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BMR Bulletin
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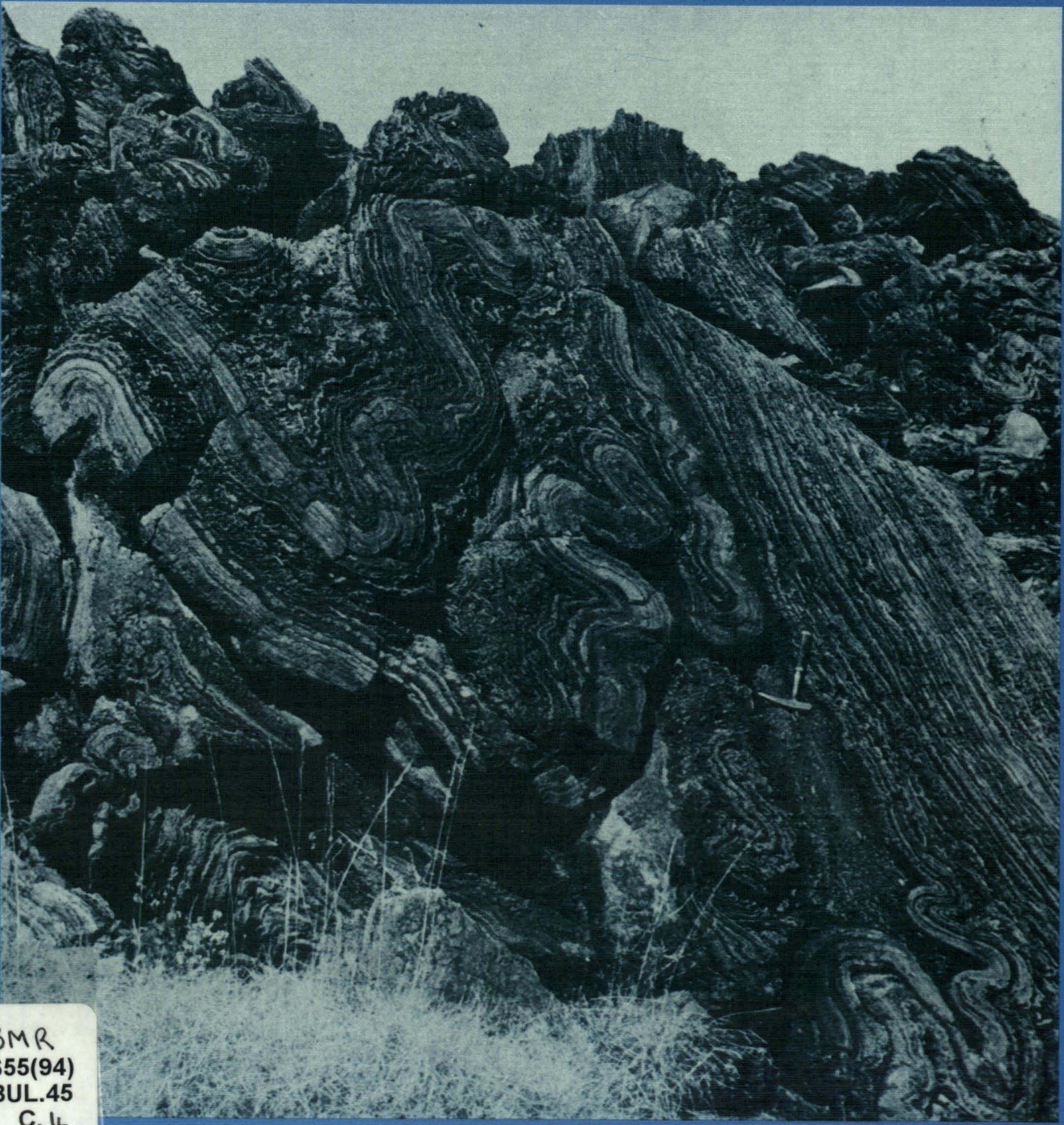

DEPARTMENT OF RESOURCES & ENERGY
BUREAU OF MINERAL RESOURCES, GEOLOGY
AND GEOPHYSICS

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Geology of the Duchess–Urandangi region, Mount Isa Inlier, Queensland

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Cover: Disharmonic folding of bedded calc-silicate rocks in the Corella Formation 7 km west of Duchess (M2633/4)

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ABSTRACT

The Duchess–Urandangi region covers the southern part of the Precambrian Mount Isa Inlier and small parts of the early Palaeozoic Georgina and Mesozoic Eromanga Basins.

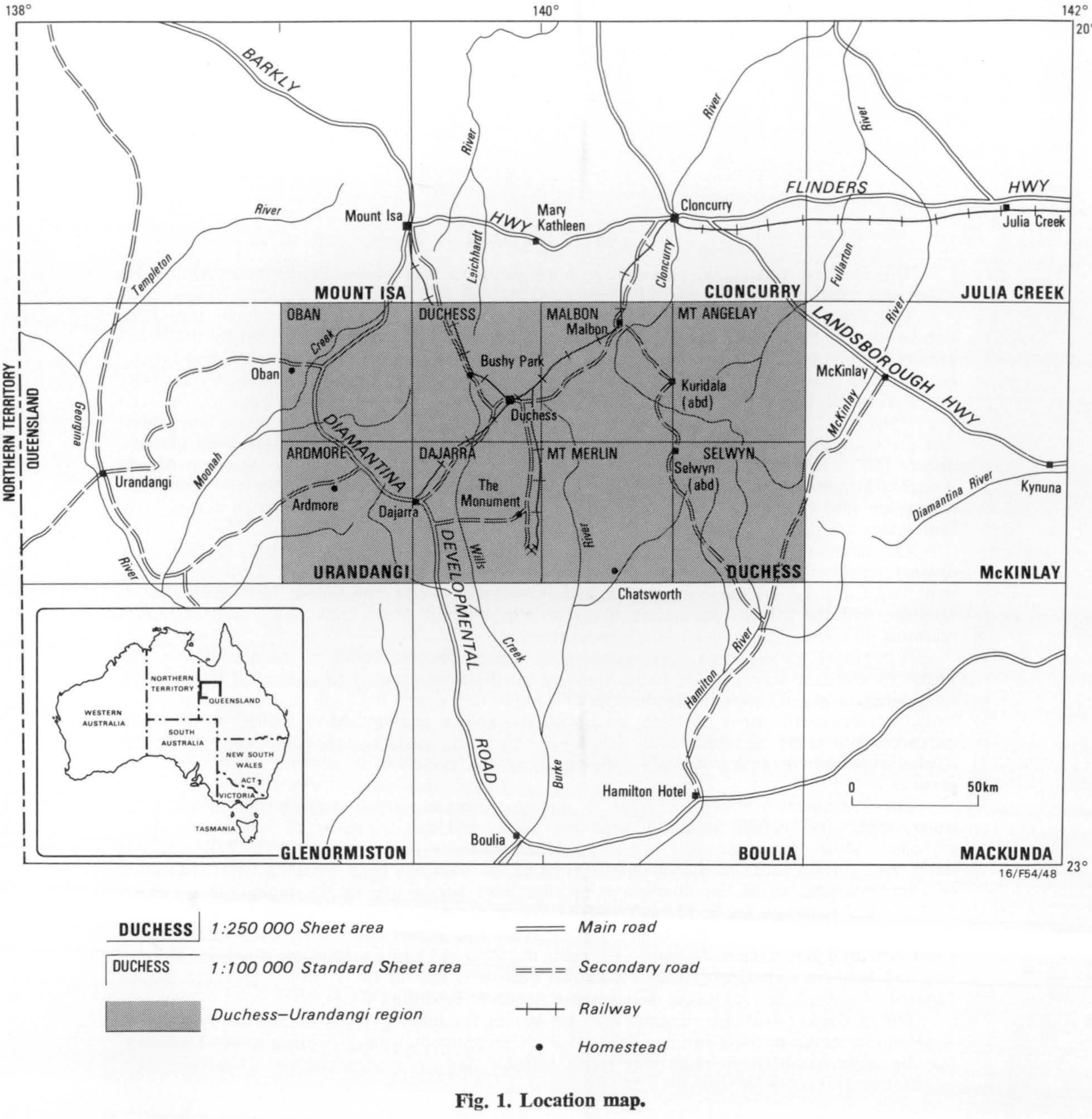
The Precambrian is represented by sedimentary rocks and volcanics which have been tightly folded about mainly northerly trending axes, extensively faulted, intruded by numerous granite plutons and mafic bodies, and regionally metamorphosed to the greenschist and amphibolite facies. Basement rocks, older than 1850 m.y., are overlain unconformably by an older cover sequence, between about 1810 and 1700 m.y. old, and a younger cover sequence, between about 1680 and 1600 m.y. old. The cover sequences were laid down mainly in shallow water, and are many thousands of metres thick. They were last deformed on a major scale between about 1600 and 1550 m.y. Two major north-trending fault zones, the Wonomo/Mount Annable/Mount Isa fault system in the west and the Pilgrim Fault Zone in the east, subdivide the region into three parts—the western, central, and eastern areas. Correlations across these fault zones are generally uncertain.

The igneous rocks are markedly bimodal; rocks of andesitic composition are rare. Five distinct geochemical suites of felsic volcanics are recognised; at least two of them are comagmatic with granite. Of the four granite batholiths present, one, the oldest, has I-type characteristics, and the others are mainly uranium-rich A-types. Most mafic lavas and intrusives resemble continental tholeiites in their geochemistry.

A regional gravity high corresponding to the Mount Isa Inlier is characterised in the region by elongate Bouguer anomalies trending north-south, parallel to geological trends; relative highs are mainly over metasediments and mafic rocks, and lows are mainly over granites. Broad aeromagnetic zones correlate well with the known geology. Most mafic volcanics and intrusives and some metasediments, felsic volcanics, and granites are significantly magnetic. Regional radiometrics are strongly influenced by the presence or absence of uranium-rich granites.

The Precambrian rocks are hosts to numerous, mainly small deposits of copper, gold, silver, lead, zinc, cobalt, tungsten, uranium, silica, and calcite, many of which have been exploited. Most copper deposits are localised along shear zones, especially in carbonaceous slates, calc-silicate rocks, and metabasalt. Most of the gold has been obtained as a by-product of copper-mining, as at the Duchess mine, the most productive in the region, from which 27 717 t Cu (average grade 12.3%) and 69 474 g Au were produced between 1906 and its closure in 1920. Silver ore has been obtained from two mines and cobalt from one. Several stratiform lead-zinc-copper deposits, at present uneconomic, occur within the Kuridala Formation and Soldiers Cap Group; the best known deposit is that at the Pegmont prospect. Major deposits of phosphate rock occur within the Palaeozoic Georgina Basin.

The geological evidence suggests that the Mount Isa Inlier evolved during the Proterozoic in an intracratonic tectonic setting, rather than at a continental margin. Since about 1500 m.y. ago the inlier has been an essentially stable tectonic unit.



DUCHESS	*1:250 000 Sheet area*
DUCHESS	*1:100 000 Standard Sheet area*
(shaded)	*Duchess–Urandangi region*
	Main road
	Secondary road
	Railway
•	*Homestead*

Fig. 1. Location map.

INTRODUCTION

The Duchess–Urandangi region, comprising the Duchess 1:250 000 Sheet area and the eastern part of the adjoining Urandangi 1:250 000 Sheet area, is bounded by latitudes 21 and 22°S, and longitudes 139 and 141°E (Fig. 1). It includes the southern part of the Precambrian Mount Isa Inlier (except for some small outcrops which extend south into the Boulia and Glenormiston 1:250 000 Sheet areas), part of the early Palaeozoic Georgina Basin (mainly the Burke River Structural Belt), and a small part of the Mesozoic Eromanga Basin. The Mount Isa Inlier is formed of metamorphosed sedimentary, volcanic and intrusive rocks, and the two basins consist of unmetamorphosed sedimentary rocks.

The Precambrian rocks in the region were mapped between 1975 and 1980 as part of a joint Bureau of Mineral Resources (BMR) and Geological Survey of Queensland (GSQ) project to update the results of the BMR/GSQ reconnaissance survey of the 1950s (Noakes, Carter, & Öpik, 1959; Carter, Brooks, & Walker, 1961; Carter & Öpik, 1963). Colour aerial photographs of about 1:25 000 scale were used for mapping and airphoto-interpretation. More detailed results of the mapping are reported in map commentaries for the following 1:100 000-scale geological maps (Fig. 2): ARDMORE* (Bultitude, 1982), DAJARRA (Blake & others, 1982a), DUCHESS REGION (Bultitude & others, 1982), SELWYN REGION (Blake & others, 1983a), and KURIDALA REGION (Donchak & others, 1983); and also in preliminary data records (Blake & others, 1978, 1979; Mock, 1978; Bultitude & others, 1978; Noon, 1978, 1979; Donchak & others, 1979; Bultitude, 1980). New and revised Precambrian stratigraphic and intrusive rock units in the region are defined by Blake & others (1981a); their definitions are summarised by Blake & others (1981b).

The main population centres in the region (Fig. 1) are the townships of Dajarra (population about 170 in 1980), Duchess (population about 30 in 1980), Malbon (population about 20 in 1980), and The Monument, which was built in the mid-1970s as a company town to serve the nearby phosphate mine at Phosphate Hill. The Monument had a population of about 150 in 1977, but became largely deserted following the suspension of mining in 1978. The only other permanent settlements in the region are station homesteads.

Access to and within the region is generally good (Fig. 1). The bitumen-sealed Diamantina Developmental Road from Mount Isa to Boulia crosses the western part of the region via Dajarra. Regularly maintained formed gravel roads branch from this road north of Ardmore homestead to Urandangi, and south of Dajarra to The Monument. Similar gravel roads link Duchess to Mount Isa, to the sealed Barkly Highway near Cloncurry (via Malbon), and to Dajarra. The partly sealed Landsborough Highway crosses the northeastern corner of the region, and the unsealed but regularly maintained McKinlay to Boulia road crosses the southeastern part. Other unsealed roads connect the former township of Selwyn with Malbon (via the former township of Kuridala) to the north, Boulia to the southwest, and Hamilton Hotel to the south. Duchess and Malbon are on the Townsville to Mount Isa railway; Dajarra is the terminus of a branch line from Duchess; and another branch line connects the Phosphate Hill mine near The Monument with the Townsville to Mount Isa railway east of Duchess. Numerous vehicle tracks in variable states of upkeep provide access to other parts of the region. Many of the roads and tracks become impassable after heavy rain. The townships and most homesteads have landing grounds suitable for light aircraft. The region is served by the Royal Flying Doctor Service based at Mount Isa.

The main local industry is cattle-raising on unimproved natural pastures. Mining has been important in the past, but most of the many mainly small mines in the region are now abandoned. The Precambrian outcrops are prospective for copper, gold, silver, lead, zinc, cobalt, uranium, and tungsten, and also for silica flux and marble (limestone), which are used in smelting operations at Mount Isa. Major deposits of rock phosphate occur within the Cambrian of the Georgina Basin sedimentary succession. Several mineral exploration companies are prospecting in the region.

Climate (based mainly on Slatyer, 1964; Bureau of Meteorology, 1975, 1977)

The region is semi-arid and has a tropical monsoonal climate with a short wet 'summer' season characterised by hot days, and a long dry mild 'winter', characterised by southeast winds. At Cloncurry, to the north, average daily temperatures range from about 10°C minimum and 24°C maximum during July, up to 24°C minimum and 38°C maximum during November, December, and January. Diurnal variations in temperature are marked, particularly in the 'winter' months, when night-time temperatures commonly fall below freezing-point. The average annual rainfall is about 380 mm, and tends to decrease from northeast to southwest. However, rainfall is variable, ranging from more than 500 mm in some years to less than 200 mm in others; droughts are not uncommon. Most rain falls between November and March, but heavy rains have occasionally been recorded in the 'winter' months (for example, 91 mm of rain fell at Dajarra between 2 and 10 July 1978, including 66 mm on 10 July). Relative humidity ranges from about 15 percent in 'winter' to 50 percent in 'summer'; annual evaporation greatly exceeds rainfall.

Vegetation (based mainly on Perry & Lazarides, 1964; Horton, 1976)

Most of the region supports a vegetation of spinifex (*Triodia* spp.), kerosene grasses (*Aristida* spp.), a diverse array of shrubs (generally dominated by *Acacia* spp. and *Cassia* spp.), and scattered trees (mainly *Eucalyptus* spp.). Some of the more common trees are snappy gum (*E. brevifolia*), western box (*E. argillacea*), bloodwood (*E. terminalis*), ghost gum (*E. papuana*), and silver-leaf box (*E. pruinosa*). Scattered, small dense stands of gidgee (*Acacia georginae* and *A. cambagei*) are common in places. Dense, in places almost impenetrable, stands of 'turpentine' bush—mainly *A. lysiphloia* and *A. chisholmii*—are locally extensive, especially on soils derived from calcareous metasediments. Grasslands, in which Mitchell (*Astrebla* spp.) and Flinders (*Iseilema* spp.) grasses predominate, cover most of the extensive cracking

* Names of 1:100 000-scale geological maps are printed in capital letters.

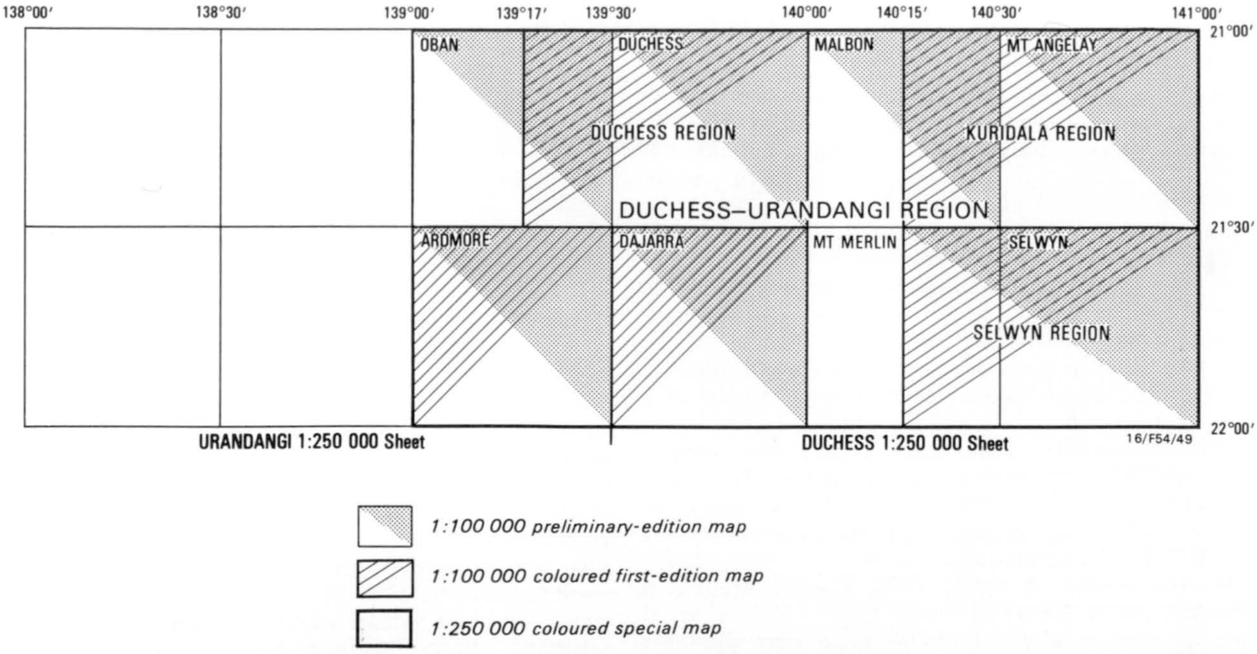


Fig. 2. Key to 1:100 000 and 1:250 000 geological maps.

clay-soil plains formed on the lower Palaeozoic rocks of the Georgina Basin succession in the western and central parts of the region, and on Mesozoic rocks of the Eromanga Basin succession in the east.

Topography and geomorphology

The region has a maximum elevation of about 550 m above sea level near Mount Guide in the northwest and a minimum of about 235 m on the alluvial plain of the Hamilton River in the southeast. Local relief is generally less than 100 m. A low divide separating the catchment of the southerly flowing Georgina–Diamantina drainage system from the northerly flowing Leichhardt–Flinders drainage system trends northwest across the region north of Duchess (Fig. 3); in the southeast, the Selwyn Range—formed of plateaus, mesas, buttes, and rocky ridges—is part of this divide.

The geomorphology of the terrain west of 139°30′E has been described by Stewart (1954) and that to the east by Twidale (1964, 1966). The geomorphological divisions generally applied to the region are those of Twidale (1964, 1966) and these are shown in Figure 3. The Isa Highlands and the Carpentaria and Inland Plains of Twidale correspond to the Erosional Land Surface and Depositional Land Surface subdivisions, respectively, of Stewart (1954).

The Precambrian metasediments exposed in the region are generally more resistant to erosion than the igneous rocks. Metamorphosed sandstones (mainly quartz arenite) typically form prominent north-trending strike-ridges with pale airphoto tones, separated by valleys developed in less resistant rocks. Vein quartz forms narrow steep-sided ridges, commonly along fault lines. Calc-silicate rocks, especially where they are metamorphosed to amphibolite facies, give rise to rugged hilly terrain that has moderately dark airphoto tones (Fig. 4).

Mafic igneous rocks generally form flat to gently undulating terrain, and typically have smooth dark airphoto tones; hence they can be readily distinguished from most other rock types on aerial photographs. Mafic dykes are mostly less resistant to erosion than the rocks they intrude, and tend to form depressions. Felsic volcanic rocks are less recessive, and mainly form low hills and tors (Figs. 5, 6) which have medium to pale airphoto tones.

Granitic rocks—granite, granodiorite, tonalite, diorite, and quartzofeldspathic gneiss—are exposed as steep-sided hills and mesas (especially in the east) capped by much weathered granite, laterite, or flat-lying Mesozoic and Cambrian rocks (e.g., Fig. 65); as tors and boulder-covered hills; and as undulating terrain and plains largely covered by granitic soil and rubble but commonly with some partly exposed large rounded boulders. Outcrop areas generally have pale airphoto tones, except where ironstained laterite cappings are present, and dendritic drainage patterns. Boulders of non-foliated granitic rocks and felsic volcanics are typically spheroidal, whereas those of foliated rocks are ellipsoidal.

The lower Palaeozoic rocks in the western and central parts of the region form broad treeless plains except locally near the Pilgrim Fault Zone, where they are uplifted and tilted to form mesas and cuestas. Flat cappings of Mesozoic sedimentary rocks, and also of laterite and deeply weathered Precambrian bedrock, are widespread, but are most extensively preserved in the Selwyn Range in the southeast. Broad alluvial plains and gently undulating terrain with some low ridges are present in the far east and far west of the region.

The crests of many of the ridges are planated surfaces representing remnants of a former peneplain (Carter & others, 1961; Twidale, 1964). Widespread remnant cappings of Mesozoic rocks and weathered Precambrian rocks provide further evidence of planation, which probably took place during the late Proterozoic, late Palaeozoic to early Mesozoic, and early Tertiary.

Previous investigations

The Duchess–Urandangi region was first mapped systematically during the reconnaissance survey of the

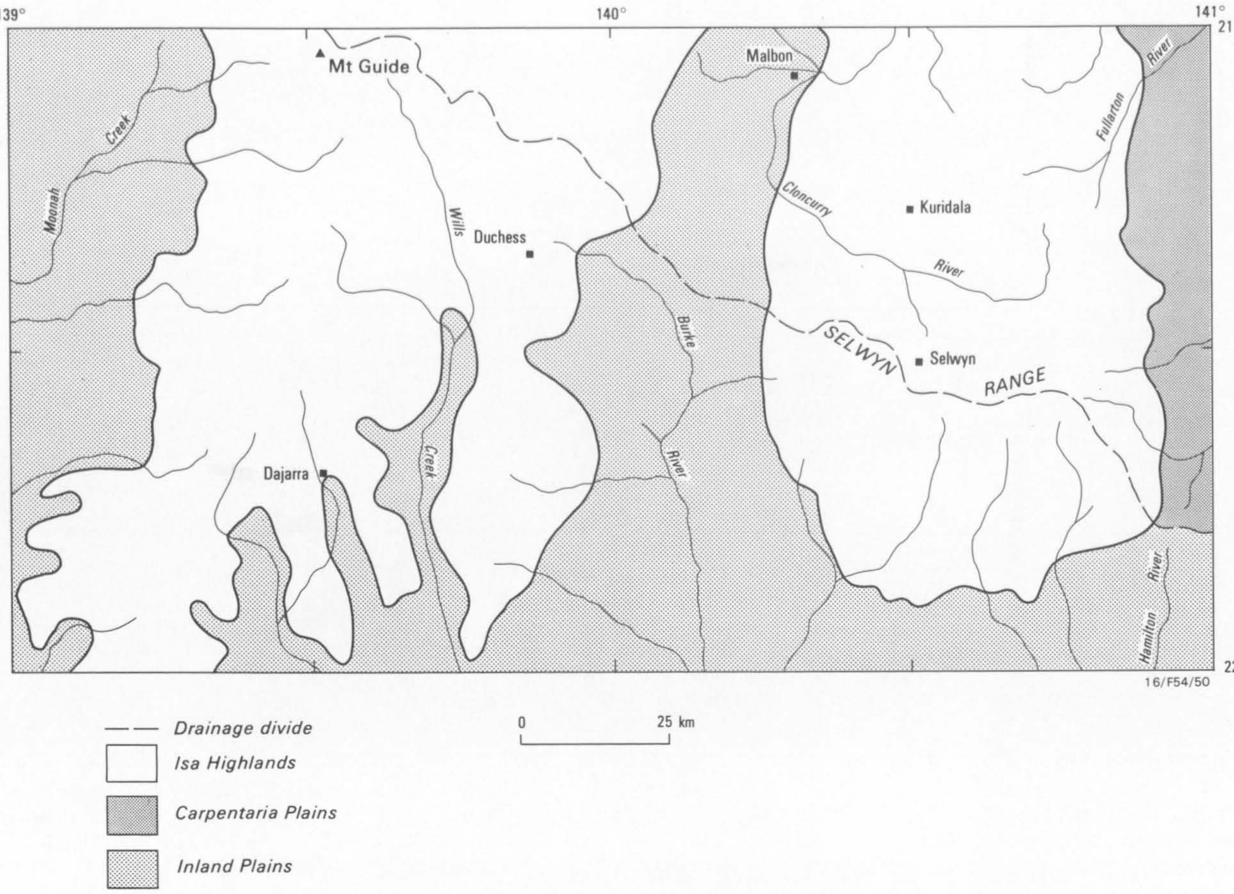


Fig. 3. Geomorphological divisions.

Mount Isa Inlier by joint BMR and GSQ field parties in the 1950s. The results of this work have been reported by Carter & others (1961), who gave an account of the geology of the whole Mount Isa Inlier, and by Noakes & others (1959) and Carter & Öpik (1963), who described the geology of the Urandangi and Duchess 4-mile (1:253 440) Sheet areas respectively. The early history of the region and previous geological work were reviewed in these publications; the early history of the Duchess area is also summarised by Bultitude & others (1978). A detailed report on the geology of an area near Selwyn was written by White (1957). Syvret (1966), Krosch & Sawers (1974), and Brooks (1977, 1979b) have described several of the small mines, and mining company activity in the region has been summarised by Noon (1976, 1977). Löcsei (1977) and Stanton & Vaughan (1979) have given accounts of the Pegmont prospect southeast of Selwyn; descriptions of this and some other prospects in the eastern part of the region have also been given by Nisbet & Joyce (1980), Orridge (1980), and Stanton (1982).

The Late Proterozoic to Ordovician succession in the Burke River Structural Belt (part of the Georgina Basin) in the central part of the Duchess–Urandangi region, and the Cambrian rocks of the Georgina Basin succession in the west, have been described by de Keyser (1968, 1972, 1973), de Keyser & Cook (1972), and Shergold & Druce (1980). The discovery of rock phosphate in Cambrian strata near The Monument and at other localities in the region has been described by, amongst others, Russell (1967), Thomson & Russell (1971), Russell & Trueman (1971), and Cook & Shergold (1979). An account of the Mesozoic rocks of the Eromanga Basin, exposed mainly in the far southeast, is given by Senior & others (1978).

Definitions of terms

Most of the terms used are defined in the AGI Glossary of Geology (2nd Edition; Bates & Jackson, 1980). Sandstones are classified according to Pettijohn & others (1972); grainsize definitions are as follows: fine, 0.125 to 0.25 mm; medium, 0.25 to 0.5 mm; coarse, 0.5 to 1 mm. The term 'quartzite' is used in a dual sense (Bates & Jackson, 1980) to describe a

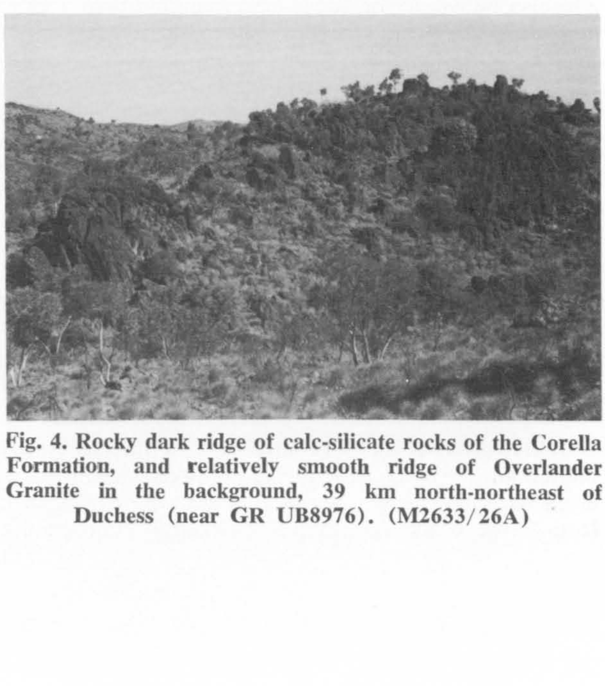


Fig. 4. Rocky dark ridge of calc-silicate rocks of the Corella Formation, and relatively smooth ridge of Overlander Granite in the background, 39 km north-northeast of Duchess (near GR UB8976). (M2633/26A)

Fig. 5. Low hilly terrain developed on sheared felsic rocks of the Leichhardt Volcanics 28 km northwest of Duchess (at GR UB623584). (M2633/7).

hard but little-metamorphosed arenite which has been diagenetically cemented by silica, and a siliceous granoblastic rock produced by regional or contact metamorphism; all gradations exist between the two types. Bedding thickness terms are: laminated, less than 1 cm; thin-bedded, 1 to 50 cm; medium-bedded, 50 cm to 2 m; thick-bedded, more than 2 m. The nomenclature for plutonic igneous rocks follows that of Streckeisen & others (1973). Grainsizes for igneous, and also metamorphic rocks are: fine, less than 1 mm; medium, 1 to 5 mm; coarse, 5 mm to 3 cm; very coarse, pegmatitic, more than 3 cm. Terms describing metamorphic facies are as defined by Turner & Verhoogen (1960). The term 'granofels' (Goldsmith, 1959) is used for medium to coarse granoblastic rocks which do not have a marked foliation or lineation; these rocks may be uniform in mineral composition, or they may contain layers of different composition in which non-directional minerals predominate. The prefix 'meta' added to a rock name indicates that the rock now has a metamorphic fabric or mineralogy, or both, but its original nature is readily apparent.

The term 'concordant' is used to describe contacts between units displaying parallelism of bedding or structure, where a hiatus cannot be recognised but may exist (Bates & Jackson, 1980).

