyolite	Includes Buddawadda Basalt Member, assigned to cover sequence 3
Pickwick Metabasalt Member	AL, KG, MMR, MK, MI, MOR, PR	Derrick & others (1976b)	Metabasalt, sandstone, siltstone	Part of Eastern Creek Volcanics, Haslingden Group
Pilpah Sandstone		Carter & others (1961)		Now assigned to formations of McNamara Group
Plain Creek Formation	CRR	Sweet (1982)	Siltstone, shale, sandstone	Part of McNamara Group
Ploughed Mountain beds		Carter & others (1961)		Now assigned to formations of McNamara Group
Plum Mountain Gneiss	DA, DUR	Blake & others (1981a)	Felsic gneiss, augen gneiss	Part of basement
Police Creek Siltstone Member	PR	Derrick & others (1976b)	Siltstone, phyllite, tuff	Part of Lochness Formation, Myally Subgroup, Haslingden Group
Quamby Conglomerate	MA, QU	Carter & others (1961)	Conglomerate, greywacke	Postdates cover sequence 3
Quilalar Formation	AL, MMR, (MK), MOR, MY, PR	Derrick & others (1980)	Sandstone, siltstone, carbonate rocks	Conformable on Haslingden Group
Revenue Granite	DUR	Blake & others (1981a)	Foliated leucocratic granite	Part of Wonga Batholith
Riversleigh Siltstone	KG, LHR, MMR, MOR	Hutton & others (1981)	Siltstone, shale, dolomite	Part of McNamara Group
Roxmere Quartzite	CL, KUR, MA	Carter & others (1961)	Feldspathic and quartz sandstone	Assigned to Mount Albert Group
Saint Mungo Granite	DA	Blake & others (1981a)	Foliated to gneissic hornblende–biotite granite	Part of Wonga Batholith
Saint Ronans Metamorphics	AR	Blake & others (1981a)	Felsic and mafic meta-volcanics, schist, gneiss	Part of basement?
Saxby Granite	KUR	Blake & others (1981a)	Pink granite	Part of Williams Batholith
Seigal Volcanics	HC, SE	Sweet (1981)	Basalt	Part of Tawallah Group
Settlement Creek Volcanics	SE	Roberts & others (1963)	Basalt, siltstone, tuff	Part of Tawallah Group; includes Carolina Sandstone Member
Shady Bore Quartzite	KG, LHR, MMR, MOR	Hutton & others (1981)	Quartz sandstone, siltstone, dolomite	Part of McNamara Group
Sly Creek Sandstone	SE	Roberts & others (1963)	Quartz sandstone	Part of Tawallah Group
Soldiers Cap Formation		Carter & others (1961)		Redefined as Soldiers Cap Group
Soldiers Cap Group	CL, CO, KUR, QU, SER	Derrick & others (1976c)	Metamorphosed greywacke, siltstone, basalt	Includes Llewellyn Creek Formation, Mount Norna Quartzite, Toole Creek Volcanics; assigned to cover sequence 2
South Nicholson Group	CRR, HC, SE	Smith & Roberts (1963)	Siltstone, shale, sandstone	Comprises Constance Sandstone, Mullera Formation and Tidna Sandstone; postdates cover sequence 3
Spear Siltstone	MK, MI	Bennett (1965), Derrick & others (1976c)	Dolomitic siltstone	Part of Mount Isa Group
Squirrel Hills Granite	KUR, SER	Blake & others (1981a)	Pink porphyritic and non-porphyritic granite	Part of Williams Batholith
Stanbroke Sandstone	DA, DUR	Blake & others (1981a)	Feldspathic and calcareous sandstone	Assigned to cover sequence 2
Staveley Formation	CL, KUR, SER	Carter & others (1981), Blake & others (1981a)	Sandstone, siltstone, shale	Assigned to Mary Kathleen Group
Sulieman Gneiss	AR	Blake & others (1981a)	Felsic gneiss, quartzite, amphibolite	Part of basement?
Surprise Creek beds	MK	Carter & others (1961)		Superseded by Surprise Creek Formation
Surprise Creek Formation	AL, DUR, MMR, (MK), MOR, MY, PR	Derrick & others (1980)	Sandstone, siltstone, shale	Assigned to cover sequence 3
Sybella Batholith	(AR, DUR, KG, MI)	Blake & others (1984)	See Sybella Granite	Comprises Sybella Granite
Sybella Granite	AR, DUR, KG, MI	Carter & others (1961)	Pink foliated granite and granodiorite	Form Sybella Batholith; dated at ~1670 Ma (U–Pb)
Tawallah Group	HC, SE	Roberts & others (1963)	Sedimentary and volcanic rocks	Includes Westmoreland Conglomerate, Seigal Volcanics, McDermott Formation, Sly Creek Sandstone, Aquarium Formation, Settlement Creek Volcanics; assigned to cover sequence 3

Name of unit	*Distribution*	*Reference to definition*	*General lithology*	*Remarks*
Termite Range Formation	LHR	Hutton & others (1981)	Sandstone, siltstone, shale	Part of McNamara Group
Tewinga Group	AL, CL, CO, DA, DUR, MA, MK, MY, PR, QU, SER	Derrick & others (1976a)	Felsic and mafic volcanics and meta-volcanics	Includes Leichhardt Volcanics, Magna Lynn Metabasalt, Argylla Formation; assigned to cover sequences 1 and 2
Tidna Sandstone			Sandstone	Part of South Nicholson Group exposed in Lawn Hill 1:250 000 Sheet area (GSQ, 1983)
Timberoo Member	DUR, KUR, MA	Derrick & others (1976d)	Sandstone, siltstone, shale	Part of Marraba Volcanics, Malbon Group
Timothy Creek Sandstone Member	AR, (DUR)	Blake & others (1981a)	Quartz and feldspathic sandstone	Part of Jayah Creek Metabasalt
Toby Barty Sandstone Member	KUR, MA	Derrick & others (1977a)	Feldspathic and quartz sandstone	Remapped as Roxmere Quartzite, Mount Albert Group (GSQ, 1983); previously part of Marimo Slate, Mary Kathleen Group
Tommy Creek Microgranite	MA	Derrick & others (1978)	Microgranite	Dated at ~1600 Ma; may be mainly extrusive and part of Corella Formation, Mary Kathleen Group
Toole Creek Volcanics	CL, KUR	Derrick & others (1976c)	Metabasalt, metasediments	Part of Soldiers Cap Group
Top Rocky Rhyolite	CRR	Sweet (1982)	Porphyritic rhyolite	Part of Carrara Range Group
Torpedo Creek Quartzite	DUR, (KG), LHR, MMR, (MI), MOR, MY	Hutton & others (1981)	Sandstone, conglomerate	Part of McNamara Group
Train Range Ironstone Member			Ferruginous sandstone, ironstone, siltstone, shale	Part of Mullera Formation, South Nicholson Group, in Lawn Hill 1:250 000 Sheet area (GSQ, 1983b)
Urquhardt Shale	MK, MI, PR	Bennett (1965); Derrick & others (1976c)	Pyritic and dolomitic shale	Part of Mount Isa Group; dated at ~1670 Ma (U-Pb)
Wakeful Metabasalt Member	KUR, MA	Derrick & others (1976d)	Basalt, sandstone, siltstone, shale	Part of Mitakoodi Quartzite, Malbon Group
Walford Dolomite	HC, SE	Sweet (1981)	Stromatolitic dolomite, shale, sandstone	Part of Fickling Group
Wallis Siltstone Member	HC, SE	Roberts & others (1963)	Micaceous siltstone	Part of Constance Sandstone, South Nicholson Group
Warrina Park Quartzite	AL, AR, DA, DUR, KG, MMR, MK, MI, MOR, MY, PR	Derrick & others (1976c)	Quartz and feldspathic sandstone	Part of Mount Isa Group
Weberra Granite	MOR	Carter & others (1961)	Medium to coarse leucocratic granite	Dated at ~1700 Ma (U-Pb zircon)
Western (sedimentary) succession	AL, MK, MI, MY, PR		Sedimentary and volcanic rocks	Equivalent to cover successions of Western Fold Belt
Westmoreland Conglomerate	HC, SE	Carter & others (1961)	Conglomerate, sandstone	Part of Tawallah Group
White Blow Formation	MK	Derrick & others (1977c)	Siltstone, phyllite, schist	Assigned to Mount Albert Group
Whitworth Quartzite	AL, KG, MMR, MK, MOR, MY, PR	Derrick & others (1976b)	Feldspathic sandstone	Part of Myally Subgroup, Haslingden Group
Widdallion Sandstone Member	CRR, LHR	Sweet (1982)	Lithic and feldspathic sandstone, greywacke	Part of Lawn Hill Formation, McNamara Group
Williams Batholith	(CL, KUR, SER)	Blake & others (1984)	Non-foliated and foliated granitic rocks	Includes Blackeye, Cowie, Gin Creek, Maramungee, Mount Angelay, Mount Cobalt, Mount Dore, Saxby, Squirrel Hills, Wimberu, and Yellow Waterhole Granites
Williams Granite	CL	Carter & others (1961)		Corresponds to most granites of Williams Batholith
Wimberu Granite	DUR, KUR	Carter & others (1961)	Non-foliated granite	Part of Williams Batholith; dated at ~1500 Ma (U-Pb)