The term 'migmatite' is used to describe a composite (mixed) rock consisting of igneous or igneous-looking and metamorphic components which are generally distinguishable megascopically (Bates & Jackson, 1980).

The term 'batholith' refers to a grouping of spatially associated granitic intrusions which may or may not be genetically related or similar in age.

Acknowledgments

We wish to express our gratitude to the residents of the region who provided hospitality and assistance during the course of the project. Special thanks are due to D. Macdonald of Devoncourt station; Mr and Mrs C. Kelly of Duchess; the McConachy family of Ashover station; L. Cozzi, formerly of the Revenue mine; P. Rons of the Answer mine; M. Dando of Mount Isa; and the Bode family of Percol Plains station. We also wish to acknowledge the assistance provided by C. M. Mock (BMR), R. N. England (formerly of BMR), and T. A. Noon (GSQ), who were members of the 1975–76 mapping parties; by A. L. Jaques (BMR), who took part in the 1978 fieldwork; by Carpentaria Exploration Company in supplying geological information; and by Queensland Phosphate Limited in allowing access to the facilities at The Monument. Throughout the course of the project the authors have greatly benefited from many stimulating discussions held with G. M. Derrick, R. N. England, and W. B. Dallwitz, all formerly of BMR, both in the field and in Canberra.

Fig. 6. Exposures of foliated felsic porphyry of the Argylla Formation 37 km north of Duchess (at GR UB805748). (M2633/10)

GENERAL GEOLOGY

Regional setting

The Duchess–Urandangi region covers the southernmost exposed part of the Precambrian Mount Isa Inlier (Geological Survey of Queensland, 1975), apart from a few outcrops in the Boulia and Glenormiston 1:250 000 Sheet areas to the south. The Precambrian rocks belong to the 'Cloncurry Complex' of Carter & others (1961), and consist of northerly trending, tightly folded and extensively faulted sediments and volcanics which have been intruded by numerous granite plutons and mafic bodies, and regionally metamorphosed to the greenschist and amphibolite facies. The inlier is flanked to the west by the early Palaeozoic Georgina Basin and to the east by the Mesozoic Eromanga Basin, and is overlain in the central part of the region by sedimentary rocks of the Burke River Structural Belt, an embayment of the Georgina Basin.

Since the work of Carter & others (1961), the Mount Isa Inlier has generally been considered to consist of a narrow central basement belt (Kalkadoon–Leichhardt Block) flanked to the west and east by thick sequences of stratigraphically equivalent cover rocks, commonly known as the western and eastern successions. This is the model favoured, for example, by Plumb & Derrick (1975), Plumb & others (1980, 1981), and Derrick & Wilson (1981b). However, Blake (1980, 1981b) has criticised some aspects of this model and made the following conclusions: (1) the oldest cover rocks in the west, mainly those of the Haslingden Group, were deposited to the west of a large and broad, rather than narrow, landmass composed of crystalline rocks which are now exposed in the central and possibly eastern parts of the Mount Isa Inlier; (2) these cover rocks predate those at the base of the eastern succession; (3) the basement of previous workers contains volcanic units which are younger than part of the western succession; and (4) the most widespread unit previously recognised in the eastern succession, the Corella Formation, includes rocks that are probably older as well as younger than the Haslingden Group.

The Precambrian succession in the southern part of the Mount Isa Inlier has been dated by U–Pb zircon geochronology of felsic volcanics and intrusives, mainly from north of the Duchess–Urandangi region (Page, 1978, 1983a, b; Wyborn & Page, 1983)*. It is characterised by the occurrence of similar rock

* Unless stated otherwise, cited isotopic ages have been determined by R. W. Page, BMR, using the U–Pb zircon method. Almost all ages of rocks determined using Rb–Sr and K–Ar techniques are too young, and are presumed to date metamorphic and other events.

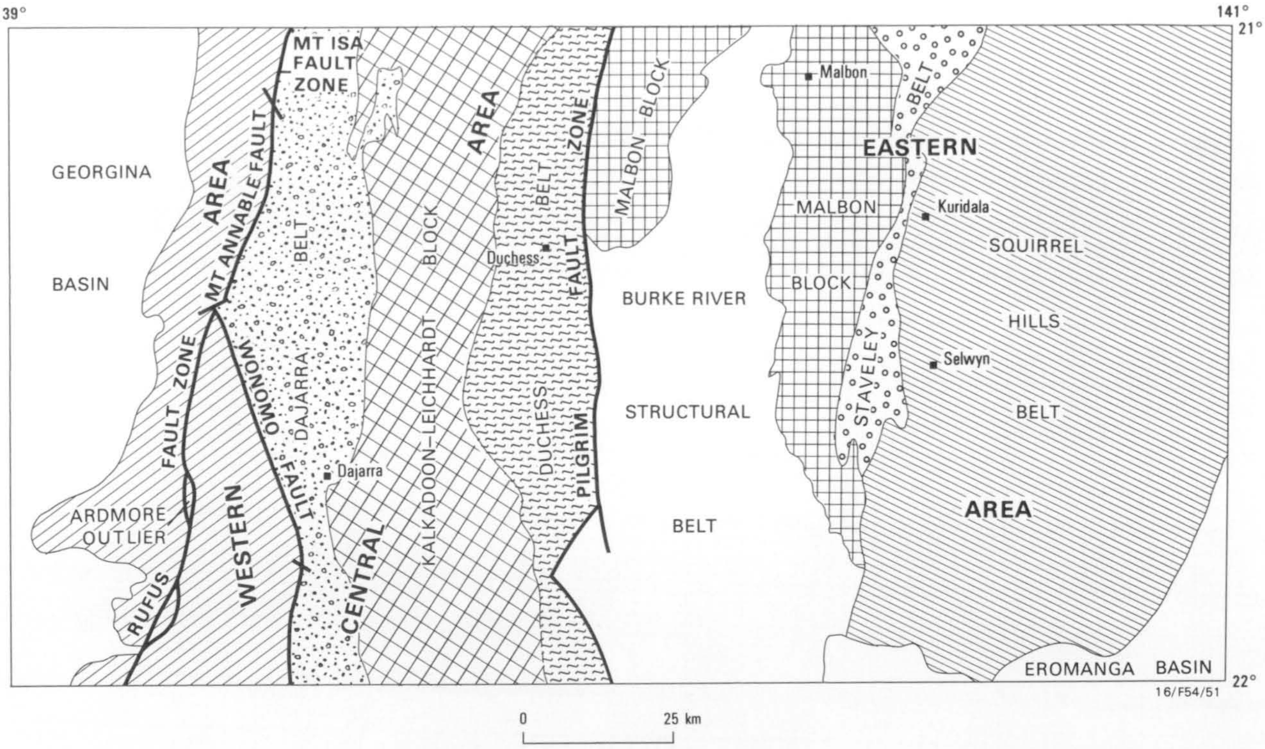


Fig. 7. Tectonic elements.

types—such as mafic and felsic volcanics, quartz arenite, calc-silicate rocks, and black slate—at several different stratigraphic levels and geographic locations, and by major breaks in the stratigraphy marked more commonly by disconformities than by angular unconformities.

A major unconformity separates metamorphic and igneous basement rocks older than about 1850 m.y. from the overlying Proterozoic cover rocks. The 'older cover' includes metasedimentary and metavolcanic sequences ranging in age from about 1810 to about 1700 m.y. The 'younger cover' comprises sequences between about 1680 and 1600 m.y. old. The older granites in the region predate the cover sequences, and were probably intruded before 1850 m.y.; the younger granites range in age from about 1740 to perhaps about 1500 m.y.

Two major northerly trending fault zones, the Wonomo/Mount Annable/Mount Isa fault system in the west and the Pilgrim Fault Zone in the east, divide the Duchess–Urandangi region into three parts: the western, central, and eastern areas (Fig. 7). Correlations between these areas are generally uncertain, and few Precambrian units have been mapped in more than one of the areas. Each area includes units assigned to the basement, to the older and younger cover sequences, and to younger granite; however, older granite, represented by the Kalkadoon Batholith, has been recognised only in the central area.

Tectonic framework

According to Plumb & others (1980), there are four principal Precambrian tectonic elements in the Duchess–Urandangi region: the Leichhardt River Fault Zone, Kalkadoon–Leichhardt Block, Malbon Block, and Mary Kathleen Fold Belt. The Leichhardt River Fault Zone, which corresponds to the Leichhardt River Fault Trough of Derrick (1980), contains the older and younger cover sequences in the western area and in the western part (the Dajarra Belt of this Bulletin) of the central area (see Fig. 7, and the structural and tectonic sketch on the accompanying

Fig. 8. Typical small-scale fold styles in the Duchess–Urandangi region.

(a) Folds in calc-silicate rocks of the Corella and Doherty Formations. In highly calcareous layers, tight to isoclinal folds are developed with little or no associated axial-plane foliation. In less calcareous and therefore more competent layers, relatively open folds are developed with an axial-plane foliation defined by alignment of mafic minerals.

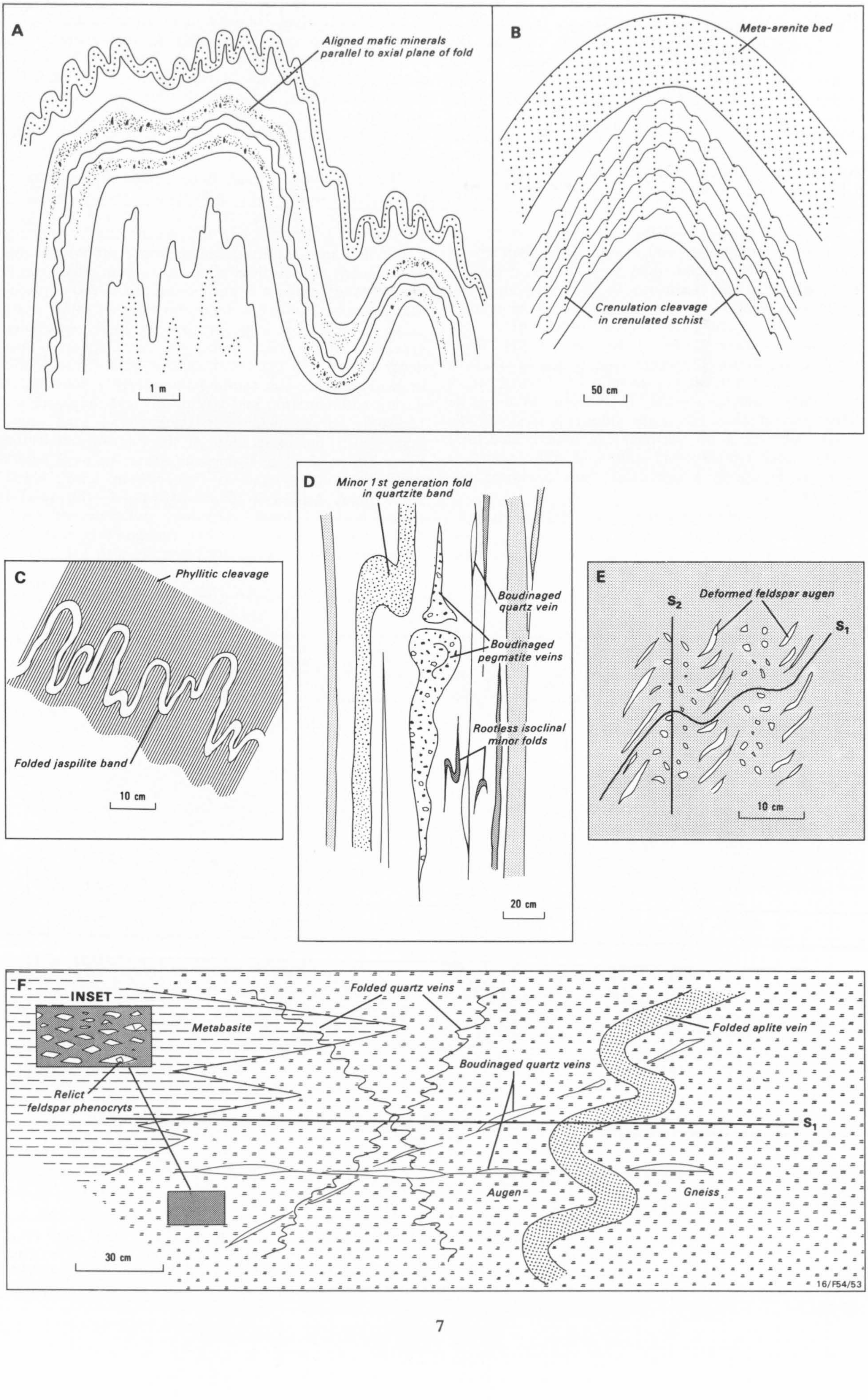
(b) Second or third-generation folds in schist interbedded with meta-arenite, as in the Kuridala Formation and parts of the Soldiers Cap Group. Relatively incompetent schists have well-developed crenulations and an associated cleavage, whereas the more competent meta-arenite beds are commonly not cleaved.

(c) Folds in parts of the Overhang Jaspilite: tightly folded jaspilite band enclosed in massive, cleaved phyllite.

(d) First-generation structures in gneiss of the Soldiers Cap Group. The first-generation foliation is defined by micaceous and felsic bands and boudinaged pegmatite, aplite, and quartz veins. Similar features occur in other gneissic units.

(e) Second-generation folds in the Plum Mountain Gneiss. S_1, the first-generation foliation, is defined by alignment of mineral aggregates and feldspar augen. Second-generation crenulations, with S_2 as axial plane, have stretched-out augen on fold limbs.

(f) Structures in the Bushy Park Gneiss. The main foliation (S_1) is defined by alignment of mineral grains and feldspar augen. Some augen consist of relict feldspar phenocrysts with deformation trails parallel to S_1. Quartz and aplite veins which are folded, and quartz veins which are boudinaged, probably predate the main deformation. The interfingering gneiss–metabasite contact may result from intense deformation, and the original contact may have been almost at right-angles to the present foliation.


A
Aligned mafic minerals parallel to axial plane of fold
1 m
B
Meta-arenite bed
Crenulation cleavage in crenulated schist
50 cm
C
Phyllitic cleavage
Folded jaspilite band
10 cm
D
Minor 1st generation fold in quartzite band
Boudinaged quartz vein
Boudinaged pegmatite veins
Rootless isoclinal minor folds
20 cm
E
S_2
Deformed feldspar augen
S_1
10 cm
F
INSET
Metabasite
Folded quartz veins
Folded aplite vein
Boudinaged quartz veins
Relict feldspar phenocryts
S_1
Augen
Gneiss
30 cm
16/F54/53

map sheet). The Kalkadoon–Leichhardt Block, formed largely of basement rocks, occupies the central part of the central area. The Malbon Block contains the older cover sequence in the western part of the eastern area. The Mary Kathleen Fold Belt lies mainly in the eastern area, where it corresponds to the Staveley Belt and Squirrel Hills Belt of this Bulletin, formed of younger and older cover sequences respectively, but it also includes tightly folded older cover and possible basement rocks which form the Duchess Belt in the eastern part of the central area (Fig. 7).

Structures

The style, orientation, and degree of development of folds in the Precambrian rocks vary according to rock types, presence and frequency of bedding planes and previous structures such as cleavage, position relative to zones of particularly intense deformation, and proximity to granite plutons and major faults. These mainly local factors, together with a general lack of overprinting criteria and a paucity of detailed structural measurements, make it difficult to correlate deformational events between different areas of the region, and hence to decipher the overall structural history. Some typical small-scale fold styles are illustrated in Figure 8. Major folds show a comparable range in style.

The earliest recognisable structural feature in most rocks is a subvertical, northerly trending cleavage/schistosity/foliation which in some cases can be related to tight to isoclinal major and minor folds. However, in the more metamorphosed rocks, none of the major folds identified can be related to the earliest and most prominent foliation present. Prevailing northerly trends may reflect the superimposition of similarly oriented (co-axial) folds of different ages, or the re-orientation of early structures and lithological boundaries by later intense folding about north–south axes.

The major faults and fault zones—the northerly trending and steeply dipping Wonomo, Mount Annable, and Cloncurry Faults, the Rufus, Mount Isa, and Pilgrim Fault Zones, and the northeasterly trending Fountain Range Fault—probably represent long-acting deep-seated crustal discontinuities along which both vertical and horizontal movements have taken place. Many faults mark lithologic boundaries, and some occur in the axial zones of major folds, especially synclines. Most faults shown on the Duchess–Urandangi region map are either at least partly syntectonic or post-tectonic, but faulting undoubtedly took place during sedimentation and volcanism, and may account for some abrupt changes in thickness of rock units. Some faults, including those of the Pilgrim and Rufus Fault Zones, displace Cambrian strata, so were active in Phanerozoic as well as Precambrian times. Shear zones many metres wide are associated with several faults; in these zones, schistose, mylonitic, or brecciated rocks predominate, but recognisable remnants of the pre-existing rocks are generally also present.

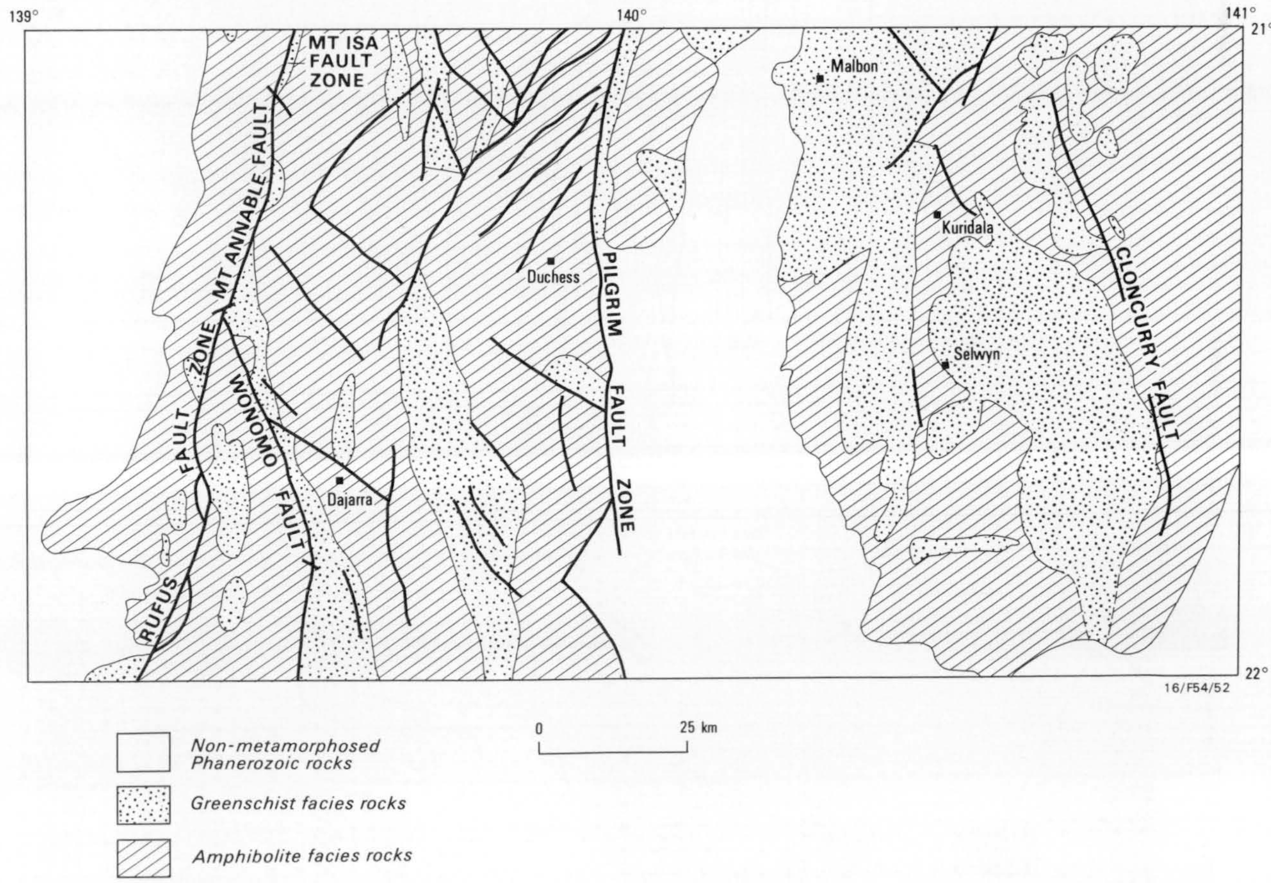


Fig. 9. Distribution of metamorphic facies.

Igneous intrusions

Mafic intrusions of several different ages occur throughout the region. Most may be related to mafic volcanic units. Northerly trending metadolerite and amphibolite dykes, commonly concentrated in swarms, predominate, but sills and irregular pods are common in some units. There are also some unmetamorphosed dolerite dykes which cut across the regional northerly trends. Some mafic bodies have been intruded into granite to form net-veined complexes (Blake, 1981a). Many mafic intrusions, especially the larger ones, have massive interiors, but their margins are generally schistose, probably because of slippage during deformation. Metadolerite ranges from fine-grained to gabbroic and in a few places shows compositional zoning. Some relict igneous features, such as ophitic textures and plagioclase phenocrysts, are commonly preserved in metadolerite, but not in amphibolite, which is a thoroughly recrystallised metamorphic rock.

Felsic dykes are much less common than mafic dykes but occur in most parts of the region. All show some recrystallisation effects.

The numerous granite plutons in the region form parts of four large batholiths—from west to east, the Sybella, Kalkadoon, Wonga, and Williams Batholiths. Most of the granitic plutons appear to have been intruded passively, causing little disturbance to bedding and pre-existing cleavage trends in surrounding country rocks.

Effects of metamorphism

The Precambrian rocks have been affected by regional metamorphism of low-pressure/high-temperature type (e.g., Jaques & others, 1982), which presumably accompanied the main deformation events. Mineral assemblages range from lower greenschist to upper amphibolite facies. No poly-metamorphic prograde mineral assemblages have been recognised, but retrograde assemblages marking relatively late low-grade metamorphic events are common. The distribution of prograde greenschist-facies and amphibolite-facies rocks is shown in Figure 9, which is based on thin-section studies—including microprobe mineral analyses—of mafic, calc-silicate, and pelitic rocks.

In greenschist-facies rocks, primary igneous and sedimentary textures are commonly well preserved. Typical metamorphic mineral assemblages are quartz ± alkali feldspar ± chlorite ± greenish brown biotite ± sericite/muscovite ± tremolite–actinolite ± epidote in felsic igneous rocks and non-calcareous sedimentary rocks; tremolite/actinolite + albite + calcite or dolomite in calcareous rocks; and actinolite + albite + epidote in mafic igneous rocks.

Lower amphibolite-facies rocks are generally more recrystallised, and most primary igneous and sedimentary textures are either poorly preserved or obliterated. Typical metamorphic assemblages are quartz + feldspar (albite and/or microcline) ± red-brown biotite ± muscovite ± garnet in felsic igneous rocks; the same minerals ± andalusite ± staurolite in non-calcareous metasediments; green hornblende (commonly chlorine-bearing) + sodic plagioclase + clinopyroxene (generally salitic) ± garnet ± scapolite ± quartz ± K–feldspar in calc-silicate rocks; and green hornblende + oligoclase/andesine ± clinopyroxene ± garnet in amphibolite.

Upper amphibolite-facies rocks are distinguished by the presence of sillimanite in gneiss and schist; andradite garnet and calcic plagioclase in calc-silicate rocks; and clinopyroxene ± andradite garnet in amphibolite.

Contact metamorphic effects are apparent locally within 100 m or so of some granitic plutons, and also within a few metres of some mafic intrusions. In the metamorphic aureoles, arenites and felsic volcanics are recrystallised to quartzitic rocks in which tourmaline needles are commonly present, and pelitic rocks may form hornfels containing adalusite, cordierite, and fibrolitic sillimanite. Skarns are commonly developed in calcareous units. Alkali feldspar (K–feldspar or albite) and hematite metasomatism, resulting in the formation of 'red rock', is extensive in places, especially within the Duchess Belt of the central area. The metasomatic effects may extend more than 100 m from igneous intrusions.

PRECAMBRIAN OF THE WESTERN AREA

The western area is bounded by the Wonomo/Mount Annable/Mount Isa fault system to the east and the Cambrian Georgina Basin sedimentary succession to the west (Fig. 7), and is part of the Leichhardt River Fault Zone of Plumb & others (1980). Many of the Precambrian stratigraphic units in this area appear to be similar to formations (mainly assigned to the Haslingden Group) exposed west of the Mount Isa Fault in MOUNT ISA, to the north (Hill & others, 1975; BMR, 1978a). However, they are referred to new formations (Blake & others, 1981a,b) because (i) their stratigraphic relations (particularly in the south) are uncertain; (ii) their isotopic ages have not been established; (iii) they cannot be correlated unequivocally with units of the central area; and (iv) not all of them may be equivalent to the Haslingden Group.

In the south the western area consists of two northerly trending belts—one to the east and the other to the west of the north-northeast-trending Rufus Fault Zone (Fig. 7). This fault zone, which is part of the Mount Remarkable fault system of Derrick & others (1980), truncates the Wonomo Fault (which is thought to be the southerly extension of the Mount Isa Fault Zone), so that only the western belt is present in the north.

In the eastern belt the oldest units are probably the Sulieman Gneiss and the Kallala Quartzite, and the most extensive unit is the Jayah Creek Metabasalt, which includes numerous metasedimentary lenses—the thickest being the Timothy Creek Sandstone Member. The relative ages of these three formations are uncertain because they have concordant contacts and generally lack facing evidence in contact zones. Meta-arenite and possibly carbonaceous metasiltstone and shale preserved in the keel of a small syncline in the south, and probably in faulted contact with Jayah Creek Metabasalt, is tentatively assigned to the Mount Isa Group.

In the western belt, west of the Rufus Fault Zone, the oldest rocks exposed are the Saint Ronans Metamorphics. This formation appears to be similar lithologically to the Yaringa Metamorphics exposed to the north, west of Mount Isa; Carter & others (1961) regarded the Yaringa Metamorphics as possibly the oldest unit exposed in the Mount Isa Inlier, and Page

& others (1982) have provisionally dated them as older than 2000 m.y. The Saint Ronans Metamorphics are overlain to the south by the Oroopo Metabasalt, which —together with the Jayah Creek Metabasalt—may be correlated with the Eastern Creek Volcanics in the central area. Rocks assigned to the Haslingden Group, Carters Bore Rhyolite, and McNamara Group crop out in the north.

The Sulieman Gneiss, Kallala Quartzite, and Saint Ronans Metamorphics (Table 1) are considered to be part of the basement; the Jayah Creek Metabasalt, Oroopo Metabasalt, and Haslingden Group (Table 2) are assigned to the older cover sequence; and the Carters Bore Rhyolite and Mount Isa and McNamara Groups (Table 3) belong to the younger cover sequence.

Sulieman Gneiss

The Sulieman Gneiss (Table 1) crops out in the southwest of the eastern belt. It is highly deformed, extensively recrystallised, and regionally metamorphosed to the amphibolite facies. Most of the main rock type, quartzofeldspathic gneiss (Fig. 10), may represent metamorphosed felsic volcanics and interlayered volcaniclastic sediments, though some augen gneisses within the unit may be metamorphosed granite and feldspar porphyry intrusives. The presence of some chlorite (replacing biotite or, less commonly, hornblende) and sericite (replacing plagioclase) indicates that the amphibolite-facies rocks have undergone a later greenschist-facies retrogressive metamorphism.

About 24 km southwest of Dajarra the Sulieman Gneiss appears to have a concordant contact with metasediments assigned to the Jayah Creek Metabasalt. The presence of pods and lenses of coarse chlorite and veins of pegmatite in both units adjacent to this contact indicates that the contact may be tectonic. Original lithologies in the Sulieman Gneiss are not obvious, whereas those in the Jayah Creek Metabasalt are readily discernible in most places, and the two units are possibly separated by a major metamorphic unconformity.

Two or more sets of pegmatite and granite veins cut the Sulieman Gneiss. The oldest, which are mainly less than 20 cm thick and are generally roughly concordant with the foliation in the host rocks (Fig. 10), may have been produced by local partial melting during regional metamorphism and deformation. They are extensively boudinaged, generally have irregular contacts, and in places show small-scale ptygmatic folds; those of pegmatite commonly contain large feldspar augen. Younger pegmatite veins are little deformed and cut across the foliation; they are probably related to the nearby Sybella Granite.

The Sulieman Gneiss may correlate with the Saint Ronans Metamorphics exposed west of the Rufus Fault Zone, with the Yaringa Metamorphics in MOUNT ISA (Carter & others, 1961; Hill & others, 1975), and with quartzofeldspathic gneiss of the undivided Tewinga Group in the central area to the east. Another possible correlative is the May Downs Gneiss in MOUNT ISA (Hill & others, 1975), which Derrick & others (1976b) considered to be a metamorphosed equivalent of the lower part of the Mount Guide Quartzite and therefore younger than the Tewinga Group.

Kallala Quartzite

The Kallala Quartzite (Table 1) forms a narrow northerly trending belt in the far south. It contains

TABLE 1. DETAILS OF STRATIGRAPHY—SULIEMAN GNEISS, KALLALA QUARTZITE AND SAINT RONANS METAMORPHICS, WESTERN AREA

Name of unit (reference to definition) max. thickness (m)	*Lithology*	*Relationships*
Saint Ronans Metamorphics (Blake & others, 1981a) 1000+	Fine-grained quartz + biotite + muscovite ± feldspar ± andalusite schist, quartzofeldspathic gneiss, extensively recrystallised even-grained to porphyritic felsic metavolcanics, amphibolite, amygdaloidal metabasalt, meta-arenite, quartzite, and metasiltstone; minor agglomerate and para-amphibolite; some small-scale cross-bedding in meta-arenite in S	Base not exposed; overlain apparently concordantly but probably unconformably by Oroopo Metabasalt, and with angular unconformity by Cambrian sediments of Georgina Basin succession; intruded by Sybella Granite, muscovite and tourmaline-bearing pegmatite, and amphibolitic metadolerite
Kallala Quartzite (Blake & others, 1981a) 350+	Medium to coarse glassy quartzite, muscovite quartzite and feldspathic? quartzite; minor amphibolite and hornblende-biotite schist and gneiss. Few sedimentary structures preserved	Concordant and apparently gradational contact with Sulieman Gneiss; concordant with rocks assigned to Jayah Creek Metabasalt; intruded by Sybella Granite
Sulieman Gneiss (Blake & others, 1981a) 1000+	Medium-grained quartzofeldspathic gneiss and augen gneiss, amphibolite, hornblende schist, glassy quartzite, muscovite quartzite, and feldspathic? quartzite; minor calc-silicate rocks, para-amphibolite, pegmatite, feldspar metaporphyry, and amygdaloidal? metabasalt *Gneiss*: medium to thin-banded; consists of quartz + plagioclase + biotite ± microcline ± minor muscovite, hornblende, garnet, sphene, epidote/clinozoisite, and chlorite; some myrmekite commonly present. Foliation commonly folded and crenulated *Amphibolite and hornblende schist*: medium to coarse aggregates of plagioclase (An_{17-60}) + brownish green hornblende + minor sphene, quartz, epidote/clinozoisite, and opaque oxide *Calc-silicate rocks*: thinly banded; consist of plagioclase (oligoclase–andesite) + clinopyroxene (salitic?) + quartz ± garnet ± minor sphene, epidote/clinozoisite, and apatite *Para-amphibolite*: commonly contains some biotite and apatite	Base not exposed; concordant or faulted contacts with Jayah Creek Metabasalt; appears to grade into Kallala Quartzite (not known which is older unit); intruded by Sybella Granite, amphibolitic metadolerite, dolerite, and pegmatite

Fig. 10. Banded gneiss with boudinaged quartz–feldspar pegmatite veins, Sulieman Gneiss 39 km southwest of Dajarra (at GR UA199700). M2633/11)

lenses of amphibolite and mafic schist and gneiss which are thought to be mainly metamorphosed mafic dykes and sills; however, some of these lenses contain possible deformed amygdales and include thin bands of quartzite and epidotic quartzite, indicating that some mafic lava flows may be present. The formation has been tightly folded about steeply dipping to vertical, north to northeast-trending axial planes. A fracture cleavage is well-developed in the hinge zones of these folds. The Kallala Quartzite may be equivalent to quartzite mapped as Mount Guide Quartzite and reported to overlie the May Downs Gneiss west of the Mount Isa Fault in MOUNT ISA (Hill & others, 1975).

Saint Ronans Metamorphics

Regionally metamorphosed argillaceous and arenaceous sediments and extensively recrystallised felsic and mafic volcanics are the predominant rock types in the Saint Ronans Metamorphics (Table 1), the oldest unit exposed west of the Rufus Fault Zone. The felsic metavolcanics contain variable amounts of epidote, little or no magnetite, abundant thin layers and lenticles rich in metamorphic biotite, and quartz and feldspar phenocrysts which tend to be concentrated in thin layers alternating with phenocryst-poor or phenocryst-free bands. Interlayered schists locally contain andalusite porphyroblasts, generally replaced by muscovite or chlorite. Lenses of fine to medium-grained amphibolite and amygdaloidal metabasalt consist of granular aggregates of mainly hornblende and relatively calcic plagioclase (An>17), indicating amphibolite-facies metamorphism. The replacement of andalusite porphyroblasts by white mica and chlorite, the partial replacement of biotite by chlorite, and the presence of bent mica flakes in some of the schists indicate later retrograde metamorphism and deformation.

The Saint Ronans Metamorphics may be equivalent to the Sulieman Gneiss east of the Rufus Fault Zone, to part of the undivided Tewinga Group of the central area, and to the Yaringa Metamorphics in MOUNT ISA. Other possible correlatives are the Leichhardt Volcanics and even the much younger Bottletree Formation of the central area.

Jayah Creek Metabasalt

The Jayah Creek Metabasalt (Table 2) crops out in a wide north-northwest-trending band in the eastern belt of the western area. Many of the individual lava flows in the formation, especially in the eastern part of the outcrop area, have well-preserved amygdaloidal zones and marginal breccias. Mafic rocks in the west, adjacent to intrusions of Sybella Granite, are more intensely foliated and more coarsely recrystallised than those to the east. Thin bands of relatively coarse-grained non-foliated to schistose mafic rocks in the sequence are probably dykes and sills.

The mafic volcanics are interlayered with bedded sediments ranging in thickness from less than 1 m up to about 2000 m. These may represent shallow-marine or fluvial deposits. Argillaceous metasediments are common in the northwest, but elsewhere arenaceous metasediments predominate. The thickest sedimentary layer, the *Timothy Creek Sandstone Member*, forms a prominent north-northwest-trending range of closely spaced planated strike ridges.

The presence of cordierite in interlayered meta-argillites and of co-existing calcic plagioclase (An>17) and hornblende in metabasalt indicate amphibolite-facies regional metamorphism. Thermal contact-metamorphic effects, such as hornfels, are generally apparent only within 5 m or less of Sybella Granite intrusions.

The Jayah Creek Metabasalt may be equivalent to the Eastern Creek Volcanics of the central area. The Timothy Creek Sandstone Member is possibly a time equivalent of the Lena Quartzite Member (Derrick & others, 1976b) of the Eastern Creek Volcanics.

Oroopo Metabasalt

The Oroopo Metabasalt is exposed west of the Rufus Fault Zone, mainly in the far southwest. It consists of basaltic lava flows and interlayered sedimentary rocks (Table 2) which have been regionally metamorphosed to the upper greenschist or lower amphibolite facies. The mafic metavolcanics are lithologically similar to those of the Jayah Creek Metabasalt to the east and the Eastern Creek Volcanics of the Dajarra Belt in the central area, which are possible correlatives. The sedimentary rocks in the Oroopo Metabasalt, and also in the Jayah Creek Metabasalt, are generally finer-grained than those in the Eastern Creek Volcanics of the Dajarra Belt, an indication that the sedimentary source may have been to the east. A sequence of meta-arenite, calcareous meta-arenite, and limestone exposed in the centre of a partly fault-bounded structural basin at about GR UA1274 is tentatively mapped as Oroopo Metabasalt, but may belong to a younger unit.

Haslingden Group

Rocks assigned to the *Mount Guide Quartzite, Eastern Creek Volcanics*, and *Judenan beds* of the Haslingden Group (Table 2) crop out in the northern part of the western area, west of the Mount Annable and Mount Isa Faults. They are generally more highly deformed and more extensively recrystallised than those of the Haslingden Group rocks of the central area: they have been regionally metamorphosed mainly to the amphibolite facies and are commonly foliated, and facing evidence is generally lacking. Schist and gneissic migmatitic rocks mapped as Eastern Creek Volcanics adjacent to the Sybella Granite near GR UB3140 have a crenulated foliation. The contact aureole of this granite pluton also contains quartzofeldspathic cordierite–garnet–biotite hornfels—some with partly retrogressed sillimanite—and granoblastic quartz-bearing amphibolite which are also mapped as Eastern Creek Volcanics.

The arenaceous and argillaceous metasediments which make up the Judenan beds may be equivalent to the upper part of the lithologically similar Myally Subgroup (Derrick & others, 1976b) exposed east of the Mount Isa Fault to the north, as suggested by Mock (1978). However, the stratigraphy of the Judenan beds is obscured by faulting, tight folding, and intrusions of Sybella Granite, and part or all of the unit may represent interbeds within the Eastern Creek Volcanics, rather than an overlying sequence.

Carters Bore Rhyolite

The Carters Bore Rhyolite (Table 3) crops out on the limbs of a syncline in the far northwest. A sample from the formation to the north has been isotopically dated at 1678 ± 1 m.y. (Page, 1978).

McNamara Group

The McNamara Group (Table 3) is preserved in the centre of the small syncline in the far northwest, where it has a maximum thickness of about 400 m. The two formations present, *Torpedo Creek Quartzite* and *Gunpowder Creek Formation*, extend northwards into MOUNT ISA, where the Torpedo Creek Quartzite has been mapped as basal Gunpowder Creek Formation (Hill & others, 1975). The McNamara Group sediments are thought to have been deposited in a shallow-marine environment. The Torpedo Creek Quartzite is correlated with the Warrina Park Quartzite of the

TABLE 2. DETAILS OF STRATIGRAPHY—OLDER COVER SEQUENCE, WESTERN AREA

	Name of unit (reference to definition) max. thickness (m)	*Lithology*	*Relationships*
HASLINGDEN GROUP (Derrick & others, 1976b)	**Judenan beds** (Carter & others, 1961; Derrick & others, 1976b) 1000?	Schistose and cleaved sericitic and feldspathic meta-arenite, quartzite (commonly ferruginous), quartz-mica schist, and spotted grey mica schist; minor gneiss. Primary textures largely obliterated by faulting, tight folding, and granite intrusion	Thought to be conformable on Eastern Creek Volcanics; overlain unconformably by Carters Bore Rhyolite; intruded by Sybella Granite
HASLINGDEN GROUP (Derrick & others, 1976b)	**Eastern Creek Volcanics** (Carter & others, 1961; Derrick & others, 1976b) 1000+?	Interlayered amphibolite, meta-arenite, quartzite, and schistose to gneissic metasediments, some of which contain cordierite and/or sillimanite; minor migmatite	Thought to be overlain conformably by Judenan beds and unconformably by Carters Bore Rhyolite and Torpedo Creek Quartzite; intruded by Sybella Granite and amphibolitic metadolerite
HASLINGDEN GROUP (Derrick & others, 1976b)	**Mount Guide Quartzite** (Carter & others, 1961; Derrick & others, 1976b) 1000+?	Pebbly, quartzose, feldspathic, and sericitic meta-arenites, and quartzite. Primary textures poorly preserved. Commonly schistose	Contacts with other formations poorly exposed
	Jayah Creek Metabasalt (Blake & others, 1981a) 15 000?	Slightly to highly foliated, variably epidotic, amphibolitic metabasalt; subordinate quartz + biotite ± muscovite ± feldspar ± cordierite schist and gneiss, quartzite, pebbly meta-arenite, muscovite ± quartz schist; minor siliceous and micaceous metasiltstone, para-amphibolite, greywacke, metagreywacke, recrystallised limestone, impure limestone, and calcareous meta-arenite. Cross-bedding and ripple marks common in E and far SW, but largely obliterated by well-developed cleavage in W. Small isoclinal folds and crenulations in gneissic rocks adjacent to Sulieman Gneiss SW of Dajarra	Concordant or faulted contacts with Sulieman Gneiss; concordant with Kallala Quartzite; intruded by Sybella Granite, metadolerite, and minor quartz porphyry, quartz-feldspar porphyry, and non-porphyritic rhyolite dykes
	Timothy Creek Sandstone Member 2000	Meta-arenite; minor metasiltstone, quartzite, metabasalt, and thin conglomerate lenses	Conformable layer within Jayah Creek Metabasalt
	Oroopo Metabasalt (Blake & others, 1981a) 1000+	Partly epidotic amygdaloidal metabasalt; epidotic quartzite; quartzose, feldspathic, and calcareous meta-arenites and metasiltstones; recrystallised limestone; dolomite; meta-arkose; some conglomeratic and gritty meta-arenite lenses; minor chlorite schist. Ripple marks and cross-bedding common in meta-arenites	Overlies Saint Ronans Metamorphics apparently concordantly and probably unconformably; overlain unconformably by Cambrian and Mesozoic strata; intruded by metadolerite and rare pegmatite (Sybella Granite?)

Mount Isa Group, and the Gunpowder Creek Formation is equated with the Moondarra Siltstone and Breakaway Shale (e.g., Plumb & others, 1980). The group has been affected by only low-grade regional metamorphism.

Mount Isa Group?

A poorly exposed sequence of quartzitic and schistose metasediments preserved in a small and at least partly fault-bounded syncline in the south, at about GR UA3483, has been tentatively assigned to the undivided Mount Isa Group (Table 3). The sequence appears to be much less metamorphosed and deformed than the adjacent Jayah Creek Metabasalt, and hence may be separated from this formation by a metamorphic unconformity.

Sybella Granite

The Sybella Granite (Carter & others, 1961) includes all granitic rocks exposed in the western area. The several discrete plutons present, none of which have been isotopically dated, are part of a major batholith, the Sybella Batholith, which extends into Sheet areas to the north and south of the region. Granites of the batholith in MOUNT ISA have been dated at between 1680 and 1670 m.y. (Page, 1981a).

The Sybella Granite includes several different types of granite (Table 4). The oldest are intensely foliated to gneissic types which form small plutons with generally concordant intrusive contacts (e.g., 10–15 km east of Ardmore homestead). They are cut in places by mafic dykes which have been regionally metamorphosed to the amphibolite facies, and are also intruded by bodies of less foliated to non-foliated and possibly significantly younger biotite granite, leucogranite, and pegmatite.

The narrow elongate pluton of foliated Sybella Granite intruding migmatitic and amphibolitic rocks mapped as Eastern Creek Volcanics near GR UB3140 has a core of medium-grained biotite granite containing augen of K–feldspar, and an outer zone of recrystallised crenulated microgranite; aplite dykes, pegmatite veins, and small stocks of foliated leucogranite intrude this granite and adjacent country rocks, and hybrid rocks ranging from quartz-rich granite to mafic hornblende granodiorite have developed locally along intrusive contacts (Mock, 1978).

The main granite type, biotite granite, forms several large plutons. It generally contains sparse to abundant feldspar phenocrysts up to about 8 cm long, and xenoliths of biotite-rich mafic rock and foliated to gneissic granodiorite; large inclusions of country rock are common in the marginal zones of plutons (Fig. 11). The granite is made up of about equal amounts of quartz, microcline, and plagioclase, 10–15 percent biotite, and commonly minor hornblende and muscovite; purple fluorite is present in places. Myrmekite is almost ubiquitous, and rapakivi textures are locally common. The granite is cut by veins and pods of biotite microgranite, pegmatitic granite, pegmatite, and aplite (Fig. 12). The pegmatites commonly contain tourmaline, muscovite, and, in the far north, beryl.

In general the main granite plutons have sharp intrusive contacts, commonly irregular in detail, which cut across, without obviously deflecting, the bedding and foliation of the country rocks. Hornfels in adjacent

TABLE 3. DETAILS OF STRATIGRAPHY—YOUNGER COVER SEQUENCE, WESTERN AREA

Name of unit (reference to definition) max. thickness (m)	*Lithology*	*Relationships*
MOUNT ISA GROUP? (Derrick & others, 1976c) 170	Thin to thick-bedded, cross-bedded and locally ripple-marked, fine to medium-grained quartzose meta-arenite commonly showing honeycomb weathering; quartzite; laminated to thin-bedded pyritic and possibly partly carbonaceous meta-siltstone and shale; minor quartz-mica schist	Uncertain, as contacts faulted or not exposed
McNAMARA GROUP (Hutton & others, 1981)		
Gunpowder Creek Formation (Carter & others, 1961; Hutton & others, 1981) 250	Black carbonaceous shale, ferruginous siltstone, and thin-bedded to laminated black siltstone; commonly cleaved	Conformable on Torpedo Creek Quartzite
Torpedo Creek Quartzite (Hutton & others, 1981) 150	Micaceous, quartzose, and feldspathic meta-arenites and quartzites; some pebbly and conglomeratic beds at base containing clasts of quartzite and porphyritic rhyolite (similar to that of underlying Carters Bore Rhyolite). Cross-beds, ripple marks, and heavy-mineral-rich laminae common	Unconformable (disconformable) on Carters Bore Rhyolite; thought to be unconformable on Eastern Creek Volcanics; overlain conformably by Gunpowder Creek Formation
Carters Bore Rhyolite (Derrick & others, 1978) <300	Foliated and cleaved rhyolite containing phenocrysts of quartz and potassic feldspar	Thought to be unconformable on Eastern Creek Volcanics; unconformable on Judenan beds; overlain unconformably (disconformably) by Torpedo Creek Quartzite

TABLE 4. SYBELLA GRANITE, WESTERN AREA

Name of unit (reference to definition)	*Lithology*	*Relationships*
Sybella Granite (Carter & others, 1961)	Massive to more commonly foliated, medium to coarse-grained, even-grained to porphyritic biotite granite; subordinate leucocratic biotite granite, leucogranite, aplite, quartz + feldspar ± muscovite ± tourmaline pegmatite, gneissic granite, biotite-hornblende granodiorite and augen gneiss, and biotite microgranite; rare diorite. Xenoliths common. Foliation is generally steeply dipping to vertical and is locally crenulated	Intrudes Sulieman Gneiss, Kallala Quartzite, Saint Ronans Metamorphics, Jayah Creek Metabasalt, Haslingden Group (Eastern Creek Volcanics and Judenan beds), and probably Oroopo Metabasalt; cut by sparse metadolerite dykes and at least one dolerite dyke; overlain by Middle Cambrian and younger sediments

rocks is generally restricted to within 5 m of intrusive contacts. Tourmaline, probably resulting from boron metasomatism, is common in nearby schistose metasediments. In shear zones adjacent to the Rufus Fault Zone the biotite granite has been converted to mylonitic rock consisting mainly of small quartz and feldspar augen and muscovite flakes in a fine-grained quartzofeldspathic groundmass.

Small bodies of leucocratic muscovite and biotite–muscovite granite intrude the Saint Ronans Metamorphics west of the Rufus Fault Zone, and similar leucocratic granite is exposed about 13 km southeast of Ardmore homestead, where it appears to be a marginal phase of a pluton formed mainly of biotite granite. The leucocratic granite contains pegmatitic patches, scattered white feldspar megacrysts up to about 15 cm long, and mafic xenoliths, and it is cut by veins of tourmaline-bearing muscovite pegmatite.

The field evidence indicates that the massive to weakly foliated granites were probably emplaced by stoping after at least some of the country rocks had been folded and regionally metamorphosed. However, petrographic evidence shows that these granites have themselves been regionally metamorphosed, probably to the greenschist facies.

The few amphibolitic metadolerite dykes which cut the older foliated granites may have been intruded before the emplacement of the main granite type. They are presumed to be older than a northeast-trending dyke of apparently unmetamorphosed dolerite which cuts porphyritic biotite granite west of Dajarra (at GR UB260010).

Minor intrusions

Dykes and pod-like intrusions of foliated to massive *metadolerite* and *amphibolite* of probably several different ages are widespread in the western area. They range from less than 1 m to more than 1000 m thick, and consist mainly of plagioclase more calcic than An_{17} and hornblende, indicating that they have been regionally metamorphosed to the amphibolite facies.

Fig. 11. Inclusions of country rock (Jayah Creek Metabasalt) in porphyritic granite at the margin of a Sybella Granite pluton 19 km west-northwest of Dajarra (at GR UB290070). (M2633/12)

Many of the thicker bodies have fine-grained, extensively recrystallised, foliated margins and coarser, non-foliated centres in which primary igneous textures are preserved. Some of the dykes contain feldspar phenocrysts, and those cutting the Jayah Creek Metabasalt in the eastern part of the area commonly have amygdaloidal zones and show compositional banding.

A few of the mafic intrusives do not appear to be metamorphosed. These intrusions, which are probably the youngest Precambrian rocks in the western area, generally consist of plagioclase (partly sericitised), pyroxene, opaque oxide, and minor primary hornblende, biotite, and interstitial and commonly granophyric quartz and K–feldspar. They may be related to the Lakeview Dolerite, which Derrick & others (1977b, 1978) described in MARY KATHLEEN.

A few *felsic dykes* have been found. They are generally formed of either quartz ± feldspar porphyry or non-porphyritic rhyolite.

Structure

Folds

The *Sulieman Gneiss* and much of the *Kallala Quartzite* in the eastern belt display a well-developed foliation (Fig. 10). However, no large-scale folds have been identified in the Sulieman Gneiss, though tight folds with mainly north to northeast-trending axial planes are present in the Kallala Quartzite. These folds may be synchronous with similarly oriented folds in the Haslingden and Mount Isa Groups to the north and east, and are thought to postdate the foliation-forming event.

The *Jayah Creek Metabasalt* generally appears to form an ordered succession with only minor internal folding. However, near plutons of Sybella Granite, the formation is more deformed, has a northerly trending foliation which obliterates bedding, and shows some small-scale north-plunging isoclinal folds and crenulations.

The *Saint Ronans Metamorphics* in the south of the western belt have a well-developed foliation, but no folds related to this foliation have been identified. The foliation is folded around a large south-southeast-plunging anticline truncated in the east by the Rufus Fault Zone, and largely concealed beneath Cambrian and superficial deposits to the west. To the northeast, a prominent synform separates this fold from a similarly oriented but smaller antiform cored by a Sybella Granite pluton, indicating a possible link between folding and granite emplacement

Equivalent folds in the overlying *Oroopo Metabasalt*, and the earliest recognised in the formation, are open south-plunging structures. The Oroopo Metabasalt was subsequently extensively deformed along the Rufus Fault Zone, where bands of kinked and crenulated chlorite and quartz–muscovite schist have been developed.

North to northwest-plunging open to tight folds with wavelengths of up to 1 km characterise the *Haslingden*, *Mount Isa*, and *McNamara Groups*. Farther north, some folding of the Haslingden Group evidently occurred before the Mount Isa and McNamara Groups were deposited (Derrick & others, 1980), but no such early folding has been recognised in the western area. Drag-folds are common adjacent to faults, especially in the Mount Isa Group (cf. Wilson, 1973).

Fig. 12. Porphyritic granite cut by veins of microgranite, Sybella Granite 20 km west of Dajarra (at GR UB017260). (M2633/8)

Faults

The oldest faults recognised in the western area are northerly trending fractures, not shown on the accompanying map, developed along lithologic boundaries parallel to bedding and foliation trends. Some of these are marked by metadolerite dykes and, in the Saint Ronans Metamorphics, possibly by quartz and pegmatite veins. They are displaced by a conjugate set of more-or-less vertical northeasterly and northwesterly trending faults which postdate the latest folding and have apparent lateral displacements of up to 1 km; those trending northeast are mainly dextral strike-slip, and those trending northwest are mainly sinistral strike-slip. Movements along the conjugate set of faults indicate an overall east-west compression.

The largest faults are the north-northeasterly trending Mount Annable Fault and those of the Rufus and Mount Isa Fault Zones, and the north to northwesterly trending Wonomo Fault, which is truncated to the northwest by the Rufus Fault Zone (Fig. 7). The Rufus Fault Zone and Mount Annable Fault may be part of the right-lateral Mount Remarkable fault system (Derrick & others, 1980). No displacements have been measured along these major and probably long-acting faults, but the difficulty in directly correlating any units across them implies movements of many kilometres. The preservation of Cambrian sediments in the Ardmore Outlier (de Keyser & Cook, 1972), essentially a graben within the Rufus Fault Zone, indicates that some movement along this fault zone took place after the deposition of the Phanerozoic Georgina Basin succession. Cambrian sediments are also displaced by some faults of the conjugate set in the far southwest.

Metamorphic effects

Calc-silicate rocks and amphibolite within the Sulieman Gneiss have amphibolite-facies mineral assemblages, characterised by co-existing clinopyroxene and oligoclase/andesine, and hornblende and andesine/labradorite, respectively. Quartzofeldspathic gneisses in this unit commonly have triple-point junctions between grains, and locally display myrmekitic intergrowths of quartz and plagioclase. The Sulieman Gneiss also contains thin pegmatite veins that may have been produced by partial melting during metamorphism.

The adjacent Kallala Quartzite is extensively recrystallised, and contains metabasite lenses with mineral assemblages indicating amphibolite-facies metamorphism. The Jayah Creek Metabasalt to the east has also been regionally metamorphosed to the amphibolite facies.

Gneissic phases of the Sybella Granite are cut by rare amphibolite-facies metadolerite dykes, implying a similar grade for these phases, but the metamorphic grade of the younger and generally less recrystallised and deformed main phase of biotite granite mapped as Sybella Granite may be lower. Although most Sybella Granite plutons do not have marked contact aureoles, the metamorphic grade of the Jayah Creek Metabasalt generally increases towards the granite, indicating that there may be a genetic relationship between the granite and the regional metamorphism.

In the Saint Ronans Metamorphics in the southwest the presence of extensively recrystallised felsic and mafic metavolcanics, metasediments with a well-developed schistosity which commonly obliterates bedding, meta-argillites with andalusite porphyroblasts, and metabasites with coexisting hornblende and calcic plagioclase ($An_{>17}$) indicates amphibolite-facies regional metamorphism. Mineral assemblages in the Oroopo Metabasalt to the north and south indicate the upper greenschist to lower amphibolite facies.

The Haslingden Group in the north consists mainly, if not entirely, of amphibolite-facies rocks. Metabasites within the Eastern Creek Volcanics contain hornblende and relatively calcic plagioclase, and cordierite and sillimanite are developed in some associated meta-argillites. Cordierite and garnet in meta-argillites adjacent to intrusions of Sybella Granite are attributed to contact metamorphism.

In the far northwest, the McNamara Group and probably the Carters Bore Rhyolite, and also rocks tentatively assigned to the Mount Isa Group, have been regionally metamorphosed to only the greenschist facies.

PRECAMBRIAN OF THE CENTRAL AREA

The central area, bounded to the west by the Wonomo/Mount Annable/Mount Isa fault system and to the east by the Pilgrim Fault Zone, is made up of three main structural elements (Fig. 7): the Kalkadoon–Leichhardt Block, formed mainly of basement rocks; the Duchess Belt, to the east, which consists of basement and older cover rocks—including the Corella Formation—and granites of the Wonga Batholith; and the Dajarra Belt, to the west, which comprises older and younger cover sequences. The highly deformed western part of the Duchess Belt is the southerly continuation of the Wonga Belt of Derrick (1980) and Derrick & Wilson (1981a,b). Details of stratigraphic and intrusive units in the central area are listed in Tables 5–10.

The oldest rocks exposed are considered to be gneisses and schists mapped as Plum Mountain Gneiss in the Duchess Belt and undivided Tewinga Group in the Kalkadoon–Leichhardt Block; these rocks—together with the Leichhardt Volcanics of the Tewinga Group, the Kalkadoon Granite, and possibly the Corella Formation (a unit of mainly calcareous metasediments forming most of the Duchess Belt)—make up the basement of the central area. The older cover comprises the Bottletree Formation and Haslingden Group of the Dajarra Belt; the Magna Lynn Metabasalt and Argylla Formation of the Tewinga Group, which crop out within the Kalkadoon–Leichhardt Block and along the western margin of the Duchess Belt; and the Ballara Quartzite, Corella Formation?, Stanbroke Sandstone, and Makbat Sandstone, which are confined to the Kalkadoon–Leichhardt Block. Units of the younger cover in the central area—Carters Bore Rhyolite?, Surprise Creek Formation?, and Mount Isa Group—crop out only in the Dajarra Belt. Granites of the Wonga Batholith, which are thought to postdate the basement and older cover units, have been emplaced within both the Kalkadoon–Leichhardt Block and Duchess Belt, and bodies of Mount Philp Breccia cut the Corella Formation of the Duchess Belt.

The Proterozoic units are intruded by metadolerite and amphibolite, which mainly form dykes with northerly trends, and also by some felsic dyke-like bodies and a few younger dykes of non-metamorphosed dolerite. One felsic minor intrusion which intrudes the Mount Guide Quartzite of the Haslingden Group in the Dajarra Belt has been formally named the Garden Creek Porphyry.

Plum Mountain Gneiss

The Plum Mountain Gneiss (Table 5) is a complex unit exposed in the western part of the Duchess Belt south of Duchess. It appears to consist mainly of felsic volcanics, subordinate interlayered partly volcaniclastic sedimentary rocks, and abundant concordant to discordant granitic intrusives, all of which have been regionally metamorphosed to amphibolite-facies gneissic rocks; it is also taken to include metasediments that Blake & others (1982a) mapped as possible Corella Formation 13 km east-southeast of Stanbroke homestead. Most of the non-intrusive gneissic rocks may be correlatives of the undivided Tewinga Group to the west, and some may be stratigraphic equivalents of the Corella Formation to the east. They are older than the Leichhardt Volcanics as they are intruded by the One Tree Granite, which is overlain by the Leichhardt Volcanics. Contacts with adjacent Precambrian units are generally concealed.

Tewinga Group

As defined by Derrick & others (1976a), the Tewinga Group (Table 5) includes the oldest rocks exposed in the Kalkadoon–Leichhardt Block, forms part of the crystalline basement on which cover rocks of the western and eastern successions (mainly the Haslingden, Malbon, and Mary Kathleen Groups) were deposited, and comprises three formations: the Leichhardt Metamorphics (the oldest), Magna Lynn Metabasalt, and Argylla Formation (the youngest). In the Duchess–Urandangi region the Leichhardt Metamorphics of these and earlier workers are mapped partly as Leichhardt Volcanics, a formation of readily recognisable felsic volcanic rocks, and partly as undivided Tewinga Group (i.e., not subdivided into formations), which consists mainly of gneissic and schistose metamorphic rocks rather than volcanic rocks. A major unconformity representing about 80 m.y. separates the Leichhardt Volcanics from the overlying Magna Lynn Metabasalt and Argylla Formation. These two younger formations may be younger, rather than older, than most of the Haslingden Group, and hence may be part of the older cover sequence, rather than part of the basement (Blake, 1980). Consequently, in a strict sense the term 'Tewinga Group', as originally defined, is probably not a valid stratigraphic unit. However, it has been referred to in numerous recent publications (e.g., Plumb & others, 1980, 1981; Blake,

TABLE 5. DETAILS OF STRATIGRAPHY—PLUM MOUNTAIN GNEISS AND TEWINGA GROUP, CENTRAL AREA

	Name of unit (reference to definition) max. thickness (m)	*Lithology*	*Relationships*
TEWINGA GROUP (Derrick & others, 1976a)	**Argylla Formation** (Carter & others, 1961; Derrick & others, 1976a) 2250	Reddish brown to grey, massive to intensely foliated, mainly porphyritic felsic volcanics, including ignimbrites showing fragmental textures, lavas showing contorted flow-banding, and possibly subvolcanic intrusions; minor agglomerate, bedded felsic and mafic tuff, metabasalt, and metasediments—sericitic to quartzose meta-arenite (commonly showing cross-bedding and ripple marks outlined by laminae rich in heavy minerals), conglomerate, meta-arkose, mica schist, and metasiltstone; cordierite-anthophyllite rock exposed at GR UB787666 *Felsic porphyry*: generally magnetic; contains euhedral to anhedral phenocrysts of microcline, and commonly sericitic plagioclase and quartz, in fine-grained recrystallised quartzofeldspathic groundmass containing biotite ± green hornblende ± muscovite ± sphene ± granules and porphyroblasts of magnetite + apatite ± epidote ± chlorite; myrmekite is developed in some samples. Phenocrysts commonly recrystallised to granular aggregates in amphibolite-facies metaporphyry	Conformable on Magna Lynn Metabasalt; overlain concordantly and possibly conformably by Ballara Quartzite and unconformably by Stanbroke Sandstone; concordant contact with Corella Formation. Intruded by Birds Well and Mairindi Creek Granites, Bushy Park Gneiss, and probably Bowlers Hole Granite, and by metadolerite and some felsic dykes
	Magna Lynn Metabasalt (Derrick & others, 1976a) 1300	Massive to amygdaloidal metabasalt consisting mainly of green hornblende and plagioclase, brecciated metabasalt (flow-margin breccia), mafic schist with biotite and/or chlorite and/or amphibole; minor quartzose, epidotic, and feldspathic meta-arenites and quartzites locally showing cross-bedding, felsic porphyry, metasiltstone, commonly deformed conglomerate, and thin-banded to laminated para-amphibolite and biotite-rich tuffaceous? metasediments	Unconformable on Leichhardt Volcanics; overlain conformably by Argylla Formation and unconformably by Stanbroke Sandstone; concordant contact with Corella Formation. Intruded by Bowlers Hole, Mairindi Creek, and Birds Well Granites, Bushy Park Gneiss, and mafic and felsic dykes
	Leichhardt Volcanics (Blake & others, 1981a) 1000+	Buff, pink, maroon, and greenish to bluish grey quartz-feldspar porphyry (mainly ignimbrite, but also some flow-banded lava flows); minor feldspar porphyry, altered basalt, bedded tuff, quartzose to volcaniclastic arenite, and conglomerate; little-recrystallised to locally foliated and schistose *Felsic porphyry*: generally non-magnetic; contains sparse to abundant phenocrysts less than 5 mm across of plagioclase + microcline + quartz, and streaky aggregates of opaque minerals + biotite + chlorite + epidote + sphene + muscovite, set in a fine to very fine-grained groundmass of quartz + alkali feldspar ± biotite, sericite, chlorite, and epidote; fragmental and eutaxitic textures common. Phenocrysts recrystallised to granular aggregates in places	Overlies One Tree Granite and possibly unnamed monzonite (map unit $Ɛg_m$); may be unconformable on undivided Tewinga Group; overlain unconformably by Magna Lynn Metabasalt, Stanbroke Sandstone, and probably Makbat Sandstone. Intruded by Wills Creek, Woonigan, Bowlers Hole, and Birds Well Granites, probably by Kalkadoon Granite, and by mafic and felsic dykes
	Undivided 1000+	Pink to grey, massive to banded, fine to coarse-grained gneiss and augen gneiss, migmatitic gneiss and schist showing streaky and contorted compositional banding and concordant and discordant veins and patches of aplitic to pegmatitic granite; minor gneissic felsic agglomerate, metarhyolite lava, massive to schistose quartzite, banded calc-silicate rocks, conglomerate, and massive to schistose metabasalt; foliation locally crenulated *Felsic rocks*: non-magnetic to intensely magnetic; consist of quartz + microcline + plagioclase + biotite ± hornblende, muscovite, epidote, garnet, sphene, allanite, apatite, chlorite, fluorite, opaque minerals, tourmaline, and zircon; myrmekite common *Metabasalt*: consists of plagioclase + hornblende + quartz + epidote ± biotite, garnet, sphene, opaque minerals, and chlorite	Overlain unconformably by Bottletree Formation, by Mount Guide Quartzite (Yappo Member), probably by Stanbroke Sandstone, and possibly by Leichhardt Volcanics. Intruded by Kalkadoon, Wills Creek, and probably One Tree Granites, by granite mapped as possible Woonigan Granite (WSW of Duchess), and by mafic and felsic dykes
	Plum Mountain Gneiss (Blake & others, 1981a) 1000+	Pink to grey, massive to banded, fine to coarse-grained gneiss and augen gneiss; concordant to cross-cutting, slightly to intensely foliated, even-grained to porphyritic granite containing biotite ± hornblende ± garnet, leuco-granite, aplite, and pegmatite; banded micaceous, feldspathic, and arkosic meta-arenite, mica schist, banded calc-silicate rocks, para-amphibolite, and schistose metabasalt; foliation crenulated in places	Concordant contact with Corella Formation to E. Intruded by One Tree, Saint Mungo, and Birds Well? Granites, Bushy Park Gneiss, and Metadolerite dykes.