Name of unit	*Distribution*	*Reference to definition*	*General lithology*	*Remarks*
Wills Creek Granite	DA	Blake & others (1981a)	Leucocratic biotite granite	Part of Kalkadoon Batholith; minimum age 1830 Ma (Pb-Pb)
Wire Creek Sandstone	HC, SE	Sweet (1981)	Sandstone, conglomerate	Assigned to cover sequence 3
Wonga Batholith	(DA, DUR, MA, MK, PR, QU)	Blake & others (1984)	Foliated to gneissic granitic rocks	Comprises Birds Well, Bowlers Hole, Burstall, Hardway, Mairindi Creek, Saint Mungo, and Wonga Granites, Bushy Park Gneiss, and Mount Erle and Myubee Igneous Complexes
Wonga Granite	MA, MK, PR, QU	Carter & others (1961)	Foliated to gneissic granite	Part of Wonga Batholith; dated at ~1740 Ma (U-Pb)
Woonigan Granite	DUR	Blake & others (1981a)	Leucocratic biotite granite	Part of Kalkadoon Batholith
Yappo Member	AR, DA, DUR, (MK)	Blake & others (1981a)	Greywacke, conglomerate	Part of Mount Guide Quartzite, Haslingden Group
Yaringa Metamorphics	MI	Carter & others (1961)	Schist, gneiss, migmatite	Part of basement, >1900 Ma (U-Pb)
Yeldham Granite	LHR	Hutton & Sweet (1980)	Muscovite granite	Dated at ~1820 Ma (U-Pb)
Yellow Waterhole Granite	SER	Blake & others (1981a)	Non-foliated granite	Part of Williams Batholith; dated at ~1500 Ma (U-Pb)

APPENDIX 2
NAMED STRUCTURAL AND TECTONIC FEATURES OF THE MOUNT ISA INLIER AND ENVIRONS

Name of feature[1]	*Location*[2]	*Remarks*
Ardmore Outlier	AR	Fault-bounded outcrop of Georgina Basin sediments within the Western Fold Belt
Armstrong Creek Fault	MK	Trends NNW in E part of Western Fold Belt
Ballara-Corella River Fault Zone	MA	NNE-trending zone in Eastern Fold Belt
Big Mick Fault	KUR	NNE-trending fault in Eastern Fold Belt
Big Toby-Yaringa Block	(MI)	'Basement' area within Western Fold Belt; named by Plumb & Derrick (1975)
Black Hills Fault	SE	WNW-trending fault in McArthur Basin
Blockade Block	MK	Part of Kalkadoon-Leichhardt Belt
Bonus Basin	KG	Outcrop of McNamara Group within Leichhardt River Fault Trough, Western Fold Belt
Boomarra Fault	CO	N-trending fault on E side of Boomarra Horst, Eastern Fold Belt
Boomarra Horst	CO, QU	Part of Eastern Fold Belt
Boomerang Anticline	MOR, MY	Fold in Lawn Hill Platform, Western Fold Belt
Bronzewing Fault	DUR	Trends NE, displacing Cambrian sediments of Georgina Basin
Bull Creek Syncline	AL, MY	Major north-trending fold in Leichhardt River Fault Trough, Western Fold Belt
Bulonga Anticline	MA	Major NE-plunging fold in Eastern Fold Belt
Burke River Structural Belt	DA, DUR, KUR, SER	Area of Georgina Basin sediments in south of region
Calvert Fault	HC, SE	SE-trending fault cutting across McArthur Basin, Murphy Tectonic Ridge, and South Nicholson Basin
Cameron Fault	MA, MK	Cuts NE across Kalkadoon-Leichhardt Belt and Eastern Fold Belt
Canobie Depression	CO	Part of Carpentaria Basin
Carlton Fault	MMR	Trends NE across Lawn Hill Platform, Western Fold Belt
Carpentaria Basin	CO, HC, MY, QU	Mesozoic sedimentary basin on NE side of Mount Isa Inlier (Doutch, 1976)
Carters Syncline	MOR	N-trending fold in Lawn Hill Platform, Western Fold Belt
Central Australian Orogenic Province	MY	Includes Mount Isa Inlier (GSA, 1971)
Central Australian Platform cover		Includes Georgina Basin (GSA, 1971)
Cliffdale Fault	HC	Trends SE across McArthur Basin and Murphy Tectonic Ridge
Cloncurry Fault *(Overthrust)*	KUR, SER	Trends NNW in E of Eastern Fold Belt
Cloncurry-Selwyn zone		Part of Eastern Fold Belt
Conglomerate Creek Fault	(PR)	E-trending fault in Leichhardt River Fault Trough, Western Fold Belt (GSQ, 1983a)
Coolullah Fault	CO	N-trending fault on W side of Boomarra Horst, Eastern Fold Belt
Counter Block	MK	Part of Leichhardt River Fault Trough, Western Fold Belt
Crystal Creek Block	(AL, KG, MMR, PR)	Part of Leichhardt River Fault Trough, Western Fold Belt, named by Bell (1983)
Crystallena Fault	MI	NW-trending fault in Leichhardt River Fault Trough, Western Fold Belt
Dajarra Belt	(AR, DA, DUR)	Part of Western Fold Belt; name used by Blake & others (1984)
Dajarra Fault	DA	N-trending fault in Kalkadoon-Leichhardt Belt
Deighton Pass Syncline	(MK)	Fold in Kalkadoon-Leichhardt Belt (GSQ 1983a)
Duchess Belt	DUR	Comprises parts of Kalkadoon-Leichhardt Belt and Eastern Fold Belt
Duck Creek Anticline	MA	Major fold in Eastern Fold Belt
Eastern Belt	DUR	Part of Eastern Fold Belt
Eastern Fold Belt		Major tectonic zone, eastern part of Mount Isa Inlier
Eastern (Geosynclinal/Synclinorial) Basin/Belt/Geosyncline		Equivalent to Eastern Fold Belt
Eromanga Basin	CL, SER	Mesozoic sedimentary basin SE and S of Mount Isa Inlier
Ewen Block	AL, MY	Part of Western Fold Belt
Federal Graben	(MA, QU)	NNE-trending structure in Eastern Fold Belt
Fiery Creek Dome	MOR	Part of Lawn Hill Platform, Western Fold Belt
Fiery Creek Fault	MOR	Trends NE across Lawn Hill Platform, Western Fold Belt
Fish River Fault Zone	HC, SE	Trends ENE along S side of Murphy Tectonic Ridge
Fountain Range Fault	DUR, MA, MK	Trends NE across Kalkadoon-Leichhardt Belt and Eastern Fold Belt
Georgina Basin	DA, DUR	Early Palaeozoic basin to S and W of Mount Isa Inlier
Gorge Creek Fault	MK	NNE-trending fault along boundary between Western Fold Belt and Kalkadoon-Leichhardt Belt
Greens Creek Fault	MK	NW-trending fault in Kalkadoon-Leichhardt Belt
Gum Creek Fault	MK	NNW-trending fault in Leichhardt River Fault Trough, Western Fold Belt
Hampden Fault	KUR	N-trending fault at Kuridala, Eastern Fold Belt

1. Features with names in italics are not distinguished on the 1:500 000 geological map
2. 1:100 000 geological map sheets; for key to abbreviations see Table 2. Feature is shown on map sheet, but is not named, if abbreviation is in parentheses.

Name of feature	*Location*	*Remarks*
Happy Valley Fault	KUR	N to NW-trending fault in Eastern Fold Belt
Haslingden Basin	PR	Part of Leichhardt River Fault Trough, Western Fold Belt
Hero Fault	KG	N-trending fault in Leichhardt River Fault Trough, Western Fold Belt
Investigator Fault	(AL), MMR	E to NE-trending fault cutting Leichhardt River Fault Trough, Western Fold Belt
Juenburra Fault	DUR	NNE trending fault near Duchess, Eastern Fold Belt
Kalkadoon-Leichhardt Belt		Major tectonic zone of Mount Isa Inlier
Kalkadoon-Leichhardt Block/Basement/ Subprovince	AL, CO, DA, DUR, MK, MY, PR	Equivalent to most of Kalkadoon-Leichhardt Belt
Kamarga Dome	LHR	Part of Lawn Hill Platform, Western Fold Belt
Kamileroi Horst	MY	Subsurface northern extension of Kalkadoon-Leichhardt Belt
Karumba Basin	CO, HC, MY	Cainozoic sedimentary basin overlying Carpentaria Basin in NE
Lagoon Creek Fault	MK	NE-trending fault in Leichhardt River Fault Trough, Western Fold Belt
Landsborough Graben	CO, (QU)	Separates Kalkadoon-Leichhardt Belt and Eastern Fold Belt in N
Lawn Hill Platform	CRR, HC, (KG), LHR, MMR, (MI), MOR, MY, SE	Western part of Western Fold Belt; extends N and W beneath South Nicholson Basin
Leander Anticline	KG	N-trending fold in Leichhardt River Fault Trough, Western Fold Belt
Leichhardt Block		Name used by GSQ (1975) and Day & others (1983) for Kalkadoon-Leichhardt Belt
Leichhardt Fault	MI	Trends N, Western Fold Belt, Leichhardt River Fault Trough
Leichhardt River Fault Trough/Zone	AL, MMR, MOR, MY	Part of Western Fold Belt
Little Beauty Syncline	MK	N-trending fold in Kalkadoon-Leichhardt Belt
Little Range Fault	CRR	Trends ENE along S margin of Lawn Hill Platform inlier in NW
Malbon Block		Part of Quamby-Malbon zone, Eastern Fold Belt (Plumb & others, 1980; Blake & others, 1984)
Martin Creek Fault	KUR	NE-trending fault in Eastern Fold Belt
Mary Kathleen Subprovince/Fold Belt/ Shelf		Terms used by Henderson (1980) and Plumb & others (1980). Corresponds to outcrop area of cover sequence 2 and 3 in eastern part of Kalkadoon-Leichhardt Belt and in Eastern Fold Belt
Mary Kathleen Shear	(MA)	N-trending feature at Mary Kathleen uranium mine (Derrick, 1980), Eastern Fold Belt
Mary Kathleen Syncline	(MA)	N-trending fold near Mary Kathleen, Eastern Fold Belt
Mary Kathleen zone		Part of Eastern Fold Belt
May Downs Fault	KG, MI	NNW-trending fault west of Mount Isa, Western Fold Belt
McArthur Basin	HC, SE	Middle Proterozoic basin in NW
Mellish Park Syncline	MOR	NNE-trending fold in Lawn Hill Platform, Western Fold Belt
Mistake Creek Depression	MY	Corresponds to Myally Shelf of Western Fold Belt
Mitchiebo Fault	CRR	ENE-trending fault in SW of South Nicholson Basin
Moondarra Block	MK	Part of Leichhardt River Fault Trough, Western Fold Belt
Moondarra Fault	MK	SE-trending fault in Leichhardt River Fault Trough, Western Fold Belt
Mount Annable Fault	DUR	NNE-trending fault in southwest of Western Fold Belt
Mount Caroline Anticline	LHR	NE-trending fold in Lawn Hill Platform, Western Fold Belt
Mount Devine Fault System	MK	N to NNW-trending faults in Kalkadoon-Leichhardt Belt
Mount Fox Outlier	AL	NNW-trending offshoot from Myally Shelf into Ewen Block, Western Fold Belt
Mount Gordon Arch	MMR	Basement high in Leichhardt River Fault Trough, Western Fold Belt
Mount Gordon Fault (*Zone*)	KG, MMR, MOR, MY	Trends NNE along E boundary of Lawn Hill Platform, Western Fold Belt
Mount Isa Block	MK	Part of Leichhardt River Fault Trough, Western Fold Belt
Mount Isa-Cloncurry Province		Alternative name for Mount Isa Inlier (Henderson, 1980)
Mount Isa Fault (Zone)	KG, MI	N-trending fault in Leichhardt River Fault Zone, Western Fold Belt
Mount Isa Geosyncline		Mount Isa Inlier E of Mount Gordon Fault Zone (GSA, 1971)
Mount Isa Inlier		Major Proterozoic province
Mount Isa Orogen/Orogenic Domain	MOR	Corresponds to Mount Isa Inlier, apart from Lawn Hill Platform (GSA, 1971)
Mount Isa Subprovince		Alternative name for Western Fold Belt (Henderson, 1980)
Mount Isa Trough	AL, MMR, PR	Equivalent to part of Leichhardt River Fault Trough of this Bulletin
Mount MacArthur Block	MK	Part of Leichhardt River Fault Trough, Western Fold Belt
Mount Novit Fault	MI	N-trending fault in Leichhardt River Fault Trough, Western Fold Belt
Mount Remarkable Fault	PR	Trends NE across Kalkadoon-Leichhardt Belt and Eastern Fold Belt
Mount Rosebee Fault	QU	Forms part of W boundary of Quamby-Malbon zone, Eastern Fold Belt
Murphy Inlier	HC, SE	Alternative name for Murphy Tectonic Ridge
Myally Shelf		Part of Western Fold Belt
Murphy Tectonic Ridge		Major tectonic unit NW of Mount Inlier (GSA, 1971)
Nicholson Orogenic Domain		Corresponds to Murphy Tectonic Ridge (GSA, 1971)
North Australian Orogenic Province		Includes Murphy Tectonic Ridge but not Mount Isa Inlier (GSA, 1971)