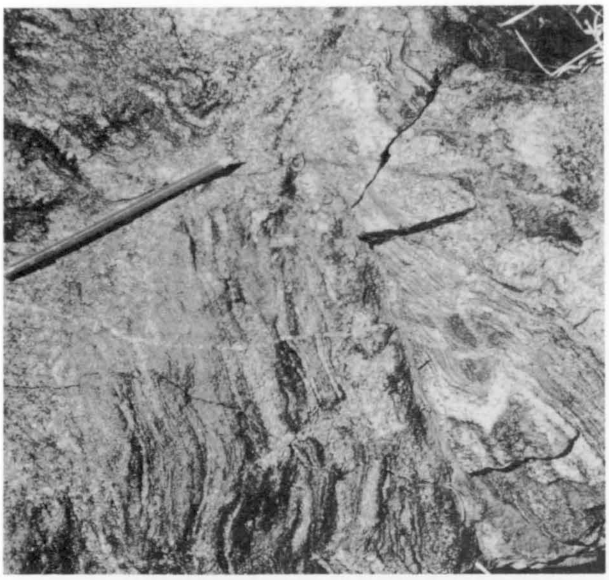


Fig. 13. Migmatitic gneiss of the undivided Tewinga Group at Yarraman Bore, 33 km northwest of Duchess (at GR UB558578). (GB 2339)

1980), and is currently being used by Derrick and co-workers north of the Duchess–Urandangi region, so its usage is considered justified on the grounds of continuity and general acceptance.

Undivided Tewinga Group

The undivided Tewinga Group crops out in the west of the Kalkadoon–Leichhardt Block. It consists of mainly gneissic rocks, some of which are migmatitic (Fig. 13), and is considered to represent a complex sequence of felsic and minor mafic volcanic rocks, interlayered sedimentary rocks which are largely volcaniclastic but include some quartz arenite, and probably some intrusions of felsic porphyry and granite, all regionally metamorphosed to the amphibolite facies. Because of structural complexities, relatively high metamorphic grade, and a lack of facing evidence and useful marker beds, no stratigraphic succession has been determined within the sequence.

Many of the gneisses are broadly banded fine to medium-grained quartzofeldspathic rocks containing wispy mafic inclusions, and are possible meta-ignimbrites (Fig. 14). Some are massive, show vaguely preserved contorted flow-banding, and probably represent metarhyolite lava. Gneissic coarse fragmental rocks, possibly representing agglomerate, are also present. The gneisses commonly contain megacrysts and augen of feldspar, which may be relict phenocrysts, and streaky clots of quartz.

The quartzofeldspathic gneisses of the undivided Tewinga Group may be correlatives of similar gneisses in the Plum Mountain Gneiss to the east and in the Sulieman Gneiss of the western area. They are generally in faulted contact with the adjacent little-metamorphosed felsic porphyries of the Leichhardt Volcanics, and were thought by Blake (1980) to be probably a much older unit separated from the Leichhardt Volcanics by a period of tectonism and regional metamorphism. However, extensively recrystallised metadacite from the undivided Tewinga Group west of Bushy Park homestead has yielded an imprecise zircon age of between 1870 and 1850 m.y. (Page, 1983a), and so may be either an extrusive or intrusive equivalent of the Leichhardt Volcanics; this metadacite is also chemically similar to the Leichhardt Volcanics (Bultitude & Wyborn, 1982). Similarities in chemistry indicate that other undivided Tewinga Group rocks may be equivalent to the Bottletree Formation (Bultitude & Wyborn, 1982).

Leichhardt Volcanics

This formation is equivalent to most of the Leichhardt Metamorphics mapped in Sheet areas to the north (and also to the informally named Standish volcanics of Blake & others, 1978; Bultitude & others, 1978; and Blake, 1980). It is termed the Leichhardt Volcanics in the Duchess–Urandangi region because it consists predominantly of readily recognisable felsic volcanic rocks, not metamorphic rocks. To designate such rocks as metamorphics is not only misleading—in that almost all other Precambrian stratigraphic units in the region are as metamorphosed or more so—but also conceals the essentially volcanic nature of the formation. Gneissic rocks previously mapped in the central area as Leichhardt Metamorphics (Carter & Öpik, 1963) are now assigned to the undivided Tewinga Group.

The Leichhardt Volcanics crop out in a series of northerly trending belts in the central and eastern parts of the Kalkadoon–Leichhardt Block. The formation consists mainly of massive porphyritic felsic ignimbrite (Fig. 15), although it also includes some flow-banded felsic lava and rare bedded volcaniclastic sedimentary rocks, tuff, and basaltic lava. A basal conglomerate containing clasts of granite is present locally in the south, where the formation overlies the

Fig. 14. Interbanded felsic fine-grained gneiss and augen gneiss (metamorphosed bedded felsic tuffs?) of the undivided Tewinga Group 25 km southeast of Dajarra (at GR UA555794). (M2633/13)

One Tree Granite. This granite is cut by dykes of porphyry which are petrographically and chemically similar to the overlying Leichhardt Volcanics.

Contacts of the Leichhardt Volcanics with the undivided Tewinga Group are either not exposed or are marked by faults. However, across contacts the degree of recrystallisation changes abruptly from little-altered porphyry (probably mainly greenschist facies) to quartzofeldspathic gneiss (amphibolite facies). This indicates that the porphyry of the Leichhardt Volcanics may be younger than the undivided Tewinga Group rocks, and may postdate a major regional metamorphic event affecting the gneissic rocks (Blake, 1981b, 1982).

The Leichhardt Volcanics are probably intruded by the Kalkadoon Granite, although relationships at some exposed contacts are equivocal. Similarities in chemistry and isotopic age indicate that these two units are comagmatic (e.g., Bultitude & Wyborn, 1982; Wyborn & Page, 1983).

No fold structures have been mapped within the belts of Leichhardt Volcanics because of the predominance of massive (unbedded) porphyries and a lack of marker units. However, in several of the belts the formation is overlain by either the Magna Lynn Metabasalt, Stanbroke Sandstone, or Makbat Sandstone preserved in synclines or half-synclines (one half 'removed' by faulting), and the belts are commonly bounded by probably older rocks (mainly undivided Tewinga Group). Hence the Leichhardt Volcanics may be largely confined to major synclinal structures and to downfaulted blocks.

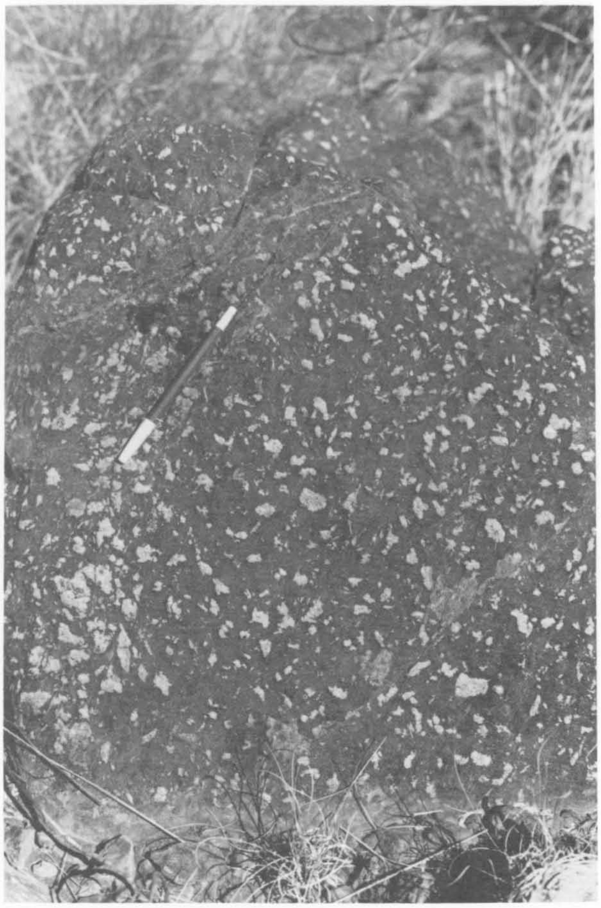


Fig. 16. Quartz-filled vesicles in mafic lava of the Magna Lynn Metabasalt 37 km north of Duchess (at GR UB807739). (M2633/14)

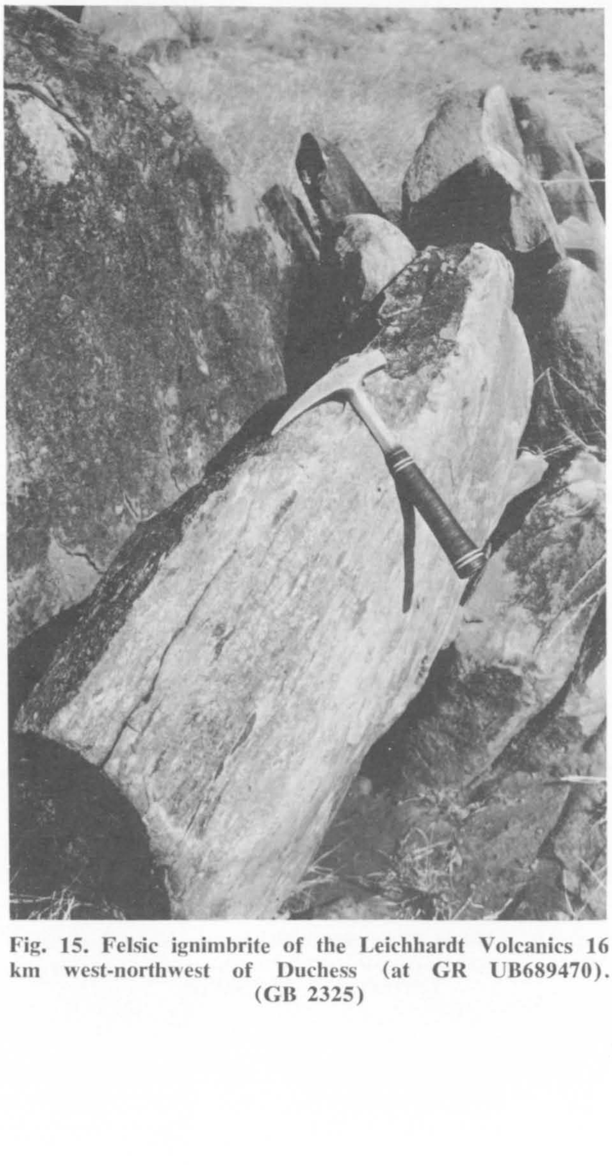


Fig. 15. Felsic ignimbrite of the Leichhardt Volcanics 16 km west-northwest of Duchess (at GR UB689470). (GB 2325)

Two samples of felsic porphyry from the Leichhardt Volcanics, one from southeast of Dajarra and the other from north of Duchess, have been isotopically dated at 1875 $^{+26}_{-19}$ m.y. (Page, 1983a), indicating that the formation is similar in age to the Leichhardt Metamorphics—dated at 1865 ± 3 m.y. (Page, 1978) —north of the region.

Magna Lynn Metabasalt and Argylla Formation

The Magna Lynn Metabasalt and conformably overlying Argylla Formation crop out in the northern part of the Kalkadoon–Leichhardt Block and in the adjoining part of the Duchess Belt. They have been regionally metamorphosed to mainly the amphibolite facies, and are most intensely deformed and recrystallised adjacent to the Bowlers Hole Granite in the Kalkadoon–Leichhardt Block and adjacent to the Corella Formation in the Duchess Belt, where the Magna Lynn Metabasalt is intruded by the Bushy Park Gneiss. The Argylla Formation north of the area has been dated at 1777 ± 7 m.y. (Page, 1978) and 1783 ± 5 m.y. (Page, 1983a).

The Magna Lynn Metabasalt consists mainly of mafic lavas (Fig. 16), but also includes some intercalated metasediment (Figs. 17, 18) and minor felsic metavolcanics of Argylla type (Fig. 19). The Argylla Formation consists mainly of felsic metavolcanics

Fig. 17. Steeply dipping beds formed mainly of mafic volcanic detritus, Magna Lynn Metabasalt near the Lady Fanny mine, 14 km north-northwest of Duchess (at GR UB748506). (GB 2364)

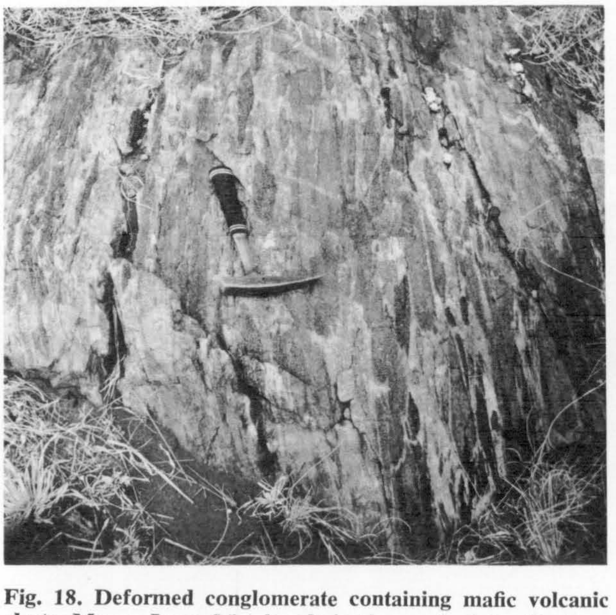


Fig. 18. Deformed conglomerate containing mafic volcanic clasts, Magna Lynn Metabasalt in the west of the Duchess Belt 9 km northwest of Duchess (at GR UB760445). (GB 2342)

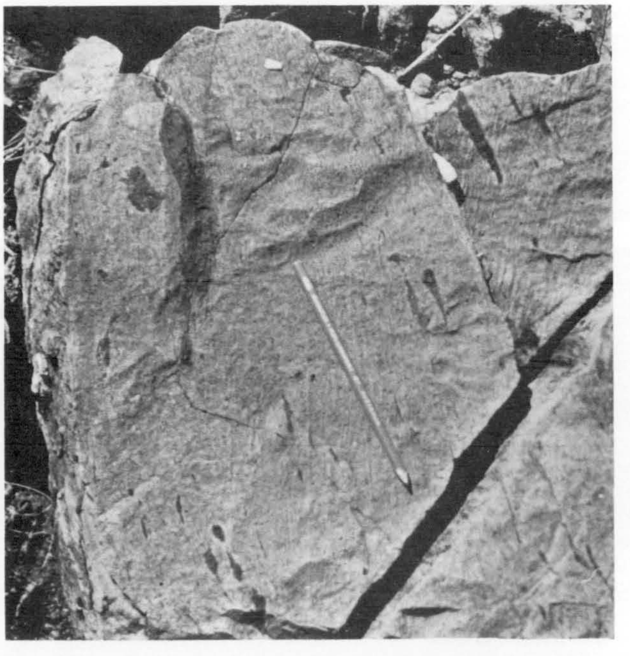


Fig. 19. Foliated felsic tuff with streaky mafic inclusions, Magna Lynn Metabasalt 38 km north of Duchess (at GR UB783756). (M2230/29)

which are generally strongly magnetic (in contrast to those of the Leichhardt Volcanics), but also includes some metasediments, especially in the upper part of the unit. Most of the felsic rocks probably represent ignimbrites, but flow-banded lava, bedded tuff and coarser fragmental rocks, and possible subvolcanic intrusive bodies are also present. At GR UB735495, the Argylla sequence includes a metabasalt lava as well as at least one flow-banded felsic lava. Some interfingering and mixing of felsic and mafic metavolcanics commonly occurs at the base of the Argylla Formation and top of the Magna Lynn Metabasalt (Fig. 20), indicating that the two formations are similar in age.

Fig. 20. A result of contemporaneous felsic and mafic volcanism—mafic lava spatter in felsic tuff at the contact between the Magna Lynn Metabasalt and Argylla Formation 39 km north of Duchess (at GR UB769766). (M2231/29)

Bottletree Formation

We consider that the Bottletree Formation (Table 6) is the oldest unit of the western succession and hence is part of the older cover sequence. However, Derrick & Wilson (1981b) and Derrick (1982) have regarded it as part of the basement. The formation crops out in the Dajarra Belt, and unconformably overlies the undivided Tewinga Group and Kalkadoon Granite along the western margin of the Kalkadoon–Leichhardt Block. Main rock types are felsic lava, ignimbrite, bedded tuff (Fig. 21), and greywacke-type sedimentary rocks, including conglomerate, but some basaltic lavas and other sedimentary rocks are also present; all of the rocks have been regionally metamorphosed to the amphibolite facies. The sediments are thought to have been deposited as fans in a partly fluvial and partly shallow-marine environment flanking a landmass to the east.

The conglomerates in the formation contain clasts derived from penecontemporaneous volcanics and from basement rocks, including granite, to the east (Fig. 22). Clasts of felsic volcanics generally predominate; many of them are intensely flattened, even where other clasts are little deformed, and may originally have been pumice.

The formation ranges in thickness from 0 to about 3000 m. This variation is attributed partly to deposition on a surface having a considerable topographic relief, and partly to localised accumulations of volcanic rocks and fanglomerate-type sediments.

The upper boundary of the formation is placed at

Fig. 21. Laminated felsic tuff in the Bottletree Formation 18 km north-northwest of Dajarra (at GR UB415175). (M2633/6)

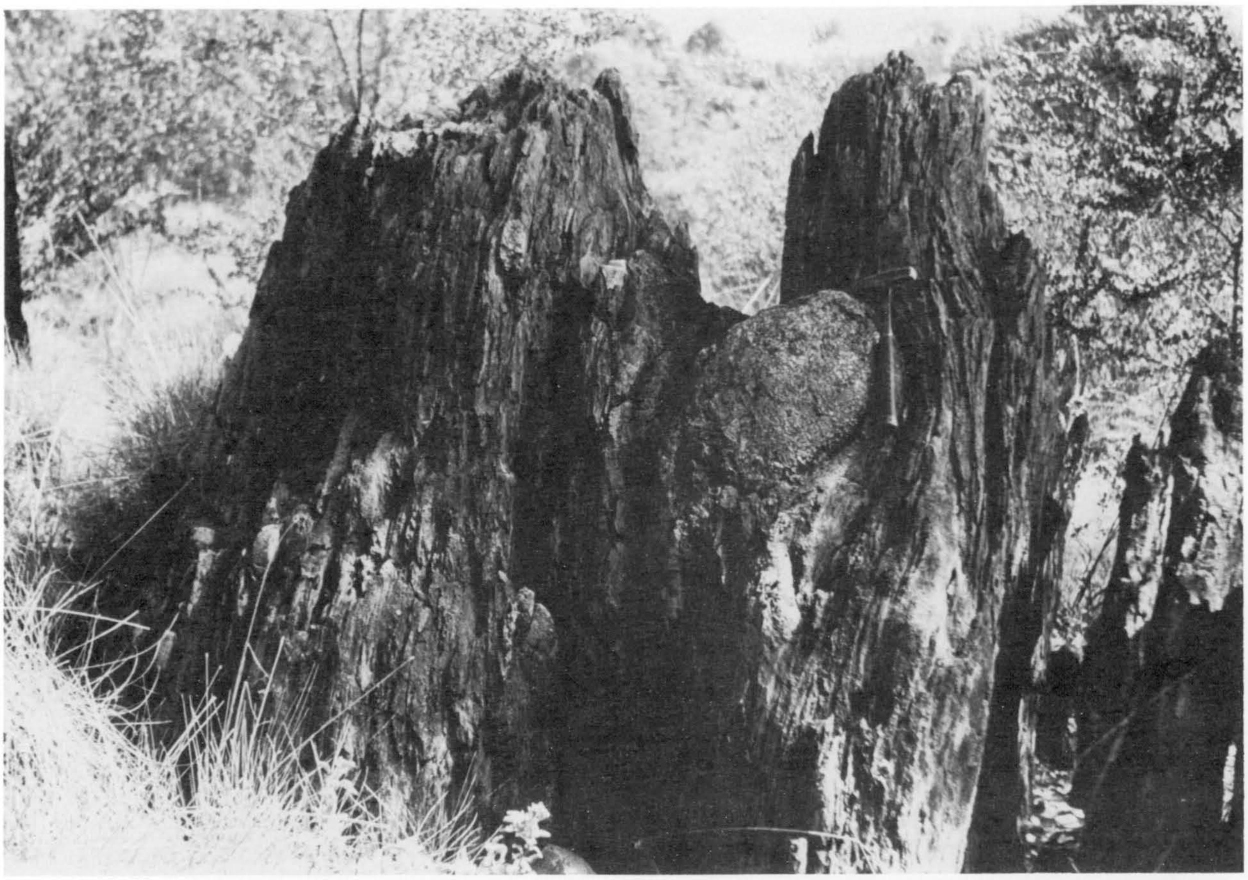


Fig. 22. Granite boulder in steeply dipping greywacke–conglomerate of the Bottletree Formation 30 km west-northwest of Duchess (at GR UB525459). (M2230/3)

the top of the uppermost readily recognisable volcanic layer. In the overlying Yappo Member of the Mount Guide Quartzite, thin beds of probable felsic tuff, greywacke-type sedimentary rocks identical with those of the Bottletree Formation, and bedding parallel to that in the Bottletree Formation are taken to indicate that the two units are conformable (e.g., Blake, 1980, 1981b); indeed Bultitude & others (1977) originally mapped the two units as a single unit, informally named the Rifle Creek beds. However, Derrick & Wilson (1981b) have suggested that the contact between the two units is an unconformity.

Metamorphosed dacitic volcanics of the Bottletree Formation from west of Bushy Park homestead and from 25 km to the north (in MARY KATHLEEN) have been isotopically dated at $1808\ ^{+22}_{-17}$ m.y. and $1790\ ^{+10}_{-8}$ m.y. respectively (Page, 1983a). In the survey of MARY KATHLEEN, the formation was mapped as Argylla Formation (Derrick & others, 1977b); its correlation with the 1780-m.y.-old Argylla Formation cropping out to the east has continued to be favoured by Derrick & Wilson (1981b), but not by Blake (1980, 1981b), who considers that the Bottletree Formation is probably the older unit.

Haslingden Group

The Haslingden Group (Table 6) crops out in the Dajarra Belt, where it is represented by the Mount Guide Quartzite, which includes the Yappo Member, and the Eastern Creek Volcanics. These units, which are part of the older cover sequence, have been regionally metamorphosed to the greenschist facies and

Fig. 23. Conglomerate in the Yappo Member of the Mount Guide Quartzite 20 km north-northwest of Dajarra (at GR UB427204). (M2633/16)

more extensively to the amphibolite facies, and are commonly schistose.

Mount Guide Quartzite

This formation is made up of a named lower member, the Yappo Member, and an unnamed upper member. The *Yappo Member* consists mainly of greywacke-type metasediments, commonly conglomeratic (Fig. 23), identical with many of the metasediments in the underlying Bottletree Formation; it similarly represents outwash fans deposited on the flanks of an elevated landmass to the east. It is equivalent to most of the lower Mount Guide Quartzite in MARY KATHLEEN, to the north (Derrick & others, 1976b, 1977b), and grades upwards into quartzose meta-arenite of the *unnamed upper member*, which is thought to have been deposited in a shallow-water nearshore environment. The upper member forms prominent hills and ridges, including Mount Guide in the north.

The Mount Guide Quartzite is intruded by mafic dykes, many of which may be related to the basaltic lavas of the overlying Eastern Creek Volcanics, although most—according to Glikson & others (1976)—postdate not only the Haslingden Group but also the Mount Isa Group.

Eastern Creek Volcanics

This formation comprises a thick sequence of metabasalt lava flows which generally form undulating terrain, and interlayered metasediments—mainly ridge-forming meta-arenites but including locally abundant conglomerate beds. No pillow lavas have been recorded, and the sequence appears to have been laid down on a shallow-marine shelf or fluvial plain which subsided at about the same rate as the rocks accumulated upon it. Traces of copper minerals are commonly present in the metabasalt lavas. Conglomerates in the sequence contain clasts of quartzite, non-magnetic felsic porphyry probably derived from the Leichhardt Volcanics to the east, and penecontemporaneous metabasalt.

TABLE 6. DETAILS OF STRATIGRAPHY—BOTTLETREE FORMATION AND HASLINGDEN GROUP, CENTRAL AREA

	Name of unit (reference to definition) max. thickness (m)	*Lithology*	*Relationships*
HASLINGDEN GROUP (Derrick & others, 1976b)	**Eastern Creek Volcanics** (Carter & others, 1961; Derrick & others, 1976b) 2000+	Massive to schistose metabasalt which is commonly amygdaloidal, brecciated metabasalt (flow-margin breccia), interlayered metasediments—medium to thin-bedded quartzose, feldspathic, and sericitic meta-arenites commonly showing cross-bedding, conglomerate, metasiltstone, recrystallised limestone, para-amphibolite (bedded basaltic tuff) *Metabasalt*: amphibolite-facies assemblages typically consist of green hornblende, oligoclase, and opaque minerals ± actinolite, albite, epidote, sphene, biotite, quartz, and calcite; greenschist-facies assemblages typically consist of albite, actinolite, quartz, titanomagnetite, epidote, chlorite, and K-feldspar	Overlies Mount Guide Quartzite with apparent conformity; overlain concordantly by Surprise Creek Formation? and unconformably (mainly disconformably) by Warrina Park Quartzite of Mount Isa Group
	Mount Guide Quartzite (Carter & others, 1961; Derrick & others, 1976b) **Unnamed upper member** 2000	Thick to thin-bedded, massive to schistose, medium-grained quartzose to micaceous meta-arenite; sericitic, feldspathic, and lithic meta-arenites; metagreywacke and metasiltstone near base; minor pebbly beds. Cross-bedding common throughout, and ripple marks common in upper part	Overlies Yappo Member conformably and Kalkadoon Granite and undivided Tewinga Group unconformably; overlain concordantly by Eastern Creek Volcanics. Intruded by Garden Creek Porphyry and by mafic and minor felsic dykes
	Yappo Member (Blake & others, 1981a) 2750	Pebbly and gritty metagreywacke and metagreywacke-conglomerate; minor meta-arkose, sericitic, feldspathic, and quartzose meta-arenites, sericite schist, muscovite-biotite schist, metasiltstone, epidotic quartzite, metabasalt, and pink to grey recrystallised felsic tuff?. Cross-bedding present in places *Conglomerate*: clasts of felsic volcanics (including flattened possible pumice), quartzite, vein quartz, granitic to dioritic plutonic rocks, mica schist, amphibolite, and phyllite in a generally abundant matrix containing biotite ± muscovite ± epidote ± chlorite; clasts commonly moderately to highly deformed	Unconformable on Kalkadoon Granite and undivided Tewinga Group; conformable on Bottletree Formation. Intruded by mafic and some felsic dykes
	Bottletree Formation (Blake & others, 1981a) 3000	Interlayered pink to grey rhyolitic to dacitic metavolcanics (pyroclastics and lava flows), and metamorphosed greywacke and greywacke-conglomrate (identical with that in overlying Yappo Member); subordinate metabasalt, mainly near base and quartzite, epidotic quartzite, and thinly banded para-amphibolite (probably mafic tuff) *Felsic metavolcanics*: commonly magnetic, massive to foliated; lavas show contorted flow banding, quartz-filled vesicles, and recrystallised spherulites, and contain sparse to abundant pheno-recrystalised quartz ± biotite ± hornblende in recrystallised quartzofeldspathic groundmass crysts of feldspar (mainly plagioclase) ± commonly rich in biotite and magnetite and locally containing metamorphic garnet *Metabasalt*: schistose to massive, commonly amygdaloidal; consists mainly of green hornblende and oligoclase	Unconformable on Kalkadoon Granite and undivided Tewinga Group; overlain conformably by Mount Guide Quartzite (mainly Yappo Member). Intruded by mafic dykes

The Eastern Creek Volcanics may be similar in age to the Magna Lynn Metabasalt exposed farther east in the central area, and to the Jayah Creek Metabasalt and Oroopo Metabasalt of the western area. The formation has been correlated with the Marraba Volcanics, which overlie the Argylla Formation in the eastern area (e.g., Carter & others, 1961; Plumb & Derrick, 1975; Plumb & others, 1980), but Blake (1980) considers it to be older than both these formations.

Mary Kathleen Group

In the central area the Mary Kathleen Group of Derrick & others (1977a) is represented by the Ballara Quartzite, Corella Formation, and Corella Formation? (Table 7). These units crop out in the Kalkadoon–Leichhardt Block and the Duchess Belt. As rocks assigned by previous workers to the Corella Formation here and in MARY KATHLEEN to the north may be of two or more different ages, as suggested by Blake (1980, 1981b, 1982), those that cannot be correlated with reasonable confidence to the type section of the Corella Formation in MARRABA are shown as Corella Formation? on the Duchess–Urandangi region map.

Ballara Quartzite

The Ballara Quartzite is exposed in the northern part of the central area, where it delineates a north-plunging syncline truncated to the north by the Fountain Range Fault. It probably represents nearshore shallow-shelf sediments (Derrick & others, 1977b), and may be partly a correlative of the Stanbroke and Makbat Sandstones, also of the central area, and the

TABLE 7. DETAILS OF STRATIGRAPHY—STANBROKE SANDSTONE, MAKBAT SANDSTONE, AND MARY KATHLEEN GROUP, CENTRAL AREA

	Name of unit (reference to definition) max. thickness (m)	*Lithology*	*Relationships*
	Stanbroke Sandstone (Blake & others, 1981a) 300	Quartzose, feldspathic, calcareous, dolomitic, and sericitic arenites; subordinate dolomite, limestone, marl, calcareous and non-calcareous siltstone, micaceous greywacke, and, at or near base, arkose and conglomerate. Beds range from thick to thin and commonly show cross-bedding; ripple marks are present in places. Basal conglomerate contains clssts of porphyritic felsic volcanics and, in places, meta-arenite, quartzite, and altered basalt in arkosic matrix	Unconformable on Leichhardt Volcanics and locally on Magna Lynn Metabasalt and Argylla Formation. Inferred to be unconformable on undivided Tewinga Group and Wills Creek Granite. Intruded by metadolerite dykes in N
	Makbat Sandstone (Carter, 1959; Carter & others, 1961) 300+	Feldspathic and quartzose arenites; subordinate greywacke, siltstone, shale, conglomerate, and volcaniclastic arenite (at base); rare possibly stromatolitic chert; generally ironstained. Beds are mainly medium or thin-bedded, commonly cross-bedded, and locally ripple-marked	Overlies Leichhardt Volcanics with presumed unconformity. Probably overlies Wills Creek Granite. Cut by dolerite dyke.
MARY KATHLEEN GROUP (Derrick & others, 1977a)	**Corella Formation** (Carter & others, 1961; Derrick & others, 1977a) 1000+	Thinly banded pink, green, and grey, granulitic to gneissic calc-silicate rocks; subordinate massive to schistose mafic and felsic metavolcanics, amphibolite, meta-arenite, quartzite, calc-silicate breccia, marble, skarn, quartz–mica schist, hornblende-biotite schist, sillimanite-bearing schist, massive to banded ironstone, probably carbonaceous metasiltstone (in NE), possibly intrusive dioritic gneiss (in S), quartzofeldspathic biotite gneiss (NW of Mayfield homestead), and cordierite–anthophyllite rock *Calc-silicate rocks*: variably scapolitic, amphibolitic, siliceous, calcareous, feldspathic (albite and/or microcline), and diopsidic/salitic; commonly contain sphene, epidote, and/or garnet; wollastonite, vesuvianite, and clinohumite? present locally. *Mafic metavolcanics*: mainly lavas, commonly amygdaloidal; typically consist of green hornblende + plagioclase (An>18) + opaque minerals ± scapolite ± clinopyroxene ± sphene ± quartz; fibrolitic sillimanite present in possible amygdales E of The Monument *Felsic metavolcanics*: pink to grey, medium to very fine-grained granulitic quartzofeldspathic rocks, commonly containing feldspar and quartz phenocrysts; represent ignimbritic deposits, tuffs, and possible lavas *Meta-arenite and quartzite*: some calcareous and pebbly beds; poorly preserved cross-bedding and graded bedding apparent in places	Concordant contacts to W with Magna Lynn Metabasalt and Argylla Formation in N and Plum Mountain Gneiss in S. Intruded by Overlander, Revenue, Saint Mungo, and possibly Birds Well Granites, Bushy Park Gneiss, Mount Erle and Myubee Igneous Complexes, Mount Philp Breccia, tourmaline-bearing quartz-feldspar pegmatite, metadolerite, and dolerite
	Corella Formation? ~200	Scapolitic and amphibolitic bedded calc-silicate rocks; mainly grey	Conformable on Ballara Quartzite. Contacts with Magna Lynn Metabasalt and Bushy Park Gneiss probably faulted
	Ballara Quartzite (Carter & others, 1961; Derrick & others, 1977a) 500	Medium to thin-bedded, medium to fine-grained, sericitic meta-arenite and quartzite, commonly showing cross-bedding and ripple marks outlined by laminae rich in heavy minerals; in upper part some interbedded banded scapolitic calc-silicate granofels, cordierite–anthophyllite rock, scapolitic biotite schist, and laminated siliceous, pyritic biotite-rich meta-argillite; local conglomeratic and arkosic meta-arenite at base	Concordant and possibly conformable on Argylla Formation; overlain conformably by Corella Formation?. May be intruded by metadolerite.

Mitakoodi Quartzite of the eastern area. It has been regionally metamorphosed to the amphibolite facies.

The nature of the contact between the Ballara Quartzite and underlying Argylla Formation has been discussed at some length by Blake (1980, 1981b) and Derrick & Wilson (1981b). Derrick & Wilson maintain that this contact is a major unconformity representing the period during which the sediments of the Haslingden and Malbon Groups were deposited to the west and east, respectively. Blake, on the other hand, suggests that the contact does not mark a significant time break, and that in places the Ballara Quartzite may interfinger with felsic volcanics of the Argylla Formation.

Corella Formation and Corella Formation?

The *Corella Formation*, a unit consisting of bedded calc-silicate rocks (Fig. 24) which are commonly scapolitic (Fig. 25), other metasediments, and interlayered felsic and mafic metavolcanics, is exposed in a broad band up to 11 km wide in the Duchess Belt, along the eastern margin of the central area. It is bounded to the east by the Pilgrim Fault Zone, and to the west by intensely deformed metamorphic rocks assigned to the Magna Lynn Metabasalt, Argylla Formation, Bushy Park Gneiss, and Plum Mountain Gneiss, and by the Saint Mungo Granite. Probably intrusive felsic gneiss assigned to the Bushy Park Gneiss is interbanded with calc-silicate rocks of the Corella Formation northwest of Mayfield homestead (Bultitude & others, 1982).

The calc-silicate rocks are considered to represent metamorphosed impure calcareous and dolomitic sediments deposited in a shallow-marine and locally evaporitic environment. The formation is tightly folded about generally steeply dipping to vertical axial planes (Fig. 26), and mineral assemblages indicate regional metamorphism to the amphibolite facies. Banding in the calc-silicate rocks generally represents bedding, but transposed bedding (metamorphic layering) is apparent locally (Fig. 27).

The scapolite in the metasediments is thought to have formed during regional metamorphism of halite-bearing beds (Ramsay & Davidson, 1970), rather than resulting from regional soda-metasomatism accompanied by the introduction of chlorine, as suggested

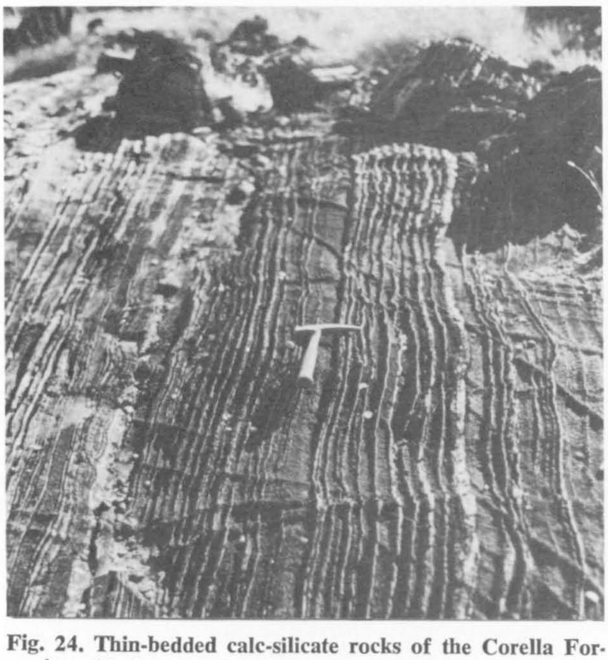


Fig. 24. Thin-bedded calc-silicate rocks of the Corella Formation 11 km north of Duchess (at GR UB790485). (M2443/6)

Fig. 25. Densely packed scapolite porphyroblasts in calc-silicate rock, Corella Formation 36 km north of Duchess (at GR UB843738). (M2633/17)

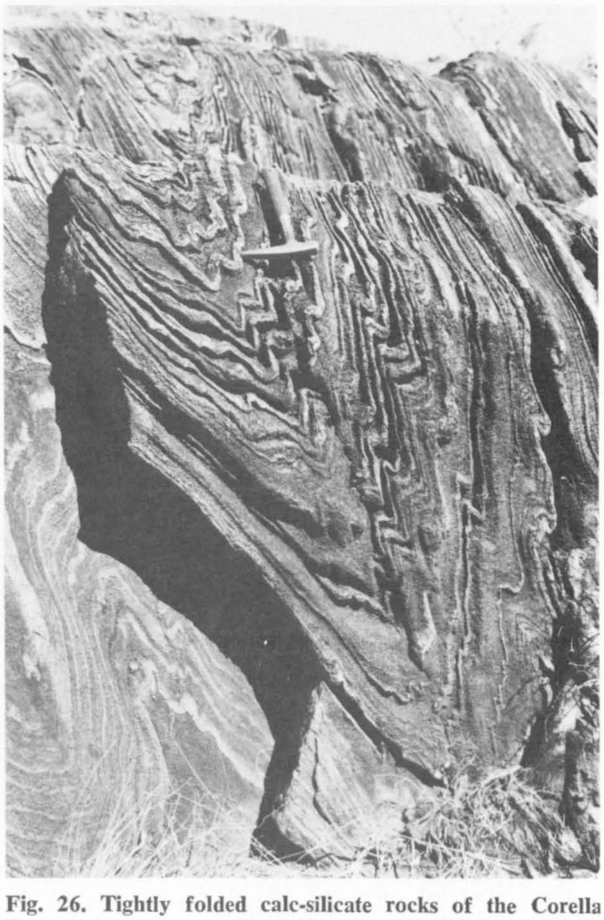


Fig. 26. Tightly folded calc-silicate rocks of the Corella Formation 11 km north of Duchess (at GR UB790485). (M2443/29)

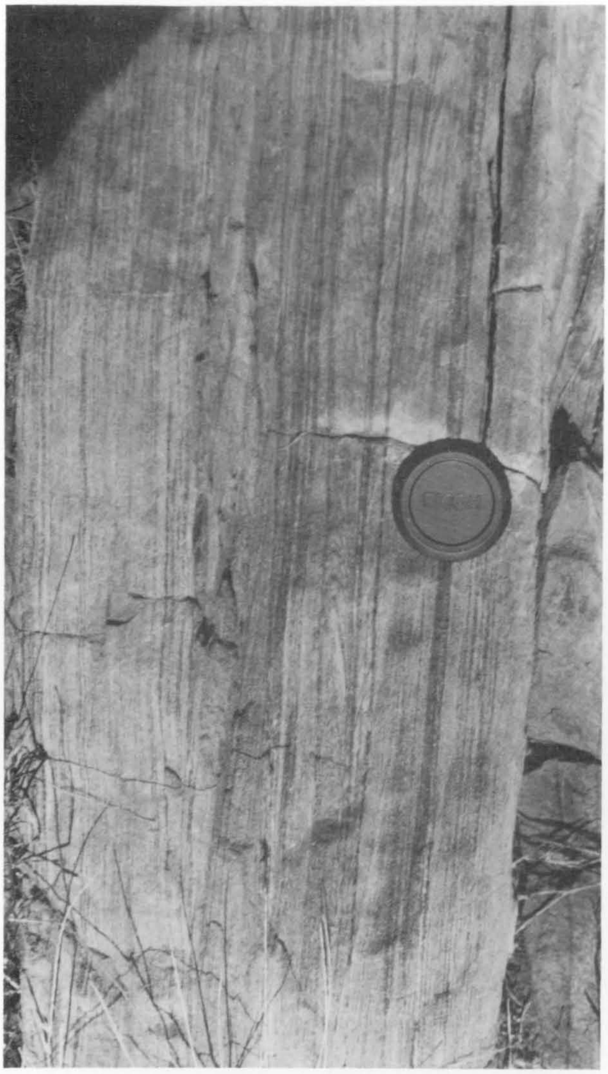


Fig. 27. Transposed bedding in calc-silicate rocks of the Corella Formation 15 km north of Duchess (at GR UB835535). (M2633/34A)

by Edwards & Baker (1954). Scapolite present in associated metamorphosed igneous rocks presumably formed during the same regional metamorphic event, when these rocks recrystallised—probably in the presence of chlorine-rich fluids derived from adjacent sediments (Ramsay & Davidson, 1970).

Rocks mapped as *Corella Formation?* crop out northwest of Duchess, mainly in the centre of the north-plunging syncline truncated by the Fountain Range Fault. Here grey scapolitic and amphibolitic calc-silicate rocks, representing calcareous siltstone and arenite and impure limestone regionally metamorphosed to the amphibolite facies, lie conformably on the Ballara Quartzite. The unit is more extensively exposed in MARY KATHLEEN to the north, where it has been mapped as Corella Formation (Derrick & others, 1977b), but its correlation with the main belt of the Corella Formation to the east, which contains the type section of the formation (Carter & others, 1961), is doubted by Blake (see below).

The possibility that the Corella Formation in the central area, and in MARY KATHLEEN and MARRABA to the north, may represent two or more quite separate stratigraphic units was suggested by Blake (1980) and has since been discussed by Derrick & Wilson (1981b), who refute the possibility, and by Blake (1981b, 1982). The Corella Formation (= 'old' Corella Formation of Blake, 1980) differs from the Corella Formation? exposed to the west (= 'young' Corella Formation of Blake, 1980) in lithology, thickness, stratigraphic relationships, and perhaps geological history (Blake, 1982): (1) it contains abundant felsic and mafic volcanics; (2) north of the Duchess–Urandangi region it is reported to be at least 2000 m thick and may be 4000 m or more thick, whereas the 'young' Corella Formation has a maximum thickness of about 1260 m; (3) its stratigraphic relationships are uncertain, as it cannot be shown, beyond reasonable doubt, to overlie the Ballara Quartzite or to underlie an equivalent of the Deighton Quartzite (which overlies the 'young' Corella Formation in MARY KATHLEEN); and (4) it appears to have been metamorphosed and deformed before it was intruded by granite plutons and rhyolite dykes 1740–1720 m.y. ago (e.g., Derrick, 1980; Plumb & others, 1980; Bultitude & others, 1982), whereas the 'young' Corella Formation was not metamorphosed or significantly deformed until after the Mount Albert Group (which includes the Deighton Quartzite) and probably also the 1670-m.y.-old Mount Isa Group had been deposited. The lithologic and thickness differences may be due to lateral facies changes, as stated by Derrick & Wilson (1981b), or may indicate that the two units are not correlatives, the interpretation favoured by Blake.

Stanbroke Sandstone

This formation, which consists mainly of ridge-forming arenites (Table 7), crops out within the Kalkadoon–Leichhardt Block in narrow northerly trending synclinal belts partly bounded by faults. The arenites probably represent shallow-marine sediments. They generally appear to be little metamorphosed, except near faults, where they are locally sheared, brecciated, and silicified. Possible correlatives are the Makbat Sandstone in the south and the Ballara Quartzite, Corella Formation?, and Surprise Creek Formation? in the north. Like the Ballara Quartzite the Stanbroke Sandstone differs from the Makbat Sandstone and Surprise Creek Formation? (but not from the Surprise Creek Formation of Derrick & others, 1980, north of the Duchess–Urandangi region) in generally containing calcareous and/or dolomitic beds, but unlike the Ballara Quartzite it mostly lies directly on the Leichhardt Volcanics rather than on the Argylla Formation.

Makbat Sandstone

The Makbat Sandstone (Table 7) forms low ranges in the southern part of the Kalkadoon–Leichhardt Block, cropping out in the troughs of relatively open north-northwesterly trending synclines. Like its possible correlative, the Stanbroke Sandstone, the formation was probably deposited in a shallow-marine environment. It appears to be little-metamorphosed, and generally overlies little-metamorphosed felsic porphyries of the Leichhardt Volcanics.

Carters Bore Rhyolite?

Interbedded porphyritic rhyolitic tuff and quartzite exposed in the far south of the Dajarra Belt are mapped as Carters Bore Rhyolite? (Table 8) and hence as part of the younger cover sequence. The stratigraphic relationships of these rocks are uncertain.

Surprise Creek Formation?

Clastic sedimentary rocks mapped as Surprise Creek Formation? (Table 8) crop out in the north, on the western side of the Kalkadoon–Leichhardt Block. They form prominent ridges which continue north into MARY KATHLEEN, where they were mapped as Surprise Creek beds by Derrick & others (1977b). The unit, which has been regionally metamorphosed only to the greenschist facies, may be partly or entirely equivalent to either the Surprise Creek Formation or the Quilalar Formation of Derrick & others (1980). Other possible correlatives are the Myally Subgroup (Derrick & others, 1976b), which forms the upper part of the Haslingden Group north of the Duchess–Urandangi region, the Ballara Quartzite and Stanbroke Sandstone to the east, and the Mount Isa Group to the west.

Mount Isa Group

Rocks assigned to the Mount Isa Group (Table 8) are preserved in partly fault-bounded synclinal belts in the Dajarra Belt, where they have been tightly folded and regionally metamorphosed to the greenschist facies. Four constituent formations, each consisting of probably shallow-water sedimentary rocks, have been distinguished. These are, from oldest to youngest, the *Warrina Park Quartzite*, the *Moondarra Siltstone*, which is host to several small copper mines and prospects, the *Breakaway Shale*, which forms low rubbly ridges with a moderately sparse vegetation, and the *Native Bee Siltstone?*, which may alternatively be part of the Moondarra Siltstone. Non-faulted contacts between the Warrina Park Quartzite and underlying Haslingden Group rocks (Eastern Creek Volcanics) are mainly concordant, but are locally discordant; this discordance appears to be due to tilting, rather than folding, before the Mount Isa Group was deposited. The group has been isotopically dated north of the region at about 1670 m.y. (Page, 1981b).

Kalkadoon Batholith

The Kalkadoon Batholith is made up of the One Tree, Kalkadoon, Wills Creek, and Woonigan Granites and a small body of unnamed porphyritic monzonite (Table 9), all of which were mapped as Kalkadoon Granite by Carter & others (1961) and Carter & Öpik (1963). It probably consists of numerous plutons, and may have been emplaced over several million years.

The *One Tree Granite* forms a large intrusion of mainly foliated biotite granite in the southeastern part of the Kalkadoon–Leichhardt Block. It is exposed as low hills and tors, as scattered spheroidal boulders on flat to gently undulating terrain, and as small mesas capped by weathered granite and laterite. Ten kilometres south-southeast of Stanbroke homestead the granite is overlain by felsic porphyries of the Leichhardt Volcanics: a thin bed of conglomerate locally present underlying the volcanics contains fragments of the granite, and felsic dykes similar in chemical composition to the volcanics intrude the granite in the general vicinity.

The *Kalkadoon Granite* forms a large composite body extending along the western side of the Kalkadoon-Leichhardt Block from south of the Duchess–

TABLE 8. DETAILS OF STRATIGRAPHY—CARTERS BORE RHYOLITE?, SURPRISE CREEK FORMATION?, AND MOUNT ISA GROUP, CENTRAL AREA

	Name of unit (reference to definition) max. thickness (m)	*Lithology*	*Relationships*
MOUNT ISA GROUP (Derrick & others, 1976c)	**Native Bee Siltstone?** Bennett, 1965; Derrick & others, 1976c) 200?	Dolomitic siltstone, siltstone, and possible carbonaceous shale	Concordant with Breakaway Shale? in N
	Breakaway Shale (Bennett, 1965; Derrick & others, 1976c) 200?	Grey, black, and brown, intensely cleaved carbonaceous, calcareous?, and siliceous shale and siltstone; pyrite casts, gossany zones, and small-scale folds and flexures common; small-scale cross-bedding and possible graded bedding present in places. Isoclinally folded in S	Conformable on Moondarra Siltstone
	Moondarra Siltstone (Bennett, 1965; Derrick & others, 1976c) 200+	Thinly bedded, generally cleaved siltstone which is commonly pyritic and dolomitic and locally shows cross-bedding; minor interbedded black-weathering limestone and brown-weathering dolomite; complex small-scale folds common	Conformable on Warrina Park Quartzite
	Warrina Park Quartzite (Derrick & others, 1976c 600	Quartzose, sericitic, and ferruginous meta-arenite, quartzite, conglomerate (at or near base), and minor siltstone. Cross-bedding is common, and pyrite casts and laminae rich in heavy minerals are present locally. Basal conglomerate contains clasts of quartzite, meta-arenite, and rare meta-basalt and granite	Unconformable (mainly disconformable) on Eastern Creek Volcanics; may disconformably overlie Carters Bore Rhyolite? in S
	Surprise Creek Formation? (Derrick & others, 1980) 700	Thin to medium-bedded, fine to medium-grained feldspathic and quartzose arenite and siltstone; minor interbedded conglomerate, grit, sericitic arenite, and ferruginous shale. Beds are locally silicified and in places show ripple marks and poorly developed cross-bedding. Conglomerate near base contains clasts of quartzite, meta-arenite, and commonly flattened felsic volcanics (deformed pumice?)	Unconformable on Kalkadoon Granite; concordant (disconformable?) with underlying Eastern Creek Volcanics
	Carters Bore Rhyolite? (Derrick & others, 1978) 200	Finely banded bluish grey rhyolitic tuff, containing small phenocrysts of quartz and alkali feldspar, interbedded with quartzite	Inferred to be faulted against Mount Guide Quartzite to E; overlain disconformably by possible Warrina Park Quartzite to W

Urandangi region northwards for more than 250 km. In the central area it consists mainly of massive to intensely foliated, commonly porphyritic (Fig. 28) biotite granite and granodiorite, which are exposed as tors, low hills, and undulating terrain with scattered spheroidal boulders.

Samples of the Kalkadoon Granite from the Cloncurry 1:250 000 Sheet area, to the north, have been dated at 1862 $^{+27}_{-21}$ m.y. (Page, 1978), and a similar age (1856 $^{+11}_{-9}$ m.y.) has been obtained on a sample of the granite from 24 km south-southeast of Dajarra (Wyborn & Page, 1983). These are the oldest granite ages so far determined by the U–Pb zircon method in the Mount Isa Inlier. The Kalkadoon Granite intrudes the undivided Tewinga Group and probably the Leichhardt Volcanics (with which it is considered to be comagmatic), but it predates the Magna Lynn Metabasalt and Argylla Formation of the Tewinga Group. It is also older than the Bottletree Formation and Haslingden Group, which overlie it to the west.

Migmatitic complexes are developed where gneissic rocks of the undivided Tewinga Group are intricately veined by the Kalkadoon Granite. Small net-veined complexes (Blake, 1981a) are present at a few localities where mafic dykes appear to have intersected partly molten granite. Recrystallisation and foliation effects and cross-cutting metamorphosed dolerite dykes show that the granite has been regionally metamorphosed to the greenschist facies and, more extensively, to the amphibolite facies; Rb–Sr isotopic data indicate

TABLE 9. GRANITES OF THE KALKADOON BATHOLITH, CENTRAL AREA

Name of unit (reference to definition)	*Lithology*	*Relationships*
Wills Creek Granite (Blake & others, 1981a)	Pink to buff, massive (non-foliated), medium to coarse-grained, even-grained to slightly porphyritic, generally leucocratic biotite granite; minor aplite which is pyritic in places, and rare porphyritic microgranite *Granite*: generally deeply weathered and friable; consists of strained quartz, microcline/orthoclase and generally subordinate plagioclase, less than 5 percent biotite, and accessory and secondary allanite, apatite, chlorite (mainly after biotite), epidote/clinozoisite, muscovite, sericite, sphene, and zircon; no myrmekite recorded	Intrudes undivided Tewinga Group, Leichhardt Volcanics, and probably One Tree and Kalkadoon Granites; cut by mafic dykes. Probably overlain by Stanbroke Sandstone and Makbat Sandstone
Woonigan Granite (Blake & others, 1981a)	Pale pink, massive (non-foliated), coarse to fine-grained, even-grained to slightly porphyritic leucocratic biotite granite which contains sparse small mafic xenoliths and, in places, inclusions of Leichhardt Volcanics and Kalkadoon Granite; minor aplite and porphyritic microgranite *Granite*: Generally deeply weathered and friable; petrographically similar to Wills Creek Granite	Intrudes Leichhardt Volcanics, undivided Tewinga Group, and Kalkadoon Granite; cut by dykes of metadolerite and porphyritic granophyre. Granite mapped as Woonigan Granite? 11 km WSW of Duchess intrudes undivided Tewinga Group
Kalkadoon Granite (Carter & others, 1961)	Pink to pale grey, massive to intensively foliated, medium to coarse-grained biotite granite and granodiorite, commonly containing feldspar phenocrysts up to 5 cm long, small mafic xenoliths, and larger inclusions of country rocks; minor tonalite, leucogranite, microgranite, porphyritic granophyre, diorite, aplite, and pegmatite *Granitic rocks*: consist of strained and recrystallised quartz; oligoclase/andesine showing alteration to sericite/muscovite and epidote/clinozoisite; microcline; 5–15 percent biotite which generally forms fine-grained aggregates, some pseudomorphing hornblende and/or pyroxene, and is commonly partly altered to chlorite and epidote; and accessory opaque minerals, apatite, zircon ± hornblende, monazite, muscovite, sphene, and metamict minerals (mainly allanite); myrmekite is commonly present *Inclusions*: schist, quartzite, meta-arkose, amphibolite, diorite, and, especially near contacts with undivided Tewinga Group and Leichhardt Volcanics, recrystallised felsic volcanics. Some metadolerite inclusions have rounded, pillow-like shapes and may form the mafic component of small net-veined complexes	Intrudes and locally forms migmatitic complexes with undivided Tewinga Group; probably intrudes Leichhardt Volcanics; intruded by Woonigan Granite, Birds Well Granite, and probably Wills Creek Granite, by innumerable mafic dykes, and by some felsic dykes. Overlain by Bottletree Formation, Mount Guide Quartzite (mainly Yappo Member), and Surprise Creek Formation?
Unnamed monzonite	Generally massive (non-foliated) monzonite, consisting of pink tabular phenocrysts of microcline and scattered small xenoliths in a grey medium-grained granitic groundmass of microcline and plagioclase in about equal amounts, about 15 percent chloritised biotite, and accessory apatite, zircon, and opaque minerals	May be overlain by Leichhardt Volcanics and intruded by dykes of felsic porphyry
One Tree Granite (Blake & others, 1981a)	Pale pink to pale grey, massive intensely foliated, medium to coarse-grained biotite granite, and dark grey, slightly foliated to gneissic, finer-grained biotite granite; minor microgranite, aplite, and pegmatite *Granites*: Commonly contain feldspar phenocrysts and scattered small xenoliths; consist of about equal amounts of plagioclase, microcline, and strained quartz, up to about 30 percent biotite, and acessory and secondary allanite, apatite, chlorite, epidote, opaque minerals, sericite, sphene, and zircon	Intrudes Plum Mountain Gneiss and probably undivided Tewinga Group; inferred to be intruded by Wills Creek Granite and Birds Well Granite?. Overlain by Leichhardt Volcanics, and cut by felsic dykes related to these volcanics; also cut by mafic dykes

Fig. 28. Porphyritic Kalkadoon Granite 30 km west of Duchess (at GR UB533454). (M2231/3)

that this metamorphism took place no earlier than 1640 m.y. ago (Wyborn & Page, 1983).

The *Woonigan Granite* forms mainly poorly exposed plutons spatially associated with the Kalkadoon Granite in the northern half of the area. It consists mostly of non-foliated leucocratic biotite granite which may be correlated with the Wills Creek Granite to the south and with leucocratic granite mapped as part of the Kalkadoon Granite (part of unit Ꝑgk_2) in MARY KATHLEEN, to the north (Derrick & others, 1977b). Biotite granite mapped as possible Woonigan Granite west and southwest of Duchess may be a more mafic variant.

Several separate bodies of *Wills Creek Granite,* forming mainly low hills and undulating terrain, are present in the southern half of the central area. The granite is readily distinguished from nearby Kalkadoon Granite and One Tree Granite by its non-foliated, even-grained leucocratic character. It intrudes the Leichhardt Volcanics, which are baked and recrystallised to hornfels adjacent to it. $^{207}Pb/^{208}Pb$ data on zircon from the granite indicate a minimum age of 1830 m.y., which is similar to the minimum ages of zircon fractions from the Kalkadoon Granite (Wyborn & Page, 1983).

A small body of *unnamed porphyritic monzonite* is exposed 20 km northeast of Dajarra. On the western side of the body, rubbly, rather than hornfelsic porphyry of the Leichhardt Volcanics appears to grade laterally into rubbly (regolithic?) monzonite, and at least one dyke-like body of felsic porphyry occurs within the monzonite, indicating that the monzonite may predate the Leichhardt Volcanics.

Wonga Batholith

The Wonga Batholith, which lies mainly to the east of the Kalkadoon–Leichhardt Block, is made up of several discrete intrusions, most of which are clearly younger than most granites of the Kalkadoon Batho-

TABLE 10. GARDEN CREEK PORPHYRY, MOUNT PHILP BRECCIA, AND GRANITES OF THE WONGA BATHOLITH, CENTRAL AREA

Name of unit (reference to definition)	*Lithology*	*Relationships*
Garden Creek Porphyry (Blake & others, 1981a)	Massive to locally sheared and quartz-veined porphyritic microgranite and minor metadolerite (at margins) *Microgranite*: contains abundant phenocrysts of andesine and microcline, some more than 1 cm across, and smaller rounded phenocrysts of strained and recrystallised quartz in a pink to grey fine-grained groundmass of quartz + microcline + sodic plagioclase + biotite + opaque minerals (including magnetite) + accessory apatite, muscovite, and zircon, and secondary chlorite and epidote/clinozoisite; also contains biotite-rich xenoliths, some with small feldspar euhedra *Metadolerite*: consists mainly of green hornblende and variably altered plagioclase	Intrudes Mount Guide Quartzite
Mount Philp Breccia (Blake & others, 1981a)	Breccia of angular to rounded fragments (derived from adjacent Corella Formation) enclosed in a pink to red matrix containing amphibole phenocrysts and miarolitic cavities in a groundmass formed mainly of albite laths	Intrudes Corella Formation and metadolerite; may be intruded by dolerite
WONGA BATHOLITH **Birds Well Granite** (Blake & others, 1981a)	Massive to intensely foliated and gneissic, slightly to richly porphyritic, medium to coarse-grained biotite granite; minor quartzofeldspathic gneiss (locally garnetiferous), augen gneiss, hornblende–biotite granite, aplite, and microgranite; rare pegmatite; scattered mafic xenoliths; inclusions of gneissic granodiorite, granite, and calc-silicate rocks present in places *Granitic rocks*: consist mainly of quartz + microcline + plagioclase largely altered to sericite + biotite ± dark blue-green hornblende; accessory and secondary minerals include allanite, chlorite, epidote, muscovite, opaque minerals, sphene, zircon, and, in places, abundant scapolite; myrmekite is commonly present	Intrudes Leichhardt Volcanics, Magna Lynn Metabasalt, Argylla Formation, Kalkadoon Granite, and perhaps Corella Formation (possible source of calc-silicate inclusions). Birds Well Granite? in S intrudes Plum Mountain Gneiss, probably One Tree Granite, and possibly Saint Mungo Granite. Cut by metadolerite dykes

TABLE 10.—(*Continued*).