Name of feature	*Location*	*Remarks*
North Australian Platform Cover	MY	Includes Lawn Hill Platform and South Nicholson Basin (GSA, 1971)
Northern Territory Shelf		Part of Phanerozoic Trans Australian Platform Cover in NW of region (GSA, 1971)
North Stone Age Fault	MK	NW-trending fault in Leichhardt River Fault Trough, Western Fold Belt
Northwest Queensland Province		Comprises Proterozoic outcrops of NW Queensland (e.g., Plumb & Derrick, 1975)
Conoomurra Syncline	CL	E-trending fold in Eastern Fold Belt
Overlander Fault	DUR	NE-trending fault in W of Eastern Fold Belt
Painted Rocks Fault	MK	NW-trending fault in Leichhardt River Fault Trough, Western Fold Belt
Parker Anticline	MY	NNE-trending fold in Lawn Hill Platform, Western Fold Belt
Paroo Fault	(PR)	NNE-trending fault in Leichhardt River Fault Trough, Western Fold Belt
Pilgrim Fault Zone	DA, DUR	Forms boundary between Mary Kathleen and Quamby-Malbon zones in S part of Eastern Fold Belt
Pinnacle Fault	CO, (QU)	N-trending fault in Eastern Fold Belt
Ploughed Mountain Anticline	LHR	NE-trending fold in Lawn Hill Platform, NE Western Fold Belt
Plum Mountain Fault	DA, DUR	NW-trending fault cutting Kalkadoon-Leichhardt Belt and Eastern Fold Belt
Police Creek Fault	MK	NW-trending fault in Leichhardt River Fault Trough, Western Fold Belt
Pumkin Gully Syncline	CL	NW to N-trending fault in E of Eastern Fold Belt
Quamby-Malbon zone		Part of Eastern Fold Belt
Quartpot Fault	DUR	NNE-trending fault in Kalkadoon-Leichhardt Belt
Quilalar Arch	AL	Eastern margin of Ewen Block, Western Fold Belt
Quilalar-Corella Shelf	AL, MMR, PR	Covers Ewen Block, Myally Shelf, and Kalkadoon-Leichhardt Belt
Quilalar Fault	PR	N-trending fault in Leichhardt River Fault Trough, Western Fold Belt
Railway Fault	DUR	NE-trending fault near Duchess, Eastern Fold Belt
Railway Fault	MK	NW-trending fault in Leichhardt River Fault Trough, Western Fold Belt
Reedie Creek Fault	MMR	NE-trending fault in Lawn Hill Platform, Western Fold Belt
Rosebud Syncline	MK	N-trending fold in Kalkadoon-Leichhardt Belt
Rufus Fault Zone	AR, (DUR)	NE to N-trending fault in SW of Western Fold Belt
Russell Creek Fault	MMR	N-trending fault in Lawn Hill Platform, Western Fold Belt
Saint Andrews Fault	DUR	NNE-trending fault in W of Eastern Fold Belt
Saint Paul Fault	AL	Trends NNE along W edge of Kalkadoon-Leichhardt Belt
Sandy Creek Dome	MOR	Part of Lawn Hill Platform, Western Fold Belt
Smiths Fault	KG	NNW-trending fault in Leichhardt River Fault Trough, Western Fold Belt
Spillway Fault	MK	NW-trending fault in Leichhardt River Fault Trough, Western Fold Belt
South Nicholson Basin	CRR, HC, SE	Major tectonic unit NW of Mount Isa Inlier
Spring Creek Fault	MI	NW-trending fault in Leichhardt River Fault Trough in Western Fold Belt