Name of unit (reference to definition)	*Lithology*	*Relationships*
Bowlers Hole Granite (Blake & others, 1981a)	Foliated to gneissic, slightly porphyritic, medium-grained biotite-hornblende granite; minor gneissic biotite granite, microgranite, aplite, pegmatite, and dark contaminated? granite; inclusions of recrystallised mafic rocks, probable felsic metavolcanics, and coarse-grained granite common *Granite*: shows reduction in grainsize towards intrusive contacts; consists mainly of granular aggregates of quartz + plagioclase (largely altered to muscovite/sericite) + microcline + dark blue-green hornblende + generally subordinate biotite; accessory and secondary minerals recorded are allanite, calcite, chlorite, epidote, muscovite/sericite, opaque minerals, sphene, and zircon; myrmekite is uncommon	Intrudes Leichhardt Volcanics, Magna Lynn Metabasalt, and probably Argylla Formation; cut by schistose metadolerite dykes
Bushy Park Gneiss (Blake & others, 1981a)	Medium to coarse-grained hornblende-biotite quartzofeldspathic gneiss commonly containing augen (deformed phenocrysts), slightly to intensely foliated (gneissic) porphyritic biotite-hornblende granite; minor biotite granitic gneiss, fine-grained leucogneiss, medium to coarse-grained leucogranite, aplite, and tourmaline-bearing pegmatite. Gneisses are locally scapolitic. Myrmekite and inclusions of amphibolite, quartzite, and felsic metavolcanics? are common	Intrudes Magna Lynn Metabasalt and Corella Formation
Mairindi Creek Granite (Blake & others, 1981a)	Medium to coarse-grained foliated biotite granite and minor aplite. Foliation locally crenulated *Granite*: contains scattered phenocrysts of microcline, quartz, and rare plagioclase in groundmass of quartz + plagioclase + microcline + biotite + accessory muscovite, blue-green hornblende, opaque minerals, allanite, and fluorite	Intrudes Magna Lynn Metabasalt and Argylla Formation; cut by metadolerite dykes
Overlander Granite (Blake & others, 1981a)	Massive to foliated, leucocratic, medium to coarse-grained, even-grained to slightly porphyritic hornblende-biotite granite; minor pegmatite and aplite	Intrudes Corella Formation and metadolerite; cut by dolerite dyke
Revenue Granite (Blake & others, 1981a)	Similar to Overlander Granite. Contains sparse mafic xenoliths and large inclusions of calc-silicate rocks. Crenulated gneissic granite present in places	Intrudes Corella Formation and metadolerite
Mount Erle Igneous Complex (Blake & others, 1981a)	Granite, metadolerite/gabbro, dioritic hybrid rocks, and inclusions of calc-silicate rocks: minor pegmatite, aplite, and veinlets of prehnite. Granite and metadolerite form net-veined complexes *Granite*: leucocratic, medium to fine-grained, locally slightly porphyritic, generally foliated and recrystallised; consists of quartz + orthoclase or microcline + sodic plagioclase + minor biotite and green hornblende, and accessory and secondary allanite, apatite, calcite, chlorite, epidote, opaque minerals, scapolite, sericite/muscovite, sphene, and zircon; myrmekite is rare *Metadolerite/gabbro*: dark grey, medium to fine-grained, ophitic to granulitic, generally not foliated, locally contains plagioclase phenocrysts. Ophitic varieties consist mainly of plagioclase laths + clinopyroxene ± orthopyroxene ± olivine ± secondary amphibole ± primary biotite; granulitic varieties consist mainly of plagioclase + hornblende + biotite ± clinopyroxene remnants ± scapolite; accessory minerals include apatite, partly micrographic quartz quartz and alkali feldspar, and opaque minerals	Intrudes Corella Formation
Myubee Igneous Complex (Blake & others, 1981a)	Granite, gabbro; minor diorite, aplite, pegmatite. Granite and gabbro locally form net-veined complexes *Granite*: leucocratic hornblende-biotite granite similar to that of Overlander Granite; in places contains inclusions of coarse-grained granite and calc-silicate rocks *Gabbro*: differentiated from olivine-rich norite, through pyroxene gabbro, hornblende gabbro, and hornblende leucogabbro, to pegmatoidal hornblende diorite	Intrudes Corella Formation; cut by dolerite dyke
Saint Mungo Granite (Blake & others, 1981a)	Slightly to intensely foliated, medium to coarse-grained, recrystallised hornblende-biotite granite crowded with microcline megacrysts up to 3 cm across; minor foliated porphyritic biotite granite, aplite, and pegmatite. Xenoliths, some with microcline megacrysts, are common *Granite*: consists mainly of quartz, microcline, partly altered plagioclase, and 10–15 percent biotite and generally subordinate dark blue-green hornblende; myrmekite is common; accessory and secondary minerals recorded are apatite, calcite, chlorite, epidote, fluorite, metamict minerals (including allanite), opaque minerals (including magnetite), scapolite, sphene, and zircon; many of microcline megacrysts are augen-like	Intrudes Plum Mountain Gneiss and Corella Formation; intruded by mafic dykes and possibly by Birds Well Granite?

lith. These intrusions are generally elongated parallel to regional northerly trends. In the Duchess–Urandangi region the Wonga Batholith comprises the Birds Well, Bowlers Hole, Mairindi Creek, Overlander, Revenue, and Saint Mungo Granites, the Bushy Park Gneiss, and the Mount Erle and Myubee Igneous Complexes (Table 10). To the north, in MARY KATHLEEN and MARRABA, it includes granites, mapped as Wonga Granite (Carter & others, 1961) and Burstall Granite (Derrick & others, 1978), which have been isotopically dated at 1740 to 1670 m.y. (Page, 1978, 1980, 1981a, 1983b).

Most of the Wonga Batholith granites are pale pink, weakly foliated to gneissic, and extensively recrystallised, and all have been regionally metamorphosed to the greenschist or amphibolite facies.

The *Birds Well Granite* forms a pluton with an outcrop area of roughly 70 km^2 about 12 km west of Duchess. Similar granite, mapped as possible Birds Well Granite, crops out to the south, 30 km east of Dajarra (Fig. 29). Both outcrops were previously mapped as Kalkadoon Granite. The *Bowlers Hole Granite*, in the northeast, which forms an oval pluton 11 km long from north to south and 3.5 km wide, and the *Mairindi Creek Granite*, a small pluton 8 to 12 km northwest of Duchess, were also previously mapped as Kalkadoon Granite; however, like the Birds Well Granite, they intrude units younger than the Kalkadoon Granite. The *Bushy Park Gneiss* is exposed as a series of intensely deformed intrusive pods and lenses along the western margin of the Duchess Belt in the northeast of the central area; associated veins of aplite and pegmatite and the gneissic foliation locally show tight to isoclinal minor folds.

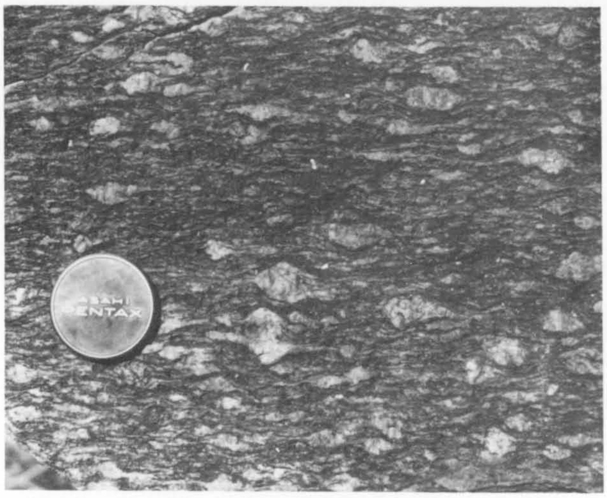


Fig. 29. Granitic gneiss with feldspar augen, Birds Well Granite? 29 km east of Dajarra (at GR UB845050). (M2443/18)

The *Overlander Granite* and *Revenue Granite* form elongate plutons, previously mapped as Wonga Granite, within the Duchess Belt north of Duchess. They intrude the Corella Formation, which is converted to skarn in places adjacent to the plutons, and are taken to include swarms of tourmaline-bearing pegmatite dykes and veins (Fig. 30). Some of these dykes cut the granite, but others appear to merge into granite at pluton margins. The Revenue Granite includes crenulated gneissic granite (Fig. 31) considered by Joplin & Walker (1961), but by neither RJB nor PJTD, to represent metasomatised (granitised) calc-silicate rocks.

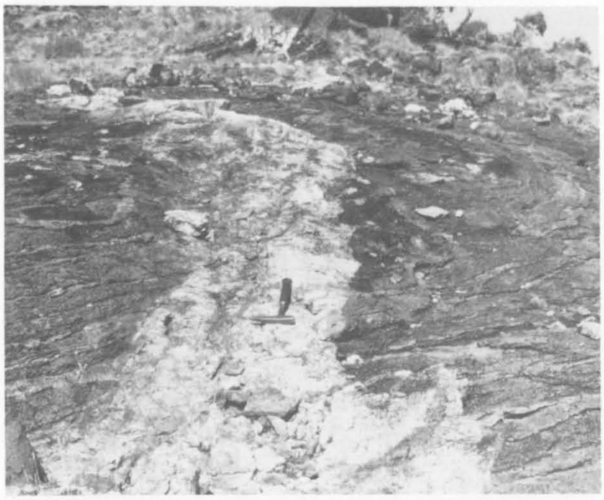


Fig. 30. Metamorphosed pegmatite vein, gently folded, cutting tightly folded calc-silicate rocks of the Corella Formation 19 km north of Duchess (at GR UB819569). (M2443/10)

The *Mount Erle Igneous Complex* crops out over about 30 km^2 in the vicinity of Duchess. It consists mainly of leucocratic granite and dolerite/gabbro which are intimately mixed locally with dioritic hybrid rocks (Fig. 32) to form net-veined complexes (Blake, 1981a). In these the dolerite/gabbro is present as angular to rounded pillow-like inclusions enclosed in and veined by granitic rock; it may be either similar in age to or younger than the granite, and is inferred to represent mafic magma intruded into either granitic magma or melted granitic rock. Inclusions of calc-silicate rocks derived from the adjacent Corella Formation are concentrated near the margins of the complex. Although igneous textures and mineralogy are preserved in places, and the dolerite/gabbro component is commonly not deformed, several features suggest that probably all components of the Mount Erle Igneous Complex have been metamorphosed to the

Fig. 31. Crenulated gneissic granite at the margin of the Revenue Granite 9 km north of Duchess (at GR UB795465). (GB1370)

Fig. 32. Net-veined complex of the Mount Erle Igneous Complex: a mixture of dolerite (rounded dark grey inclusions), granite (pale grey), and heterogeneous hybrid dioritic rocks (medium grey) 5 km south of Duchess (at GR UB823325). Field of view is about 1 m across. (M2231/35)

amphibolite facies: the presence of symplectic textures in gabbro; mineral assemblages and granulitic textures in much of the dolerite/gabbro; and the recrystallised and foliated nature of the granite.

The *Myubee Igneous Complex* forms a circular body about 2 km in diameter (Fig. 33) 16 km north of Duchess. It consists of an outer zone of granite partly surrounding a core of gabbro. The granite contains sparse angular inclusions of coarser-grained granite. The gabbro is cut by granitic veins, and is locally converted to amphibolite adjacent to granite. It also forms a net-veined complex with the granite (Fig. 34), similar to that of the Mount Erle Igneous Complex; hence it was probably emplaced either at the same time as the granite or later. The gabbro may be related to the dolerite and gabbro of the Mount Erle Igneous Complex, and also to the Lunch Creek Gabbro in MARRABA (Derrick, 1980), which in places forms net-veined complexes with the Burstall Granite (Blake, 1981a). Although the gabbro generally appears to be an unaltered igneous rock, coronas formed of fine-grained magnetite and orthopyroxene? between olivine and plagioclase grains and the presence of symplectic intergrowths of hornblende and spinel indicate regional metamorphism to the amphibolite facies, as in the Mount Erle Igneous Complex.

The granitic components of the Mount Erle and Myubee Igneous Complexes are similar in composition to, and may be comagmatic with, the Overlander and Revenue Granites, and also with the Burstall Granite to the north, in MARRABA, which has been isotopically dated at 1720–1740 m.y. (Page, 1980, 1981a, 1983b). All these granitic units may have been emplaced after the surrounding Corella Formation had first been tightly folded and regionally metamorphosed to the amphibolite facies (Derrick, 1980; Blake, 1981b).

The *Saint Mungo Granite*, previously mapped as part of the Kalkadoon Granite, crops out over about 90 km^2 in the southeast part of the central area. The main rock type, porphyritic foliated granite containing both biotite and hornblende, is similar to much of the Bushy Park Gneiss, a probable correlative.

Mount Philp Breccia

The Mount Philp Breccia intrudes the Corella Formation in the northern half of the Duchess Belt. Two main bodies are known: one in the far north which extends into MARY KATHLEEN and was previously mapped as Mount Philp Agglomerate (Carter & others, 1961; Carter & Öpik, 1963; Derrick & others, 1977a, b); and the other 7 km southeast of Duchess.

The Mount Philp Breccia (Table 10) consists 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 matrix (Fig. 35). The fragments are formed of banded calc-silicate rocks, albitite, metabasalt, amphibolite, quartzite, schist, quartz-feldspar pegmatite, and possibly metadolerite, all of which can be matched with rocks in the adjacent Corella Formation. The matrix of the breccia has an igneous-type texture, and consists mostly of stubby phenocrysts of amphibole (mainly tremolite) enclosed in a groundmass of interlocking albite laths in which there are many small and irregular miarolitic cavities lined with inward-growing albite crystals. A detailed description of the Mount Philp Breccia and a discussion of its origin are given by Blake & others (1982b).

Minor intrusions

Dykes and pod-like intrusions of *metadolerite* and *amphibolite* of several different ages occur throughout the central area, and at some localities metamorphosed mafic dykes form 10 percent or more of the bedrock. They generally consist mainly of green hornblende and variably sericitised oligoclase/andesine, typical of the amphibolite facies, and commonly also contain epidote, chlorite, and biotite. Some of the intrusions contain relict clinopyroxene, and those intruding the Corella Formation in the east are typically rich in scapolite. Textures range from relict ophitic (relict igneous) to schistose or granulitic (completely recrystallised).

Non-metamorphosed *dolerite* dykes are relatively rare. They have ophitic textures, and generally consist of plagioclase (partly sericitised), clinopyroxene, opaque oxides, minor primary hornblende and biotite, and interstitial and commonly granophyric quartz and alkali feldspar. These dykes may be related to the Lakeview Dolerite in MARRABA and MARY KATHLEEN, to the north, which has an Rb–Sr age of about 1116 m.y. (Derrick & others, 1978; Page, 1983b).

Felsic dykes, though common in parts of the central area, are much less numerous than mafic dykes. They are generally formed of grey or pink fine-grained quartzofeldspathic rock containing phenocrysts of feldspar and quartz. The largest felsic minor intrusion is the *Garden Creek Porphyry* (Table 10), which forms a discontinuous subvertical sheet up to 250 m wide intruding the Mount Guide Quartzite more or less concordantly on the east side of the Dajarra Belt. It may represent a composite intrusion, as the porphyry is almost invariably flanked by metadolerite. It was pre-

Fig. 33. Aerial view, from the south, of the circular Myubee Igneous Complex 16 km north-northwest of Duchess. Gabbro in the central part of the complex is encircled by granite and ridge-forming granite-veined calc-silicate rocks of the Corella Formation. (M2443/31)

viously mapped as Kalkadoon Granite (Carter & others, 1961; Carter & Öpik, 1963), which is now known to predate the Mount Guide Quartzite.

Structure

Folds

The first major folding event within the *Kalkadoon–Leichhardt Block* (and probably the whole region) is thought by Blake (1980, 1981b) to have affected much of the undivided Tewinga Group, and to have predated the Leichhardt Volcanics; alternatively, it may have been associated with the emplacement of the Kalkadoon Granite, although this is now considered unlikely. A gneissic foliation and some small-scale folds in undivided Tewinga Group rocks and also in the Plum Mountain Gneiss (Fig. 8e) to the east may have been developed during this event.

A later deformation resulted in the Magna Lynn Metabasalt and older units, and the Argylla Formation, Ballara Quartzite, Corella Formation?, Stanbroke Sandstone, Makbat Sandstone, and Surprise Creek Formation? being moderately to tightly folded (Figs. 36, 37). The trends of these folds are subparallel to the trends of the postulated earlier structures. One of the later folds is the large north-plunging syncline which is truncated in the north by the Fountain Range Fault, and in which rocks mapped as Corella Formation? are preserved (Fig. 36). This syncline is similar in style and probably age to synclines in MARY KATHLEEN, to the north (Derrick & others, 1977b). This folding appears to have been the first to affect the Magna Lynn Metabasalt to Corella Formation? sequence, and was possibly also the first to affect the Leichhardt Volcanics (Blake, 1981b, 1982). Other folds of probably similar age include the synclines and half-synclines in which the Stanbroke and Makbat Sandstones (Fig. 37) and Surprise Creek Formation? are preserved. In the south, east of Dajarra, large folds possibly related to this later folding have folded earlier structures in the undivided Tewinga Group (Blake & others, 1982a). In the north, near GR UB5953, small-scale crenulations in foliated undivided Tewinga Group rocks may also be related to the later folding.

The dominant folding event in the *Dajarra Belt* produced major open to tight, mainly north-plunging structures with steeply dipping to vertical northerly trending axial planes. The Eastern Creek Volcanics of the Haslingden Group, for example, are largely preserved in partly fault-bounded synclines, the faults paralleling the axial planes of the folds. These folds appear to be the earliest that affected the Dajarra Belt, and may be related to the folds affecting the Magna Lynn Metabasalt and younger units in the Kalkadoon–Leichhardt Block. Angular discordance of up to 30° between the Haslingden and Mount Isa Groups locally

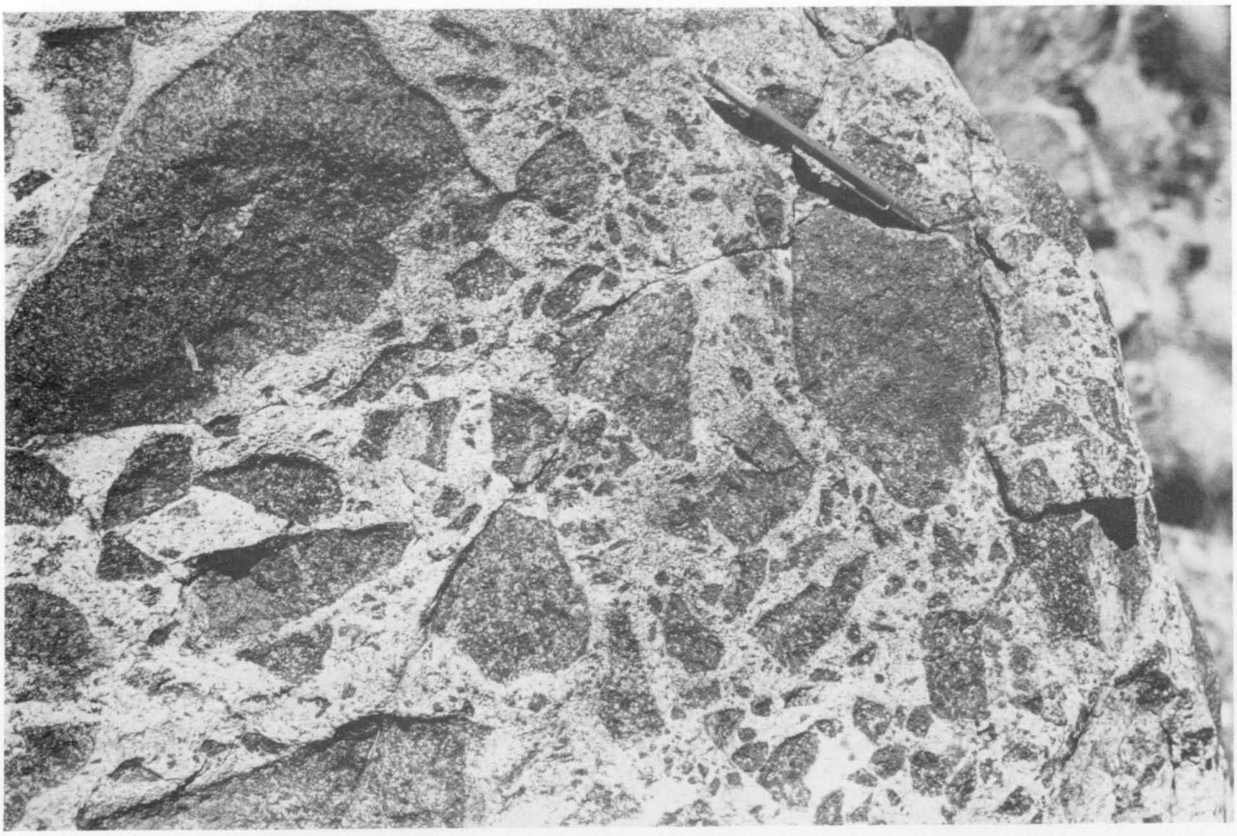


Fig. 34. Net-veined complex of the Myubee Igneous Complex: predominantly angular fragments of gabbro enclosed in granite. (M2633/19)

evident west of Dajarra appears to have resulted from tilting, rather than tight folding, before the Mount Isa Group was deposited. In the far south a genetic relationship between faulting and folding is indicated by an increasing number of parasitic folds (in the Eastern Creek Volcanics and overlying Warrina Park Quartzite) westwards, towards the Wonomo Fault, on the western side of a broad north-plunging anticline (near GR UA4176).

The western margin of the *Duchess Belt* is marked by a highly deformed zone a few kilometres wide represented by interlayered augen gneiss, granitic gneiss, schistose metasediments and metavolcanics, foliated granite, and amphibolite. No major folds have been recognised in this zone (the southern continuation of the Wonga Belt), probably because of widespread transposition, but small-scale tight to isoclinal folds are common in cross-cutting veins of quartz and aplite; the axial planes of the folds are parallel to the main gneissic foliation (Fig. 8f). The small folds indicate that some, if not all, the deformation in this zone took place after granite emplacement (cf. Holcombe & Fraser, 1979; Holcombe, 1981).

To the east, in the Corella Formation, the mainly calc-silicate rocks have generally been deformed plastically to produce spectacular small and medium-scale folds which are locally disharmonic (Figs. 26, 38, 39, front cover). The earliest folds are tight to isoclinal, and commonly have high amplitude-to-wavelength ratios, shallow plunges, and subvertical axial planes. Axial-plane foliations are generally restricted to hinge areas, and range from a fracture cleavage to an alignment of mafic mineral grains and porphyroblasts (Fig. 40). Tectonic transposition and metamorphic differentiation—pseudobedding—are developed in some of the most deformed rocks (Fig. 27).

Later open to tight folds, coaxial with the earlier folds, are sporadically developed in calc-silicate rocks —for example, in a small area about 20 km north of Duchess (Fig. 39). Early minor folds have been reoriented around the hinge of one fold here, a north-plunging synform 2 to 3 km wide. This synform is in a zone of open folds and basin-and-dome structures, which may represent interference fold patterns, lying to the west of the Revenue and Overlander Granite plutons. The later folding event in the Corella Formation may represent an initial ductile response of the calc-silicate rocks to compressive forces which subsequently formed a northeast-trending dextral strike-slip fault system, or it may represent large-scale drag-folding related to movements along the Pilgrim Fault Zone.

Late open folds occur in the Corella Formation adjacent to the Revenue Granite. These appear to have been formed during the emplacement of this granite. Associated foliation and lineation styles are indistinguishable from those of the earlier folding event. The age of the late folds relative to the late folds farther north is unknown.

Rocks of the Duchess belt south of the Plum Mountain Fault generally show evidence of only one major deformation event. The Plum Mountain Gneiss, Saint Mungo Granite, and Corella Formation here are highly deformed and possess a prominent subvertical, northerly to northwesterly trending foliation, but whether this is the result of one or more major tectonic events is not clear. Minor folds related to the foliation are rare, and no related major folds are evident.

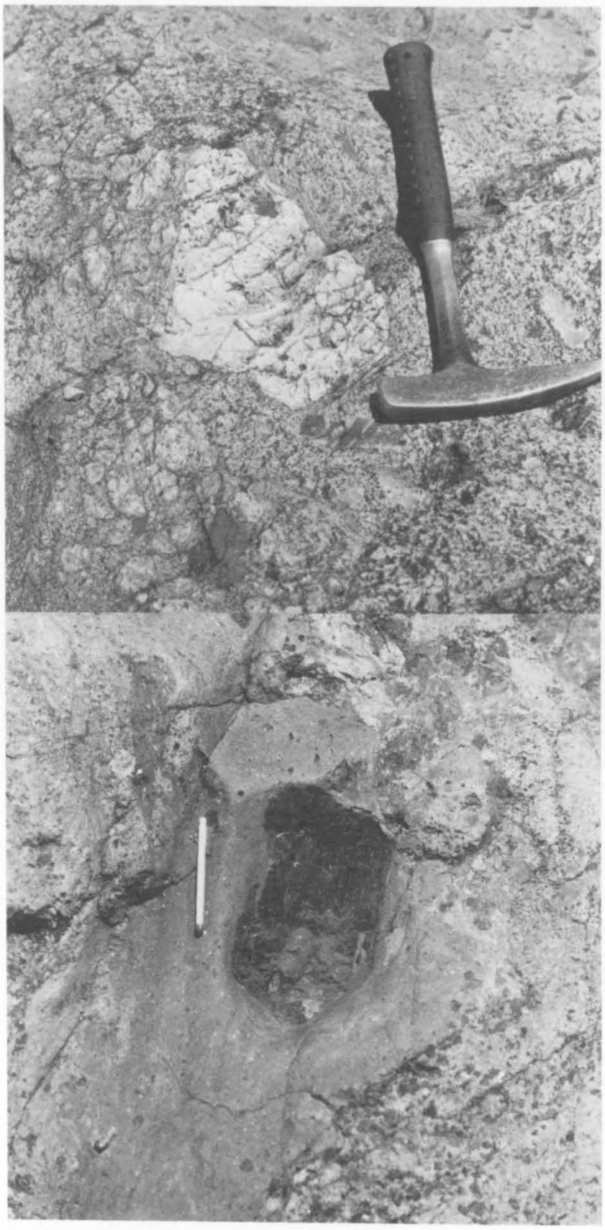


Fig. 35. *Top:* **Fragments of quartzite (white, amphibolite (dark grey), and other rocks types in Mount Philp Breccia 38 km north-northeast of Duchess (at GR UB907756).** *Bottom:* **Large fragmental amphibole crystal in Mount Philp Breccia 38 km north-northeast of Duchess (at GR UB907756). (M2633/20, 21)**

Younger folds have been recognised in the Plum Mountain Gneiss immediately south of the Plum Mountain Fault, whose movement has resulted in the development of large open drag-folds.

Faults

The most prominent faults in the central area form a northeast and northwest-trending conjugate strike-slip set which postdates the latest major folding event. These faults may result from east-west compressive stresses, as suggested by Carter & other (1961). The northeast-trending faults commonly have dextral displacements and are best developed in the Duchess Belt, whereas the northwest-trending faults have sinistral movements and are best developed in the Dajarra Belt. The greatest horizontal displacements occur along major northeast-trending faults, where some vertical movement is also commonly evident. A good example is the Fountain Range Fault, which juxtaposes a synclinal sequence of Ballara Quartzite–Corella Formation? rocks to the south against older Argylla Formation rocks to the north (Fig. 36); the lateral dextral movement along this fault was estimated by Derrick & others (1977b) to be about 25 km.

A series of north-trending faults predate the conjugate set. Many of these earlier faults mark boundaries between rocks of contrasting competencies, and are thought to have resulted from differential bedding-plane slip during folding. Other faults related to folding include north-trending axial-plane shears, along which the horizontal and vertical movements have separated or removed adjacent fold limbs to form 'half-synclines'. The north-trending Dajarra Fault in the south of the Kalkadoon–Leichhardt Block may have a considerable displacement, as in places it separates amphibolite-facies rocks to the west from greenschist-facies rocks to the east.

Metamorphic effects

In the central area, as in the western and eastern areas, the Precambrian rocks are metamorphosed to the greenschist and amphibolite facies (Fig. 9). The highest-grade rocks occur in the northeast and probably the south of the Kalkadoon–Leichhardt Block and in the Duchess Belt. The lowest-grade rocks are probably those of the younger cover in the Dajarra Belt, but relatively low-grade rocks are also present in the Kalkadoon–Leichhardt Block, alongside much higher-grade rocks.

The felsic gneisses which predominate in the Plum Mountain Gneiss of the Duchess Belt and undivided Tewinga Group of the Kalkadoon–Leichhardt Block generally contain no diagnostic metamorphic mineral assemblages. However, several features indicate that these units have been regionally metamorphosed to the amphibolite facies: the common presence of myrmekite; the extensive obliteration of primary igneous and sedimentary textures owing to extensive recrystallisation; the local occurrence of leucocratic veins and migmatitic patches resulting from partial melting; and the presence of hornblende and relatively calcic plagioclase in associated metabasites.

The main granites of the Kalkadoon Batholith—the Kalkadoon Granite and One Tree Granite—have also been metamorphosed mainly to the amphibolite facies. Metamorphism in these units is indicated by the breakdown of primary biotite and in places hornblende into fine-grained biotite aggregates, the straining and common recrystallisation of quartz and locally feldspar, and the development of secondary chlorite, epidote, and white mica. Most cross-cutting mafic dykes have amphibolite-facies mineral assemblages. In contrast the Wills Creek and Woonigan Granites appear to be metamorphosed only to the greenschist facies. No metamorphic aureoles have been found at intrusive contacts of the Kalkadoon Granite, but some contact effects occur in the Leichhardt Volcanics adjacent to the Wills Creek Granite: the volcanics are mottled and partly recrystallised, and some contain small tourmaline needles.

The felsic volcanics of the Leichhardt Volcanics generally have well-preserved primary igneous textures, show no marked recrystallisation effects, and contain only small amounts of metamorphic biotite, white mica,

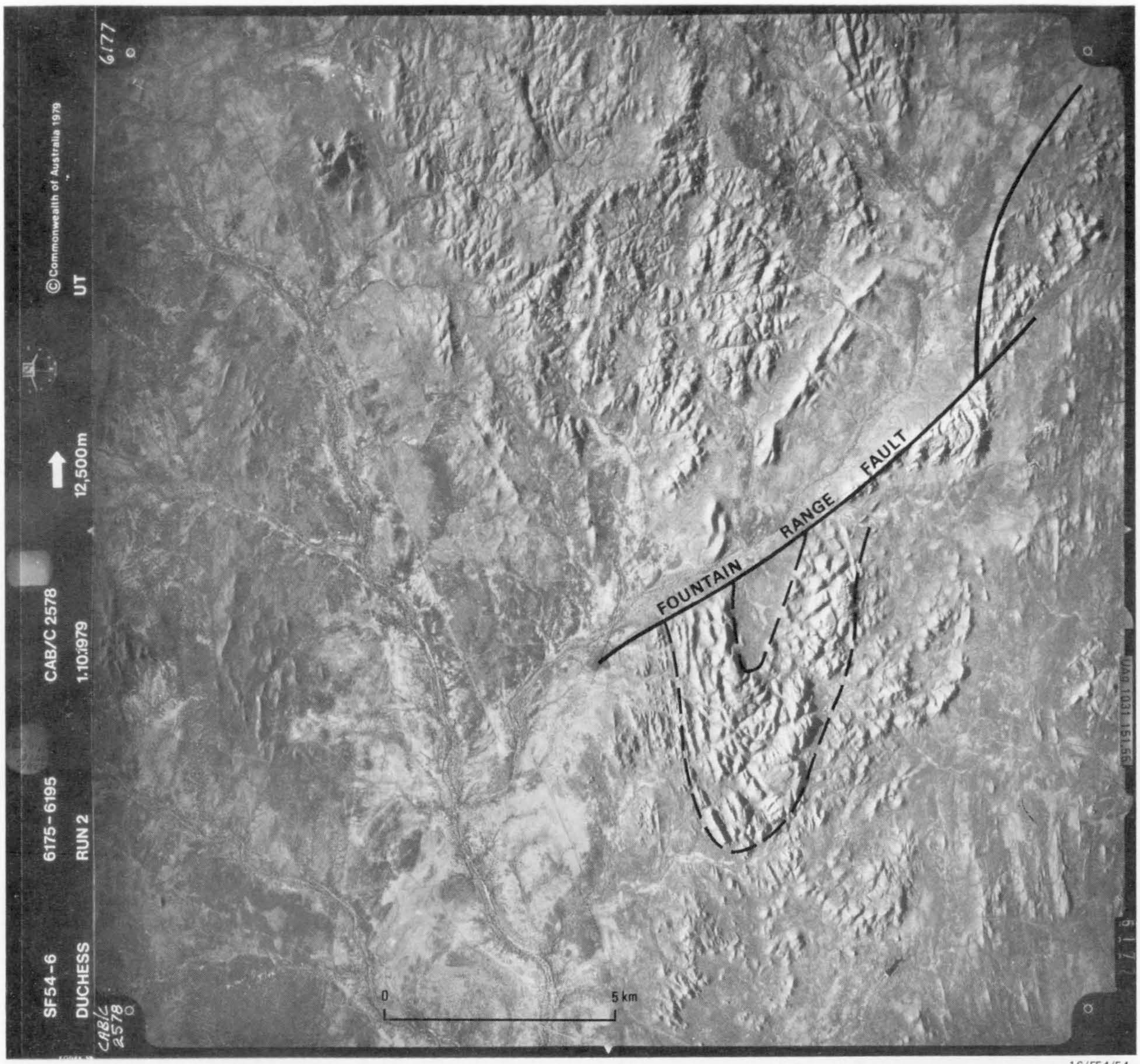


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Fig. 36. Infrared airphoto of the area north of the Lady Fanny mine and centred about 23 km northwest of Duchess, where a major north-plunging syncline is truncated by the northeast-trending Fountain Range Fault. Recessive calc-silicate rocks of the Corella Formation? in the core of the syncline overlie hill-forming meta-arenites of the Ballara Quartzite and Argylla Formation (outlined by dashed lines). The upstanding terrain north of the fault consists mainly of Kalkadoon Granite and Leichhardt Volcanics, but also includes strike-ridges of Stanbroke Sandstone. Northerly trending Bushy Park Gneiss, Argylla Formation, Magna Lynn Metabasalt, and Corella Formation of the Duchess Belt are exposed along the eastern margin of the photo.

sphene, and epidote. These features have been taken to indicate greenschist-facies metamorphism, but other features show that in places the Leichhardt Volcanics are more intensely metamorphosed: more pronounced recrystallisation effects; development of a metamorphic foliation; presence of cross-cutting amphibolite-facies metadolerite dykes; and, in the north, amphibolite-facies mineral assemblages in the overlying Magna Lynn Metabasalt.

Greenschist-facies metabasalts with well-preserved primary textures are rare within the Magna Lynn Metabasalt, and most parts of this unit, and also of the overlying Argylla Formation, have been metamorphosed to the amphibolite facies. Metabasites in these two formations generally have granoblastic to intensely foliated fabrics and contain co-existing hornblende and relatively calcic plagioclase. The highest-grade metabasites are adjacent to the Bowlers Hole, Mairindi Creek, and Birds Well Granites. Like the rocks they intrude, these granites are extensively recrystallised and commonly intensely foliated. Cordierite–anthophyllite assemblages in rocks of the Ballara Quartzite, and clinopyroxene and hornblende in overlying calc-silicate rocks of the Corella Formation?, show that these two units have also been regionally metamorphosed to the amphibolite facies.

The Surprise Creek Formation? and the Stanbroke and Makbat Sandstones are generally not extensively recrystallised and have well-preserved primary sedimentary textures (except near faults). They are inferred to be regionally metamorphosed mainly to the greenschist facies.

The Duchess Belt consists almost entirely of amphibolite-facies rocks. Felsic and mafic metavolcanics,

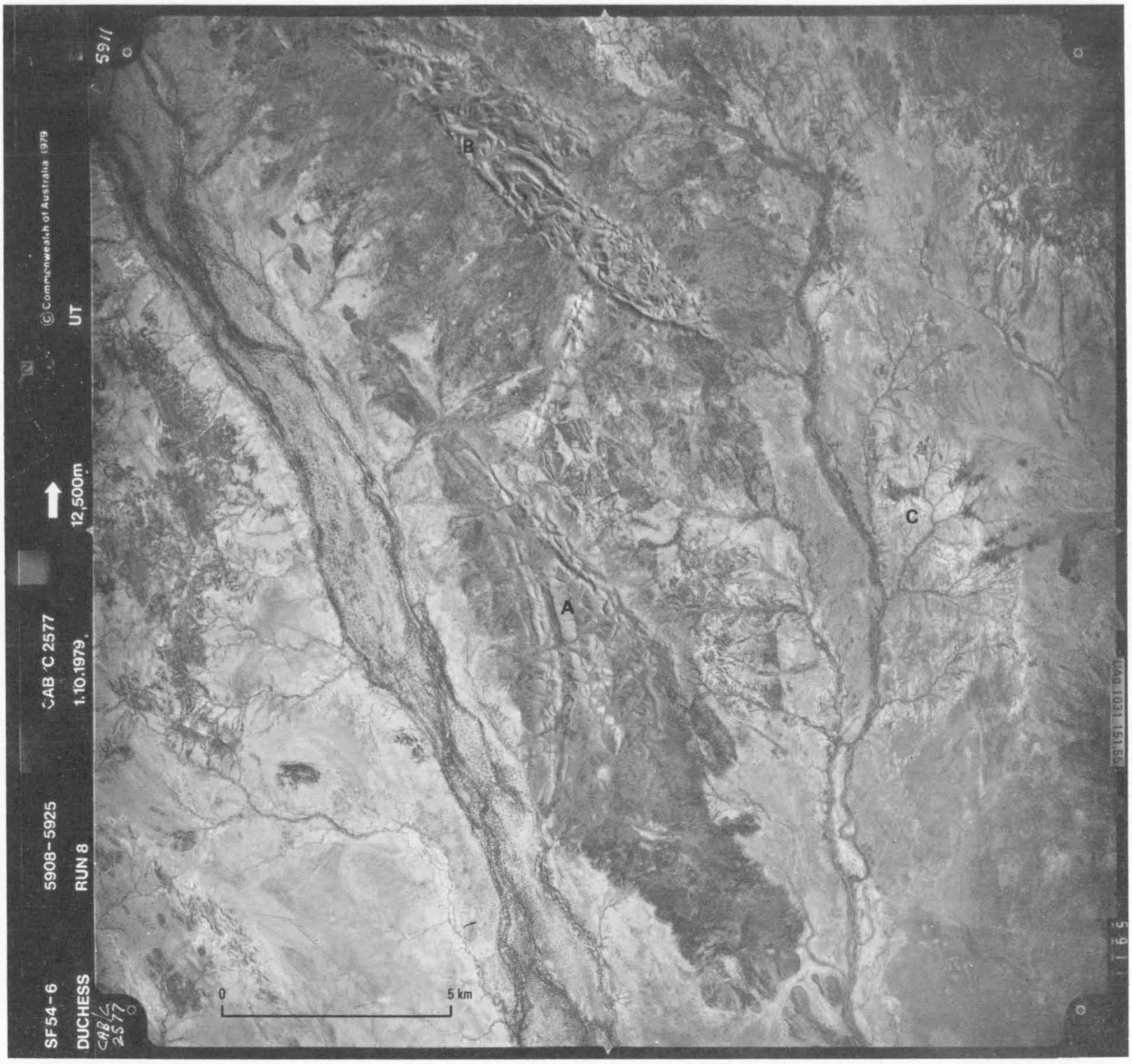

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Fig. 37. Infrared airphoto of the area centred about 37 km southeast of Dajarra, showing northwest-trending synclines of ridge-forming Makbat Sandstone (A and B) mainly overlying the Leichhardt Volcanics. The One Tree Granite in the east (around C) has a pronounced north-trending structural grain which appears to predate the synclines.

metasediments, and gneissic granites in the highly deformed western zone are extensively recrystallised and tectonically transposed. Cordierite–anthophyllite assemblages have been recorded in metasediments at one locality, and metabasites have hornblende–calcic plagioclase assemblages. The amount of deformation indicates that pressures may have been higher in this belt than in most other parts of the central area during the main metamorphism.

Metasediments in the Corella Formation typically have granoblastic textures, and contain K–feldspar, scapolite, hornblende (rather than tremolite/actinolite), clinopyroxene (mainly salitic), epidote, quartz, plagioclase, sphene, and less commonly muscovite, garnet, biotite, zircon, apatite, and opaque oxides. Sillimanite and cordierite have been recorded locally. Hornblende crystals are commonly aligned parallel to the axial planes of the oldest folds identified, but in places are also aligned parallel to the axial planes of younger folds. Metabasites within the Corella Formation have typical amphibolite-facies mineral assemblages. The presence of wollastonite, vesuvianite, and garnet in calc-silicate rocks adjacent to the Myubee Igneous Complex indicates hornblende-hornfels facies contact metamorphism. Contact metasomatic effects are common in the Corella Formation alongside granite intrusions, and banded to massive garnet-rich and clinopyroxene-rich skarns (Fig. 41) and alkali feldspar-rich metasomatic rocks persist for more than 100 m from some granite margins.

The Haslingden Group of the Dajarra Belt comprises both greenschist and amphibolite-facies rocks. The sedimentary rocks of the Mount Isa Group contain small amounts of fine-grained metamorphic biotite, muscovite, and chlorite, and have probably been regionally metamorphosed to mainly the lower greenschist facies.

Three main tectonic elements are distinguished in the eastern area (Fig. 7); from west to east these are the Malbon Block of Plumb & others (1980), and the newly named Staveley and Squirrel Hills Belts, which form part of the Mary Kathleen Fold Belt of Plumb & others (1980).

The Proterozoic formations in the western part of the area lie in the core and on the flanks of a major anticlinal structure, the Malbon Block, which continues northwards into MARRABA where it forms the Bulonga and Duck Creek Anticlines (Derrick, 1980). The sequence here is reasonably well established, although it is partly concealed beneath Cambrian and younger sediments. Felsic metavolcanics and associated metasediments of the Argylla Formation in the core of the anticlinal structure are overlain to the east and west by the Malbon Group, comprising the basaltic Marraba Volcanics and the Mitakoodi Quartzite, and the Overhang Jaspilite of the overlying Mary Kathleen Group. The Overhang Jaspilite on the eastern side of the anticlinal structure crops out mainly in the north, and to the south it appears to pass along strike into the Answer Slate.

Farther east the stratigraphy is less clear. The Answer Slate is in contact eastwards with the Double Crossing Metamorphics, a probably older formation, and with metasediments of the Staveley Belt—the Staveley Formation and Agate Downs Siltstone—which are probably younger. In the south, the Answer Slate grades eastwards into generally coarser metasediments of the Kuridala Formation, which in turn grades eastwards into coarser and more feldspathic metasediments and interlayered metabasalt of the Soldiers Cap Group. These last two units, together with the Doherty Formation, form the Squirrel Hills Belt. In the north, the Overhang Jaspilite is overlain to the east, possibly unconformably, by units of the Staveley Belt sequence—the Staveley Formation, Marimo Slate, and Roxmere Quartzite?. This sequence is faulted to the east against the probably older Doherty Formation, an extensive unit of banded and brecciated calc-silicate rocks previously assigned to the Corella Formation. Near Kuridala and to the south, the Staveley Formation is inferred to overlie the

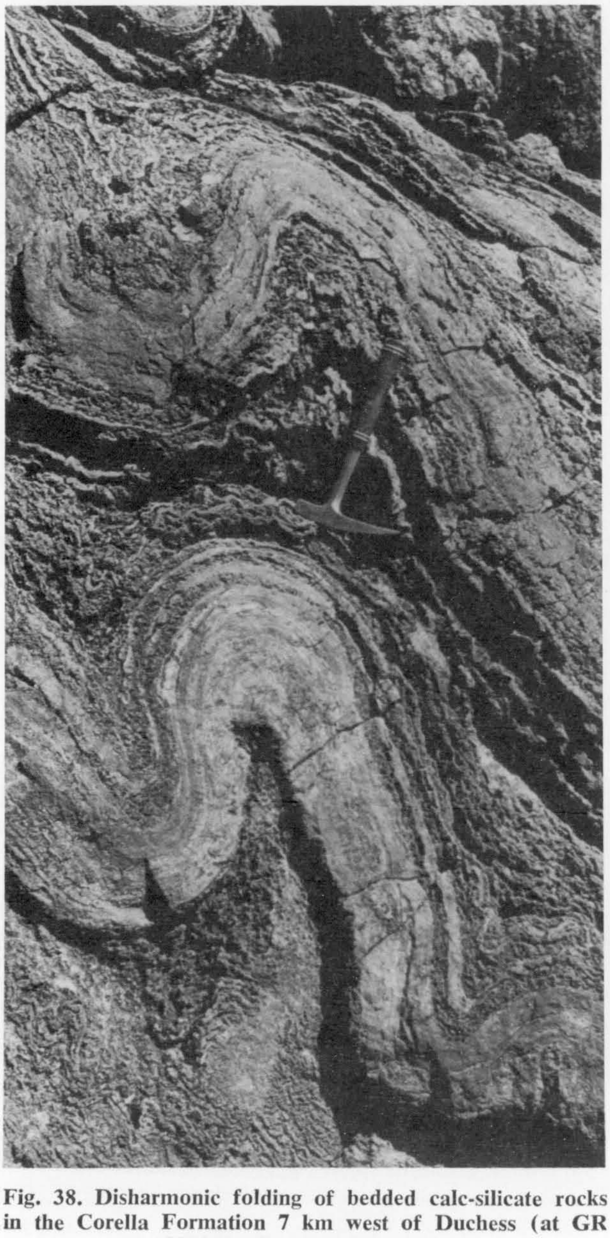

Fig. 38. Disharmonic folding of bedded calc-silicate rocks in the Corella Formation 7 km west of Duchess (at GR UB840447). (M2633/24A)

Fig. 39. Thinly bedded calc-silicate rocks showing small-scale early isoclinal folds refolded by later more open folds which have an associated axial-plane cleavage—Corella Formation 19 km north of Duchess (at GR UB806570). (M2633/22)

Fig. 40. Mafic minerals aligned parallel to the axial plane in the hinge of a small fold in calc-silicate rocks of the Corella Formation 7 km north-northeast of Duchess (at GR UB842444). (M2633/23)

Kuridala Formation, perhaps unconformably. The Doherty Formation may overlie the Soldiers Cap Group either conformably or disconformably, but most contacts between these two units are marked by faults.

The favoured stratigraphic interpretation for the eastern area is that the Argylla Formation, Malbon Group, Overhang Jaspilite, and Answer Slate form a conformable sequence (representing the Malbon Block) which correlates in part with the Kuridala Formation, Soldiers Cap Group, and Doherty Formation (Squirrel Hills Belt) to the east. All these units are interpreted to be part of the older cover sequence, and are inferred to be overlain unconformably (mainly disconformably) by the younger cover sequence, comprising the Staveley Formation, Agate Downs Siltstone, Marimo Slate, and Roxmere Quartzite? (Staveley Belt). Alternatively, the entire succession in the western half of the area, from the Argylla Formation to the Roxmere Quartzite?, may be essentially conformable (e.g., Derrick, 1980). Also, as suggested by Carter & others (1961) and other workers, the Soldiers Cap Group may be separated from the calc-silicate rocks now mapped as Doherty Formation by an unconformity representing a considerable time break. The stratigraphic position of the Double Crossing Metamorphics is uncertain. Detailed descriptions of the stratigraphic units are listed in Tables 11–13.

The Proterozoic succession is intruded by numerous mafic dykes and sills and by granites of the Williams Batholith. The youngest intrusions are non-metamorphosed dolerite dykes trending east-west, roughly at right-angles to the trends of most of the older rocks.

Tewinga Group

Argylla Formation

Of the three formations making up the Tewinga Group of Derrick & others (1976a), only the youngest, the Argylla Formation, is exposed in the eastern area. It crops out in the core of the Malbon Block, and consists mainly of felsic volcanics, which include ignimbritic deposits that were probably deposited subaerially, and quartzose to feldspathic arenites (Table 11). Its thickness is uncertain, as it may be tightly folded in places, and its base is not exposed; however, it is at least 2000 m thick in MARRABA, to the north (Derrick, 1980). Sedimentary rocks predominate in the upper part of the formation, and are much more voluminous generally than in the Argylla Formation of the central area. The formation is little-deformed or metamorphosed in the far north, but is regionally metamorphosed to amphibolite-facies gneissic and quartzitic rocks in southwestern and southeastern exposures. A felsic volcanic sample from the formation in MARRABA has been isotopically dated at 1766 $^{+23}_{-19}$ m.y., statistically indistinguishable from ages of about 1780 m.y. obtained for the Argylla Formation in the central area, and a more highly metamorphosed sample from GR VB251096 is inferred to be of a similar age (Page, 1983a).

Malbon Group

The Malbon Group comprises two formations, the basaltic Marraba Volcanics and the conformably over-

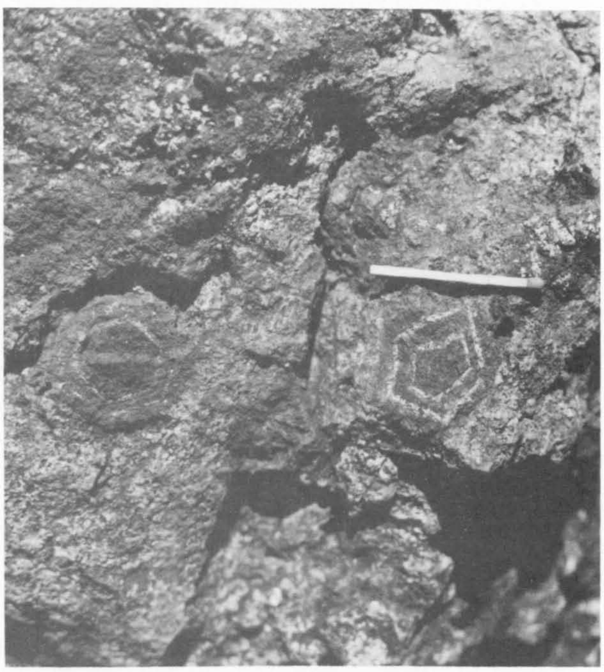

Fig. 41. Zoned garnet porphyroblasts in skarn, Corella Formation adjacent to the Myubee Igneous Complex 19 km north of Duchess (near GR UB790540). (M2204/4)

lying Mitakoodi Quartzite (Table 11). Sediments in these two formations were probably deposited in shallow water, and interlayered volcanics may have been erupted subaerially. Like the Argylla Formation, the Malbon Group has been regionally metamorphosed to the amphibolite facies, except in the far north, where the regional metamorphism only reached the greenschist facies.

Marraba Volcanics

This formation has been subdivided by Derrick & others (1976d) into three members, two of which have been recognised in northern outcrops (though not distinguished on the Duchess–Urandangi region map): the (lower) Cone Creek Metabasalt Member, which consists mainly of basaltic lava, and the (upper) Timberoo Member, which consists mainly of metasiltstone but locally includes some mafic and felsic volcanics (Donchak & others, 1983). To the south, the formation consists of interlayered metasediments and basaltic metavolcanics. Metasediments become more arenaceous upwards, and the formation has a gradational contact with the overlying Mitakoodi Quartzite. Disseminated sulphides, mainly pyrite and chalcopyrite, and malachite stains are widespread, and several small copper mines and prospects occur within the formation.

Mitakoodi Quartzite

This formation consists of ridge-forming meta-arenites and minor mainly silty interbeds, some of which are calcareous, and some interlayered mafic and felsic metavolcanics. It is tightly folded in the north. Cross-bedding and graded bedding are well developed in northern outcrops, but are generally difficult to recognise to the south because of recrystallisation effects resulting from more intense metamorphism. The Wakefield Metabasalt Member of Derrick & others (1976d) has been recognised in northeastern outcrops (Donchak & others, 1983), though not distinguished on the Duchess–Urandangi region map, and thin metabasalt layers occur elsewhere within the Mitakoodi Quartzite. Felsic porphyry of Argylla-type, probably extrusive, is interlayered with sedimentary rocks of the Mitakoodi Quartzite both east and west of the Burke River Structural Belt; in the east the porphyry is associated with volcaniclastic breccia and a possibly laharic conglomerate.

The Mitakoodi Quartzite becomes generally fine-grained towards its top, and grades upwards into conformably overlying Overhang Jaspilite and, in the south, Answer Slate. The presence of some banded jaspilite in the upper part of the formation in the southeast indicates possible equivalence to part of the Overhang Jaspilite to the north.

TABLE 11. DETAILS OF STRATIGRAPHY—TEWINGA GROUP, MALBON GROUP, AND DOUBLE CROSSING METAMORPHICS, EASTERN AREA

	Name of unit (reference to definition) max. thickness (m)	*Lithology*	*Relationships*
	Double Crossing Metamorphics (Blake & others, 1981a) 1000+?	Micaceous and feldspathic gneiss and schist, migmatitic gneiss with leucosomes, augen gneiss, amphibolite, quartzite, meta-arkose, banded quartz-tourmaline and quartz–hematite rock; concordant and discordant veins of quartz–feldspar pegmatite (containing tourmaline and/or muscovite), leucogranite, and quartz *Gneiss and schist*: consist of biotite ± muscovite + quartz + microcline and/or plagioclase	Intruded by Gin Creek Granite; concordant and probably partly faulted contacts with Answer Slate and Staveley Formation
MALBON GROUP (Derrick & others, 1976d)	**Mitakoodi Quartzite** (Carter & others, 1961) 2000+	Pinkish brown, mainly fine-grained feldspathic and quartzose meta-arenite; minor calcareous meta-arenite, metagreywacke, micaceous metasiltstone, phyllite, schist, metabasalt, quartz-feldspar porphyry, conglomerate, jaspilite, scapolitic calc-silicate rocks, pyritic tuff?, and quartz–hematite rock. Meta-arenites commonly show cross-bedding and graded bedding, especially in N	Conformable on Marraba Volcanics; concordant (conformable?) on Argylla Formation; overlain conformably by Overhang Jaspilite and Answer Slate. Intruded by Wimberu Granite and metadolerite
	Marraba Volcanics (Carter & others, 1961) ~3000	Dark greenish grey metabasalt and possible meta-andesite, grey metasiltstone, locally cross-bedded meta-arenite, and biotite schist; minor felsic metavolcanics, conglomerate, and calcareous metasiltstone and meta-arenite *Metabasalt*: mainly massive in far N and schistose to S; locally porphyritic; contains traces of malachite, pyrite, chalcopyrite, rare azurite; commonly contains amygdales with chlorite, epidote, and calcite in N; represented by biotite schist and oligoclase–green hornblende rock in S	Overlies Argylla Formation with apparent conformity; overlain conformably by Mitakoodi Quartzite. Intruded by Wimberu Granite and metadolerite
TEWINGA GROUP (Derrick & others, 1976a)	**Argylla Formation** (Carter & others, 1961; Derrick & others, 1976a) 2000+	Massive (in N) to intensely foliated and recrystallised (in S) felsic volcanics, clastic sedimentary rocks, and minor mafic volcanics; regionally metamorphosed to greenschist facies in N and amphibolite facies in S *Felsic volcanics*: generally magnetic, pinkish brown to grey ignimbrite, tuff, flow-banded lava; contain phenocrysts of sodic plagioclase and/or microcline and commonly quartz in fine-grained groundmass of quartz + alkali feldspar + minor biotite ± dark blue-green hornblende (in S) ± opaque minerals (mainly magnetite) *Sedimentary rocks*: commonly cross-bedded quartzose and feldspathic arenites and meta-arenites; minor interbedded siltstone, phyllite, and schist	Overlain concordantly by Marraba Volcanics and Mitakoodi Quartzite. Intruded by Wimberu Granite and metadolerite

Double Crossing Metamorphics

This somewhat enigmatic formation crops out over an area of about 30 km² on the eastern margin of the Malbon Block 20 km southwest of Selwyn. It consists predominantly of gneiss and schist which appear to be mainly quartzofeldspathic metasediments, but also includes augen gneiss and amphibolite which possibly represent felsic and mafic metavolcanics (Table 11). The formation has been tightly to isoclinally folded, regionally metamorphosed to the amphibolite facies, and partly granitised, and appears to be more deformed and metamorphosed than adjacent rocks mapped as Answer Slate and Staveley Formation, which are pelitic rather than quartzofeldspathic. It may represent pre-Argylla Formation basement rocks or lateral equivalents of the Argylla Formation and Malbon Group rocks in the core of an anticline or horst; alternatively, it may represent rocks brought up from deeper in the crust during the emplacement of the spatially associated Gin Creek Granite, which in places contains abundant large inclusions of rocks identical with those of the Double Crossing Metamorphics. The only sample chemically analysed, a felsic gneiss from near Gin Creek Bore, is similar in chemistry to felsic volcanics of the Argylla Formation (Bultitude & Wyborn, 1982).

Soldiers Cap Group

The Soldiers Cap Group (the Soldiers Cap Formation of Carter & others, 1961; Carter & Öpik, 1963) crops out extensively in the east—in the Squirrel Hills Belt, mainly east of the Cloncurry Fault—and is probably several thousands of metres thick (Table 12). It is less resistant than the adjacent Doherty Formation, and forms mainly low hills and ridges and undulating terrain. Rocks of the group are generally tightly folded and steeply dipping, and have been regionally metamorphosed to a high grade. The group was divided into three formations by Derrick & others (1976e): from oldest to youngest, the *Llewellyn Creek Formation, Mount Norna Quartzite*, and *Toole Creek Volcanics*. These formations have been recognised only in the far north; elsewhere in the eastern area the Soldiers Cap Group is not divided into formations.

The main rock types exposed are mica schist, quartzofeldspathic gneiss, meta-arenite, and amphibolite; some banded iron formation is also present. Many of the gneissic rocks are migmatitic (Fig. 42). Amphibolite thought to be metabasalt lava forms concordant layers, commonly has heterogeneous and garnetiferous zones and patches which may represent originally scoriaceous and amygdaloidal flow margins, and is locally interlayered with thinly banded para-amphibolite. No undoubted intrusive bodies of amphibolite in the region have been found to contain garnet.

Felsic volcanics are much less widespread than mafic volcanics in the Soldiers Cap Group, but metarhyolite is present in the north near the Williams River, and possible felsic metavolcanics represented by garnetiferous quartzofeldspathic gneiss petrographically similar to the Potosi Gneiss of the Broken Hill area, New South Wales, are exposed in the east, near GR VB9723 (Donchak & others, 1983).

Banded iron formation forms finely laminated beds, averaging about 1 m thick, which commonly show tight folding. In places the beds are hosts to low-grade copper, lead, and zinc deposits of possibly exhalative type. They may be confined to the same stratigraphic

TABLE 12. DETAILS OF STRATIGRAPHY—SOLDIERS CAP GROUP, EASTERN AREA

	Name of unit (reference to definition) max. thickness (m)	*Lithology*	*Relationships*	
SOLDIERS CAP GROUP (Derrick & others, 1976c)	**Toole Creek Volcanics** (Derrick & others, 1976c) 1000+	Amphibolitic metabasalt, mica schist, carbonaceous metasiltstone, and quartzite	Conformable on Mount Norna Quartzite	Intruded by Saxby Granite and amphibolitic metadolerite sills. Pass laterally into undivided Soldiers Cap Group
	Mount Norna Quartzite (Derrick & others, 1976c) 1000+	Feldspathic meta-arenite, quartzite, and mica schist commonly with garnet and/or andalusite; minor conglomerate, metagreywacke, and amphibolitic metabasalt	Conformable on Llewellyn Creek Formation; in contact with (faulted against?) Doherty Formation breccia	
	Llewellyn Creek Formation (Derrick & others, 1976c) 1000+	Mica schist, commonly with garnet and andalusite; minor phyllite and amphibolitic metabasalt	Base not exposed	
	Undivided 1000+	Mica schist, gneiss, migmatitic gneiss with leucosomes, meta-arenite (including quartzite), amphibolitic metabasalt; minor finely banded para-amphibolite, calc-silicate rocks, chert, banded iron formation, metarhyolite, quartz + feldspar ± tourmaline ± muscovite pegmatite *Schist, gneiss, and meta-arenite*: pale to dark; medium to coarse-grained; consist mainly of quartz + plagioclase ± microcline ± biotite ± muscovite ± sillimanite ± porphyroblasts of garnet and andalusite *Amphibolitic metabasalt and para-amphibolite*: schistose to gneissic; consist mainly of plagioclase ($An_{>18}$) + green hornblende + sphene + opaques ± quartz ± garnet ± clinopyroxene ± copper minerals (mainly malachite) *Calc-silicate rocks*: banded, massive, and brecciated; similar in mineralogy to those of Doherty Formation except more commonly scapolitic *Banded iron formation*: dark brown to black; very fine to medium-grained; typically consist of quartz + feldspar + hematite + magnetite ± gahnite ± apatite	Base not exposed; concordant and possibly interfingering contacts with Doherty Formation; appears to grade laterally to W in S into Kuridala Formation; intruded by Cowie, Maramungee, Mount Angelay, Saxby, and Squirrel Hills Granites, unnamed granite, pegmatite, metadolerite, and dolerite	

Fig. 42. Irregular minor folds in migmatic gneiss of the Soldiers Cap Group 45 km southeast of Kuridala (at GR VB873271). (M2304/33)

level as banded iron formation in the Kuridala Formation at the Pegmont prospect.

The stratigraphic relationship between the Soldiers Cap Group and the Doherty Formation is uncertain. In the eastern area no evidence has been found to support the view—for example, of Carter & others (1961) and Glikson (1972)—that a major angular unconformity separates the Soldiers Cap Group from the Doherty Formation (= Corella Formation of earlier workers), and there is no clear indication as to which is the older unit. At exposed contacts, schistose rocks of the Soldiers Cap Group invariably lie adjacent to calc-silicate breccia of the Doherty Formation, but bedding orientation in the two units is generally concordant, indicating a possible conformable relationship. This is supported by the presence near some contacts of interbedded schists and Doherty-type calc-silicate rocks within the Soldiers Cap Group. Our favoured interpretation is that the Soldiers Cap Group is overlain conformably by, and locally interfingers laterally with, the Doherty Formation, and that the calc-silicate breccia at the contact was formed when the two units were tightly folded.

Mary Kathleen Group

The Mary Kathleen Group, as defined by Derrick & others (1977a), includes the following formations exposed in the eastern area: the Overhang Jaspilite and Answer Slate of the Malbon Block, the Kuridala Formation and Doherty Formation (= Corella Formation of previous workers) of the Squirrel Hills Belt, and the Staveley Formation, Agate Downs Siltstone (formerly a member of the Staveley Formation), and Marimo Slate of the Staveley Belt (Table 13). These formations consist mainly of fine-grained sedimentary rocks, especially carbonates, siltstones, and shales, which have been regionally metamorphosed to the greenschist and amphibolite facies, and they were presumably considered by Derrick & others to form an essentially conformable sequence. However, the Overhang Jaspilite, Answer Slate, Kuridala Formation, and Doherty Formation may form an older sequence separated by a major unconformity from an overlying much younger sequence comprising the Staveley Formation, Agate Downs Siltstone, and Marimo Slate of the Mary Kathleen Group, and also the Roxmere Quartzite?

Isotopic age data indicate that rocks of the Mary Kathleen Group probably range in age from pre-1740 m.y. to about 1600 m.y. (Page, 1983a,b): the Overhang Jaspilite is younger than the underlying Argylla Formation (1780 m.y.) but is considered to be older than the Burstall Granite (1720–1740 m.y.) exposed in MARRABA (Derrick, 1980); metarhyolite in the Doherty Formation has been dated at about 1720 m.y.; in MARRABA, rocks possibly equivalent to the Staveley Formation/Marimo Slate sequence in the eastern area, but mapped as Corella Formation, include felsic volcanics 1600 m.y. old.