Squirrel Hills Belt	(DA, DUR)	Corresponds to S part of Cloncurry-Selwyn Zone, Eastern Fold Belt (Blake & others, 1984)
Straight Eight Fault	KUR	NNW-trending fault in Eastern Fold Belt
Staveley Belt	(DA, DUR)	Corresponds to part of Quamby-Malbon zone, Eastern Fold Belt (Blake & others, 1984)
Tectonic welt		Term used by Carter & others (1961) for 'basement high' separating Western and Eastern Successions
Termite Range Fault	LHR, MOR	NW-trending fault cutting Lawn Hill Platform, Western Fold Belt
Tewinga Platform	PR	Corresponds to Kalkadoon-Leichhardt Belt
Theresa Syncline	MOR	S-plunging fold on E margin of Lawn Hill Platform, Western Fold Belt
Tin Hole Hinge Line	SE	Part of N margin of Murphy Tectonic Ridge
Trans-Australian Platform Cover		Incorporates Mesozoic Carpentaria and Eromanga Basins (GSA, 1971)
Transmitter Fault	MI	NW-trending fault in Leichhardt River Fault Trough, Western Fold Belt
Trey Bit Fault	MK	NNE-trending fault in Kalkadoon-Leichhardt Belt
Twenty-mile Fault Zone	KG	NNW-trending feature in Leichhardt River Fault Trough, Western Fold Belt
Valparaisa Fault	MOR	N-trending fault in Lawn Hill Platform, Western Fold Belt
Valparaisa Syncline	MOR	N-trending fold in Lawn Hill Platform, Western Fold Belt
Waggaboonyah Syncline	KG	N-trending fold in Leichhardt River Fold Trough, Western Fold Belt
Wakeful Syncline	MA	NE-trending fold in Quamby-Malbon zone, Eastern Fold Belt
Weatherly Creek-Toole Creek Syncline	CL	N to WNW-trending fold in E of Eastern Fold Belt
Wearyan Shelf	(HC, SE)	Southern part of McArthur Basin
Weberra Fault	MOR	NE-trending fault in Lawn Hill Platform, Western Fold Belt
Western Border Fault	MMR	N-trending fault in Lawn Hill Platform, Western Fold Belt
Western Fault	KG	NNE-trending fault in Leichhardt River Fault Trough, Western Fold Belt
Western Fold Belt		Major tectonic zone forming western part of Mount Isa Inlier
Western (Geosynclinal/Synclinorial) Basin/Belt/Geosyncline		Equivalent to Western Fold Belt of this Bulletin
White Wings Belt	AL	Corresponds to Myally Shelf, Western Fold Belt

Name of feature	*Location*	*Remarks*
Wonga Belt	(MA)	Highly deformed zone on E margin of Kalkadoon-Leichhardt Belt (Derrick, 1980)
Wonga Fault	MK, MA	NE-trending fault cutting across Kalkadoon-Leichhardt Belt and Eastern Fold Belt
Wonomo Fault	AR, (DUR)	NNW-trending fault in S of Leichhardt River Fault Trough, Western Fold Belt
Yappo Fault	DUR	NE-trending fault cutting across Leichhardt River Fault Trough (Western Fold Belt) and Kalkadoon-Leichhardt Belt

APPENDIX 3
DEFINITION OF NEW STRATIGRAPHIC UNIT—KURBAYIA MIGMATITE

NAME OF UNIT: *Kurbayia Migmatite* (new name)

PROPOSER: D. H. Blake

RESERVED IN REGISTER OF PROPOSED NAMES: May 1985

DERIVATION OF NAME: Kurbayia siding, on the Duchess-Mount Isa railway at GR 580703, DUCHESS REGION.

DISTRIBUTION: Crops out in belt 90 km long and up to 10 km wide on west side of the Kalkadoon-Leichhardt Belt, Mount Isa Inlier, extending north from McPhee Creek in DUCHESS REGION to 16 km north of the Barkly Highway in MARY KATHLEEN (Duchess and Cloncurry 1:250 000 Sheets).

TYPE SECTION: In DUCHESS REGION, from east side of rocky ridge 2 km southeast of O'Briens Tank, at latitude 21°14'08"S, longitude 139°37'54"E, GR 586510, west-northwest for 7.5 km, to east side of ridge at GR 518540, where the unit is seen to be overlain unconformably by metasediments and metavolcanics of the Bottletree Formation. Along this line, and within 1 km to either side, the main rock types of the Kurbayia Migmatite—tightly folded, thinly banded migmatitic gneiss (metasediments) and massive migmatitic gneiss (metavolcanics)—are well exposed on low ridges, undulating terrain, and rock pavements in creek beds. They are seen to be intruded by pale grey medium-grained granite, various phases of Kalkadoon Granite (dark grey tonalite, porphyritic granodiorite, even-grained granite, and leucogranite), felsic porphyry of Bottletree type, and numerous dykes of metadolerite.

LITHOLOGY: Thinly banded, pale to dark grey, medium-grained, micaceous quartzofeldspathic gneiss with fine to coarse leucosomes, representing metasediments and commonly showing complex tight folding; subordinate grey, massive, fine-grained, crenulated gneiss with wispy leucosomes, representing dacitic metavolcanics; minor gneissic amphibolite veined by leucogranite.

THICKNESS: Not known because of structural complexities and concealed base.

RELATIONSHIPS: The Kurbayia Migmatite is overlain unconformably by the Bottletree Formation (age 1790 Ma) to the west and is faulted against felsic metavolcanics of the Leichhardt Volcanics (age 1860–1875 Ma) to the east; it is intruded by Kalkadoon Granite (age ~1860 Ma), metadolerite, and felsic dykes of Bottletree type.

AGE: Probably early Proterozoic (pre-1900 Ma): zircon (metamorphic?) from migmatitic metadacite in the type section (at GR 585510) has been dated at 1866±5 Ma (Page, 1983) and 1850±16 Ma (Blake & Page, in preparation).

SYNONYMY: Included as part of the undivided Tewinga Group in DUCHESS REGION (Bultitude & others, 1982) and as part of the Leichhardt Metamorphics in MARY KATHLEEN (Derrick & others, 1977c).

REMARKS: Before being intruded by Kalkadoon Granite at about 1860 Ma, the protoliths of the Kurbayia Migmatite were buried, regionally metamorphosed to amphibolite facies, and partially melted to form migmatite. Hence, they are significantly older than the Kalkadoon Granite, and could be correlatives of the Yaringa Metamorphics to the west, which are older than 1900 Ma. The Kurbayia Migmatite was regionally metamorphosed again to upper greenschist and amphibolite facies when the Leichhardt Volcanics, Kalkadoon Granite, and the Bottletree Formation were first metamorphosed and deformed on a regional scale, 1620–1550 Ma ago.

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GEOLOGY OF THE MOUNT ISA INLIER AND ENVIRONS

QUEENSLAND AND NORTHERN TERRITORY

by D.H. Blake

1987

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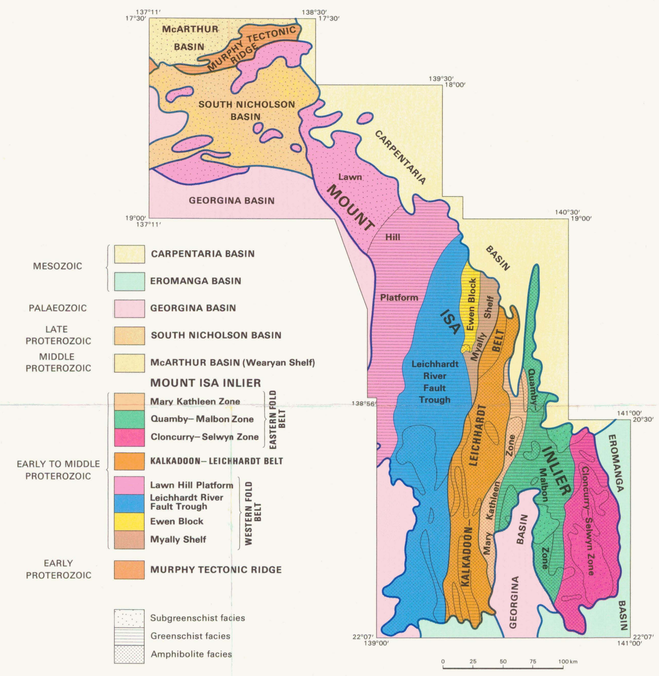
TRANSVERSE MERCATOR PROJECTION

TECTONIC FRAMEWORK AND REGIONAL METAMORPHISM



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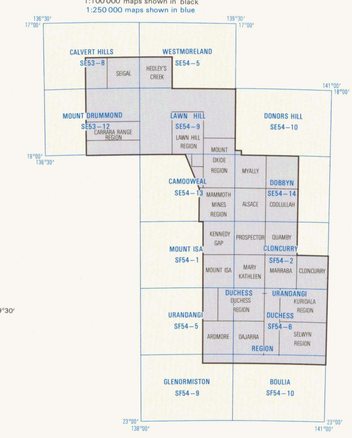

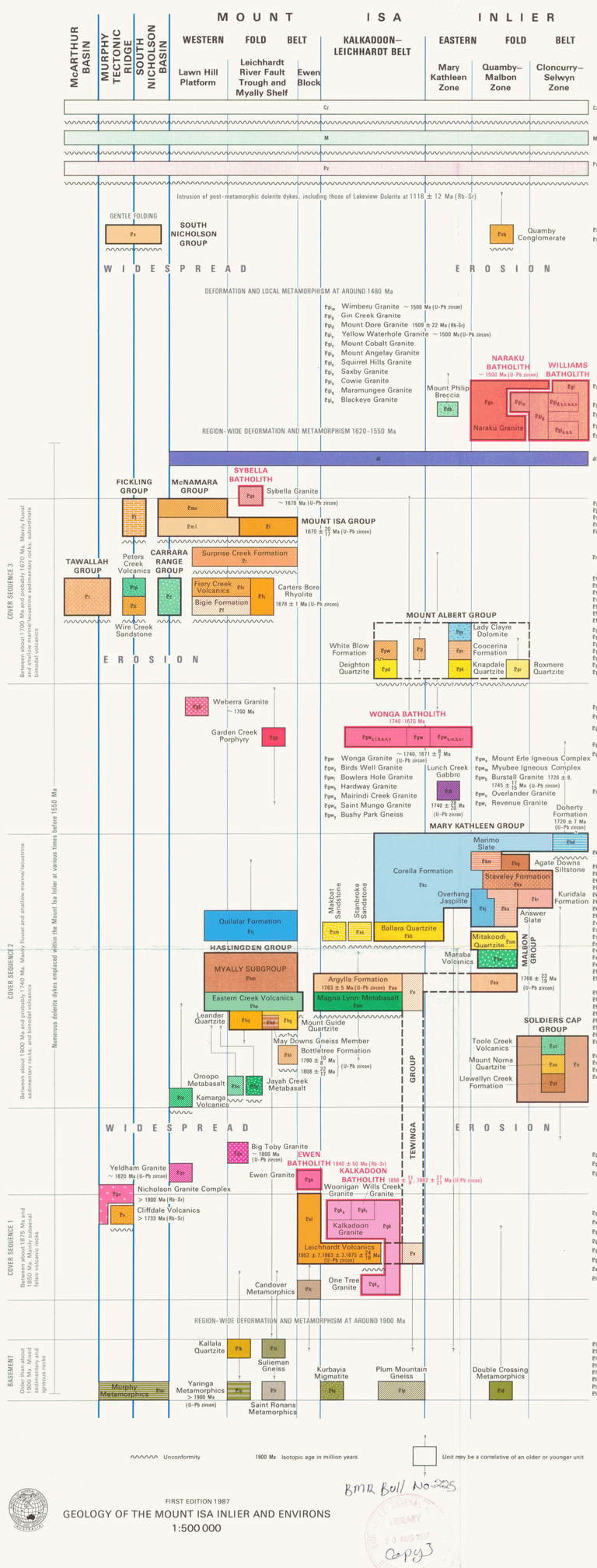

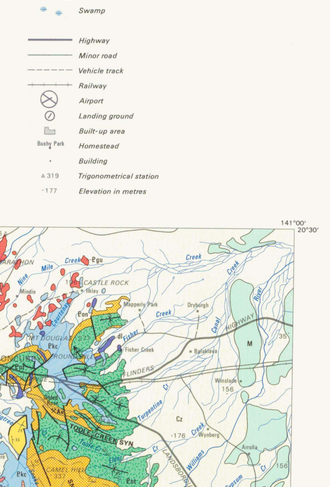

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