Overhang Jaspilite

This formation crops out mainly in the northern central part of the area, where it is tightly folded on a major scale, and in the northwest. It consists mainly of thin-bedded fine-grained calcareous and cherty sedimentary rocks (Fig. 43), including some jaspilite. In northeastern exposures, and especially in MARRABA to the north (Derrick, 1980), the uppermost part of the formation comprises iron-rich and manganese-rich brecciated beds (part of the Chumvale Breccia in MARRABA). The breccias may be part of a fossil regolith representing a major erosional

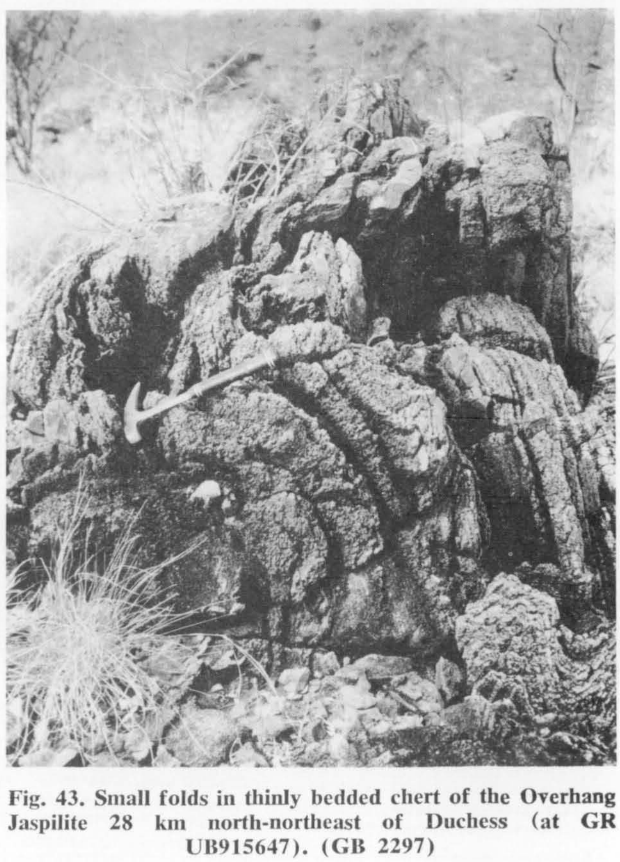

Fig. 43. Small folds in thinly bedded chert of the Overhang Jaspilite 28 km north-northeast of Duchess (at GR UB915647). (GB 2297)

TABLE 13. DETAILS OF STRATIGRAPHY—MARY KATHLEEN GROUP AND ROXMERE QUARTZITE?, EASTERN AREA

	Name of unit (reference to definition) max. thickness (m)	*Lithology*	*Relationships*
	Roxmere Quartzite? (Carter & others, 1961)	Brown, fine to medium-grained feldspathic arenite and pink, fine-grained quartzite; minor grey calcareous siltstone, micaceous siltstone, and sedimentary breccia. Ripple marks and cross-bedding common; graded bedding and convolute bedding present in places	Overlies Staveley Formation with apparent conformity
MARY KATHLEEN GROUP (Derrick & others, 1977a)	**Marimo Slate** (Carter & others, 1961) 1000+	Grey to black, variably carbonaceous slate and siltstone; subordinate interbedded arenite, chert, cherty siltstone, breccia, and impure limestone. Some arenite shows small-scale cross-bedding	Partly overlies and may interfinger with Staveley Formation. Intruded by small dolerite body
	Toby Barty Sandstone Member (Derrick & others, 1977a) 1000?	White to grey, fine to medium-grained, generally poorly sorted, feldspathic arenite and quartzite	Partly faulted concordant contacts with Staveley Formation and Marimo Slate
	Agate Downs Siltstone (Blake & others, 1981a) 500+	Pale grey to brown, cherty and slaty metasiltstone, phyllite, and fine-grained meta-arenite and quartzite; minor breccia; some calcareous and ferruginous beds, mainly in lower part. Rare cross-bedding and ripple marks	Faulted against Answer Slate; overlies Staveley Formation with apparent conformity
	Staveley Formation (Carter, 1959; Carter & others, 1961; Blake & others, 1981a) 2000+	Interbedded arenite, siltstone, and phyllite/shale/mudstone which are variably calcareous, ferruginous, feldspathic, siliceous, and micaceous; breccia; minor pyritic siltstone, impure limestone, marble, banded calc-silicate rocks, mica schist, conglomerate, banded quartz + hematite + magnetite rock, and altered basalt consisting mainly of epidote, actinolite, and albite, with garnet in some amygdales (SW of Selwyn). Arenite and siltstone commonly show convolute/recumbent bedding, cross-bedding, graded bedding, and ripple marks (partly outlined by laminate rich in heavy minerals). Halite casts in places	Inferred to overlie with possible unconformity Double Crossing Metamorphics, Answer Slate, Overhang Jaspilite, Kuridala Formation, and Doherty Formation; overlain with apparent conformity by Agate Downs Siltstone, Marimo Slate, Roxmere Quartzite?, and possibly Toby Barty Sandstone Member. Intruded by Gin Creek, Wimberu, and Squirrel Hills Granites, unnamed granite, metadolerite, and feldspar porphyry
	Doherty Formation (Blake & others, 1981a) 1000+	Thin-banded to laminated calc-silicate granofels and massive calc-silicate breccia; minor massive calc-silicate granofels, marble, mica schist, carbonaceous black slate, chert, variably calcareous and feldspathic quartzite, metarhyolite, para-amphibolite, metabasalt, and banded quartz–tourmaline rock *Calc-silicate rocks*: pink, grey, and green; consist of albite ± microcline ± quartz ± calcite ± hornblende ± actinolite ± salitic clinopyroxene ± epidote ± sphene ± opaque minerals ± garnet (rare) ± scapolite (rare) *Marble*: consists of calcite ± scapolite ± tremolite *Black slate*: andalusite needles in places; locally pyritic; host to Cu and Mo deposits *Metarhyolite*: pale pink to grey; contains small phenocrysts of albite, microcline, and quartz in fine-grained recrystallised quartzofeldspathic groundmass	Probably overlies Soldiers Cap Group, either conformably or disconformably; faulted against Staveley Formation, Kuridala Formation, and Marimo Slate. Intruded by Wimberu, Saxby, Mount Angelay, Squirrel Hills, Cowie, and Blackeye Granites, unnamed granite, metadolerite, and dolerite
	Kuridala Formation (Carter, 1959; Carter & others, 1961) 1000+	Pale to dark grey or ironstained, medium to thin-bedded mica schist, schistose metagreywacke, meta-arkose, quartzite, and graphitic slate and meta-siltstone; also phyllite and minor thin-banded to laminated calc-silicate granofels, chert, cherty quartz–albite rock, metarhyolite, felsic tuff?, banded iron formation, banded quartz + hematite + magnetite rock, para-amphibolite, and metabasalt? *Schists*: medium to fine-grained; crenulated in places; commonly contain garnet porphyroblasts up to 5 mm across and andalusite poikiloblasts up to 5 cm long; staurolite porphyroblasts in places *Graphitic rocks*: commonly contain 'matchstick' porphyroblasts of andalusite and anhedral poikiloblasts of muscovite (pseudomorphs?) *Calc-silicate rocks*: commonly contain clinopyroxene, less commonly scapolite	Appears to merge laterally with Answer Slate to W and Soldiers Cap Group to E; faulted against Doherty Formation; inferred to be overlain, possibly unconformably, by Staveley Formation. Intruded by Gin Creek, Squirrel Hills, Mount Cobalt, Mount Dore, and Yellow Waterhole Granites, unnamed granite, metadolerite, and dolerite
	Answer Slate (Carter, 1959; Carter & others, 1961; Blake & others, 1981a) 1000?	Buff to brown or dark grey, intensely cleaved and locally crenulated metasiltstone, slate, and phyllite; minor interbedded feldspathic quartzite, quartzite, metagreywacke, chert, cherty quartz–albite rock, impure limestone, mica schist, and banded quartz–hematite rock. Carbonaceous, pyritic, and calcareous beds common. Scapolite present in places. Widespread quartz-veining	Conformable on Mitakoodi Quartzite and Overhang Jaspilite; may be unconformable on Double Crossing Metamorphics; appears to merge laterally with Kuridala Formation; faulted against Agate Downs Siltstone; inferred to be overlain, possibly unconformably, by Staveley Formation. Intruded by Wimberu and Gin Creek Granites and metadolerite
	Overhang Jaspilite (Derrick & others, 1977a) 1000?	Thin-bedded ferruginous and calcareous siltstone with bands of red jaspilite, buff to brown arenite and quartzite, grey to brown chert and phyllite, impure scapolitic limestone, and hematite + magnetite rock	Conformable on Mitakoodi Quartzite; overlain conformably by Answer Slate and possibly unconformably by Staveley Formation. Intruded by Wimberu Granite

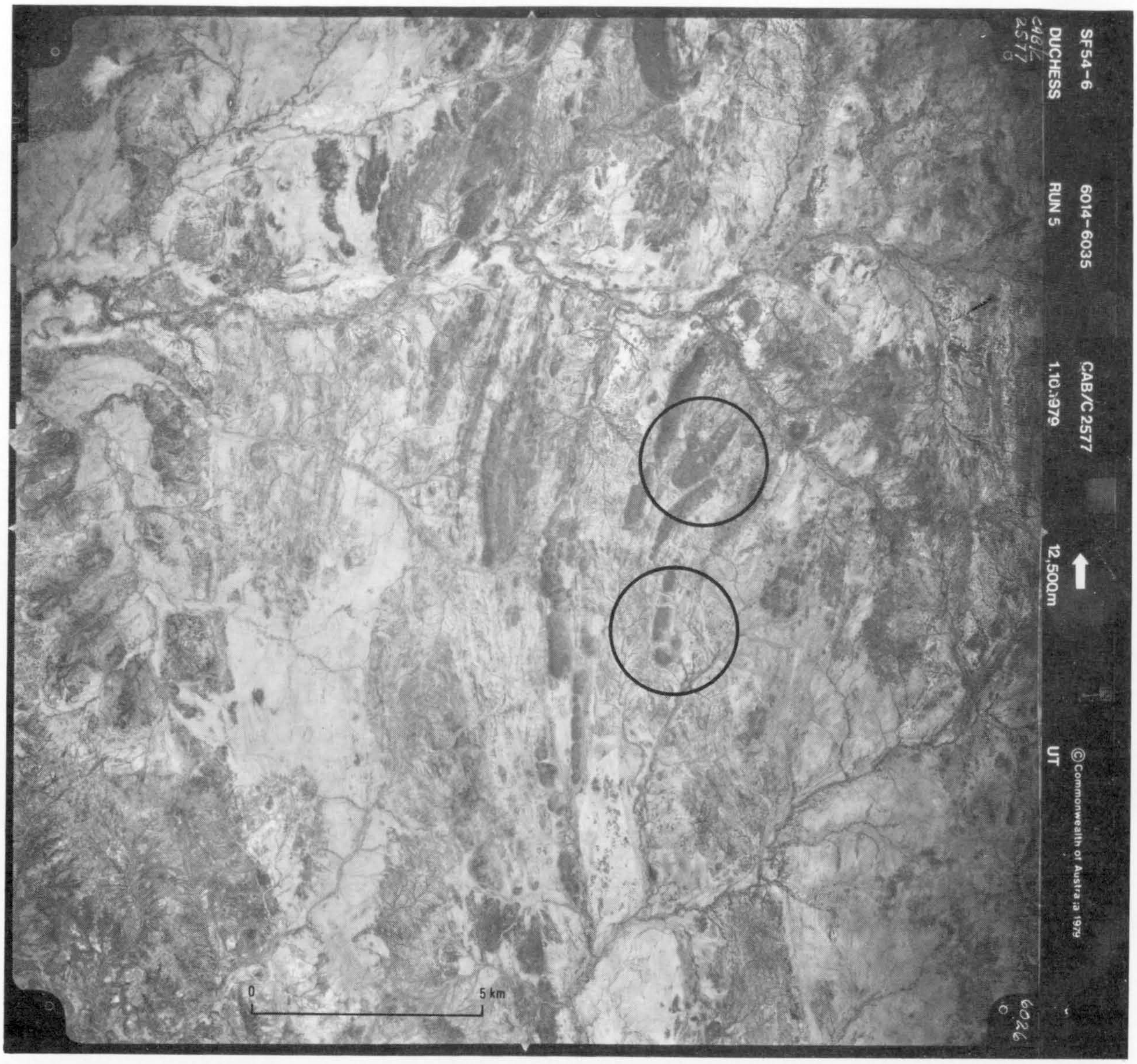

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Fig. 44. Infrared airphoto of the area centred about 20 km west-southwest of Selwyn, showing metadolerite sills (dark grey) within the Mitakoodi Quartzite, Answer Slate, and Staveley Formation. The sills in the circled areas outline tight to isoclinal first-generation folds with axial planes parallel to the prevailing first-generation cleavage in the adjacent Answer Slate.

unconformity, or they may be a tectonic feature (Derrick & others, 1977a; Derrick, 1980). The Overhang Jaspilite was probably deposited in a stable shallow-marine or lagoonal environment (Derrick, 1980), possibly on a shelf or platform close to a low-lying landmass.

Answer Slate

The Answer Slate forms a northerly trending belt of low strike ridges and undulating terrain 72 km long and up to 6 km wide on the east side of the Malbon Block. Its contacts with the Staveley Formation and Agate Downs Siltstone to the east are at least partly faulted. In the south the Answer Slate appears to grade laterally eastwards into the Kuridala Formation, and it may represent the distal facies equivalents of turbidites and other sediments of the Kuridala Formation deposited in a quiet, moderately deep marine environment. The presence of pyritic and carbonaceous beds may be attributed to local reducing conditions.

Fig. 45. Crenulated fine-grained mica schist in the Kuridala Formation 12 km southeast of Selwyn (at GR VB596065). (M2303/32)

The Answer Slate is tightly folded, and several major folds outlined by metadolerite sills are clearly visible on aerial photographs (Fig. 44). Many of these sills are multiple intrusions which include thin metasedimentary screens. Mineral assemblages in the metadolerites are typical of regional metamorphism of the upper greenschist and lower amphibolite facies. Quartz veins are common throughout the formation, and many outcrop areas are partly covered by quartz rubble.

Several copper lodes are known within the formation, the largest being at the Answer mine.

The Answer Slate is a possible correlative of both the Overhang Jaspilite and Kuridala Formation. We tentatively consider it to be older than the Marimo Slate exposed to the north, unlike earlier workers (e.g., Carter & others, 1961; Noon, 1978) who have suggested that they are correlatives.

Kuridala Formation

The Kuridala Formation crops out as hills, strike ridges, and undulating terrain in the western central and southern parts of the Squirrel Hills Belt. The highest ridges are formed of quartzite and banded quartz–hematite rock. The main rock types of the formation—schistose greywacke, siltstone, and shale (Fig. 45)—may be moderately deep-water turbidites derived from a landmass to the east. The formation has been tightly folded, probably at least twice, and many large, medium, and small-scale tight to isoclinal folds have been identified. Several major fold structures are outlined by metadolerite bodies, as at Kuridala, where a series of sills intruded parallel to the schistosity has been folded to form a tightly appressed, northerly trending structural basin (Fig. 46). The formation is intruded by a number of granite plutons,

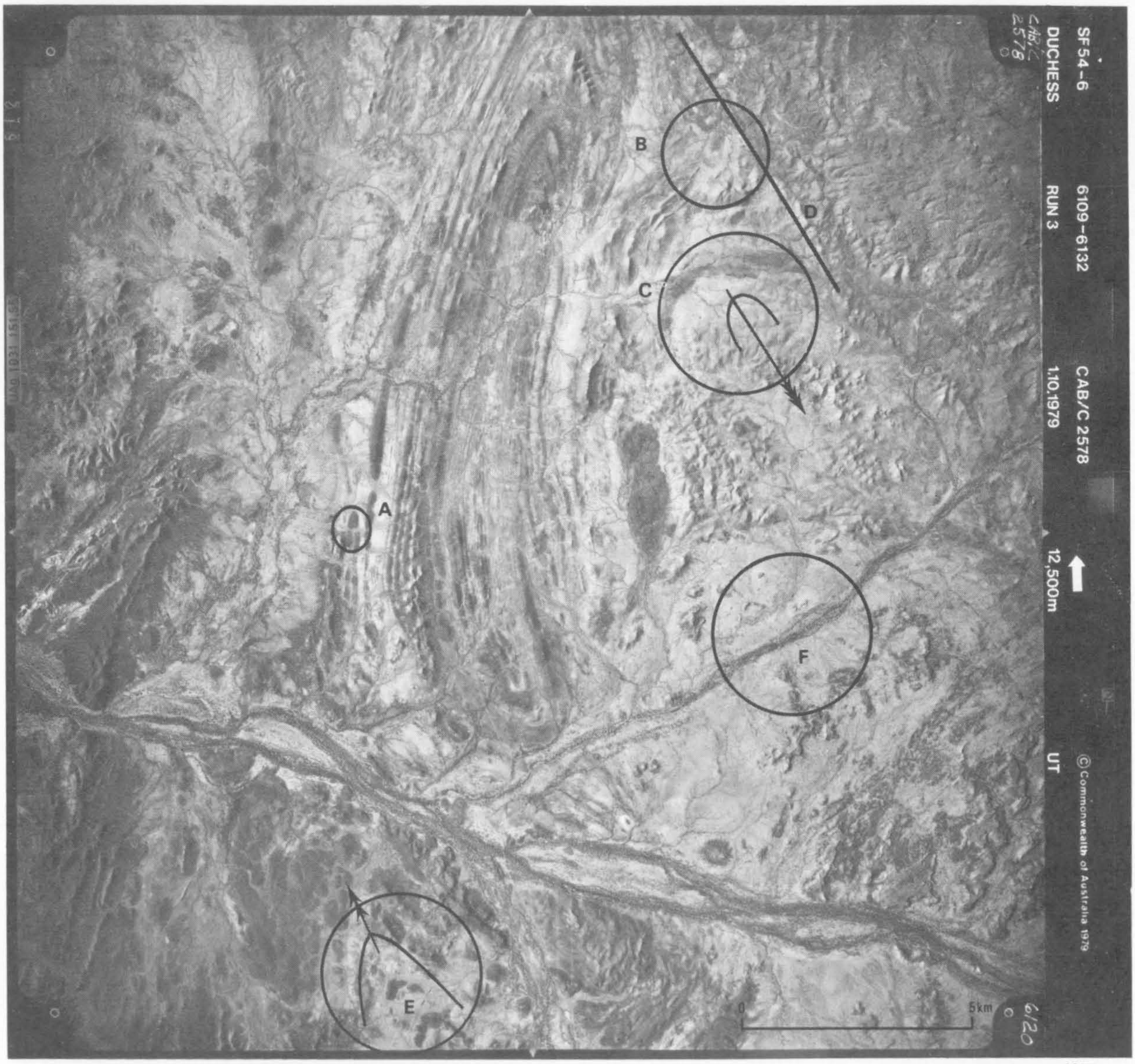

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Fig. 46. Infrared airphoto of the area around Kuridala, showing a north-trending, probably second-generation, tight structural basin (synform), outlined by dark grey metadolerite sills, within the Kuridala Formation. The dominant layering in the Kuridala Formation in the synform is a first-generation schistosity which is generally parallel to bedding and the sills. A weak crenulation cleavage present in the hinge areas is parallel to the axial plane of the synform. Small-scale first-generation folding is inferred where bedding is at a high angle to the schistosity. Folded metadolerite to the west, at locality A, may define a first-generation fold. In the northeast, third-generation box folds at locality B and southeast-plunging open folds at locality C may be related to movement along the nearby Straight Eight Fault (labelled D). Northwest-plunging second-generation folds are evident in the Kuridala Formation at E, in the south. A post-tectonic granite body, mapped as Squirrel Hills Granite, forms subdued terrain in the east, near locality F.

Fig. 47. Tourmaline-bearing quartz–feldspar pegmatite vein within the Kuridala Formation 6.5 km south of Selwyn (at GR VB482128). The pegmatite may be related to the nearby Mount Dore Granite of the Williams Batholith. (M2304/25)

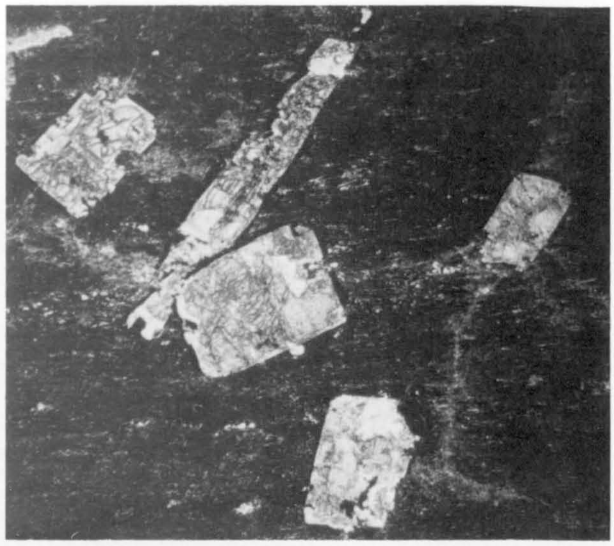

Fig. 49. Photomicrograph of matchstick-type andalusite porphyroblasts in carbonaceous slate of the Kuridala Formation at the Mount Elliott mine near Selwyn (at GR VB443179). (M2442/25)

by a few tourmaline-bearing pegmatite veins (Fig. 47), and, in the vicinity of Pegmont prospect in the south, by irregular veins of muscovite granite.

Because of the structural complexities, a lack of marker beds, and a paucity of sedimentary structures giving facing directions, no stratigraphic sequences have been recognised within the formation. Also, neither the top nor base of the formation has been unequivocally determined. Hence the thickness of the Kuridala Formation, though probably in the order of several thousand metres, is unknown.

Mineral assemblages indicate regional metamorphism to the amphibolite facies and some possible retrogression to the greenschist facies. Porphyroblastic garnet, andalusite, and staurolite developed in the metasediments (Figs. 48–50) either during or before the main schistosity-forming event. Hornblende-hornfels facies rocks—consisting of fibrolitic sillimanite, andalusite, cordierite, muscovite, biotite, quartz, microcline, and sodic plagioclase—occur in metamorphic aureoles up

Fig. 48. Stubby andalusite porphyroblasts in mica schist of the Kuridala Formation 13 km southeast of Selwyn (at GR VB605064). (M2303/33)

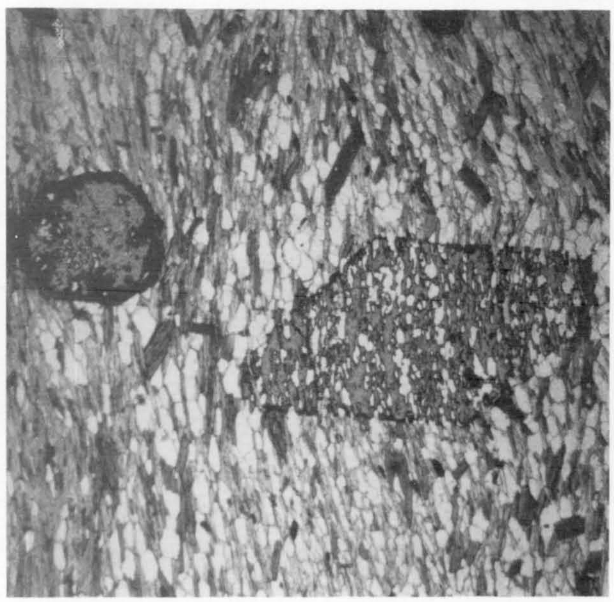

Fig. 50. Photomicrograph of euhedral porphyroblasts of staurolite (poikilitic) and garnet (left) in mica schist of the Kuridala Formation west of the Mount Cobalt mine and 23 km south of Selwyn (at GR VA477969). (M2442/32)

to 100 m wide in places adjacent to granite intrusions; however, at most granite contacts the rocks of the Kuridala Formation show little evidence of contact metamorphism.

Doherty Formation

The Doherty Formation crops out in a broad belt, up to 21 km wide, extending from the southeastern part of the Squirrel Hills Belt northwards for over 100 km into the Cloncurry 1:250 000 Sheet area. It consists predominantly of thinly banded calc-silicate granofels and massive calc-silicate breccia (Figs. 51, 52) which—being more resistant to erosion than most adjacent rocks—form rugged hills and ridges. Banding in the metasediments generally represents bedding. No thicknesses of the formation have been determined because of medium to large-scale open to tight folding, faulting, a general lack of both marker beds and facing evidence, and uncertain stratigraphic relationships. However, a maximum thickness of several thousand metres is likely.

Massive metarhyolite isotopically dated at 1720 ± 7 m.y. (Page, 1983a) occurs within the formation in the east (Blake & others, 1983a). It is considered (by DHB) to be extrusive because breccia, possible agglomerate, and regularly banded rhyolitic rock which may represent contemporaneous bedded tuff occur near its margins. Metabasalt and para-amphibolite are present in the north of the Doherty Formation outcrop.

Calc-silicate breccia making up much of the Doherty Formation forms irregular bands and lenses, some of which are hundreds of metres thick. The breccia consists of angular to rounded fragments ranging from a few centimetres to tens of metres long enclosed in an abundant to sparse matrix of generally similar overall composition. Some breccia bodies are oligomictic, consisting of essentially one type of calc-silicate rock; others are polymictic, and may contain fragments of jasper, chert, and amphibolite, in addition to various calc-silicate rocks. Although the breccia is mainly massive and chaotic, some is banded and possibly of sedimentary origin (Fig. 51). Most of the breccia, though, is considered to be tectonic, and may be related to postdepositional folding, faulting, and igneous intrusion (e.g., Glikson, 1972).

The thinly banded calc-silicate rocks represent medium to fine-grained, possibly shallow-marine, impure calcareous sediments which may include some tuffaceous material derived from local contemporaneous rhyolitic and basaltic volcanism. Subsequent tectonism resulted in the formation being folded, regionally metamorphosed to the amphibolite facies, and partly brecciated. Black carbonaceous and locally pyritic slate present in places was probably deposited in a quiet reducing environment; it is host to copper and minor molybdenum and silver deposits (e.g., at Mount Arthur mine).

The stratigraphic relationship between the Doherty Formation and the Soldiers Cap Group is uncertain because most contacts between the two units are probably faulted, and the Doherty Formation at the contacts is invariably represented by calc-silicate breccia. However, where bedded rocks are present in both units close to their contacts, bedding is concordant, indicating conformity or disconformity, and a

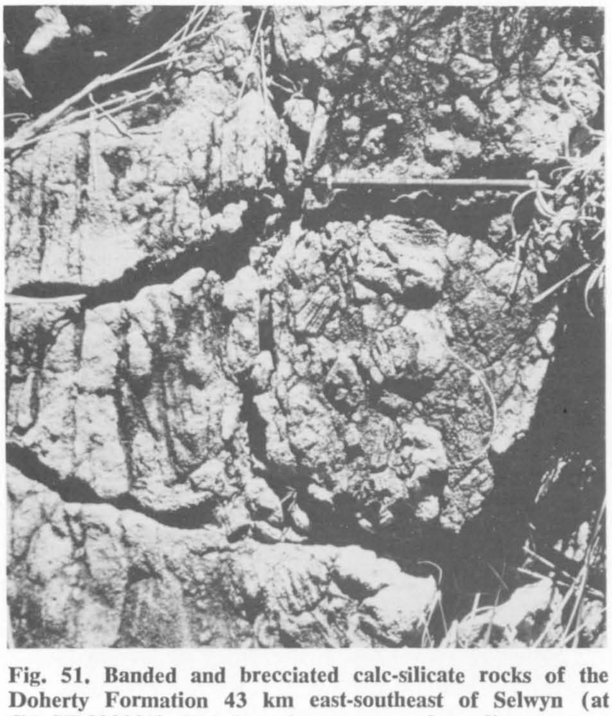

Fig. 51. Banded and brecciated calc-silicate rocks of the Doherty Formation 43 km east-southeast of Selwyn (at GR VB880025). This breccia appears to be sedimentary or diagenetic, rather than being related to later tectonism. (M2304/6)

Fig. 52. Tectonic calc-silicate breccia in the Doherty Formation 38 km east of Selwyn (at GR VB870188). (M2304/22)

possible interfingering relationship is apparent from the presence of some Soldiers Cap-type schist within the Doherty Formation and some Doherty-type calc-silicate rocks within the Soldiers Cap Group. Previously the Doherty Formation (= Corella Formation of earlier workers) was considered to be unconformable on the Soldiers Cap Group (e.g., Derrick & others, 1977a), as calc-silicate breccia of the formation was thought to form flat-lying outliers overlying steeply dipping Soldiers Cap Group rocks near Cloncurry (Carter & others, 1961; Glikson, 1972). However, at least some of these so-called outliers have been found to be dyke and pod-like bodies which were probably injected during tectonism (Blake & Derrick, 1980; Wilson, 1979).

Contacts between the Doherty Formation and granite are generally clear-cut (Fig. 53), but in places, especially in the north, calc-silicate rocks appear to grade laterally into contaminated clinopyroxene-bearing granite.

The Doherty Formation has been defined as a new formation (Blake & others, 1981a; see also Blake, 1982) for several reasons: it is geographically separated from the outcrop area of the Corella Formation type section in MARRABA; it is in contact with units which are not obvious correlatives of those adjacent to the Corella Formation exposed to the west; and it includes metarhyolite (considered to be extrusive) dated at 1720 ± 7 m.y., whereas the Corella Formation in the outcrop area of its type section is intruded by granite dated at 1720–1740 m.y., and hence is significantly older than the metarhyolite.

Staveley Formation

The Staveley Formation, which includes some outcrops previously mapped as Marimo Slate and Corella Formation, is the most extensive unit in the Staveley Belt. It forms undulating terrain, low hills and ridges, and soil-covered plains in a belt up to 16 km wide and more than 75 km long, extending northwards from the southern central part of the eastern area. It consists mostly of well-bedded to locally brecciated sandy, silty, and clayey sedimentary rocks (Table 13). These have been tightly folded and regionally metamorphosed mainly to the lower greenschist facies. Upper greenschist to lower amphibolite-facies rocks are present locally, mainly near granite plutons; they include mica schist, some of which contains staurolite porphyroblasts, and calc-silicate rocks containing hornblende and/or clinopyroxene. Rock types and sedimentary structures (e.g., Fig. 54) indicate probable shallow-water deposition. Some contemporaneous tectonism is indicated by the presence of basaltic lava at GR VB455140, and possibly by convolute to recumbent bedding structures and the widespread occurrence of breccia. The thickness of the formation is uncertain.

Contacts between the Staveley Formation and adjacent units are either concordant or faulted, or both. In the north of the Staveley Belt, and farther north in MARRABA, rocks of the Staveley Formation and its correlatives overlie breccia consisting almost entirely of chert fragments enclosed in a siliceous and ferruginous matrix; if this breccia, which is mapped as part of the Overhang Jaspilite (and also, in MARRABA, as Chumvale Breccia), is regolithic, as favoured by Blake (*in* Blake & others, 1983a; Donchak & others,

Fig. 53. Cross-cutting contact of leucogranite, possibly related to the Blackeye Granite, and banded calc-silicate rocks of the Doherty Formation 50 km southwest of Selwyn (at GR VA914937). (M2304/16)

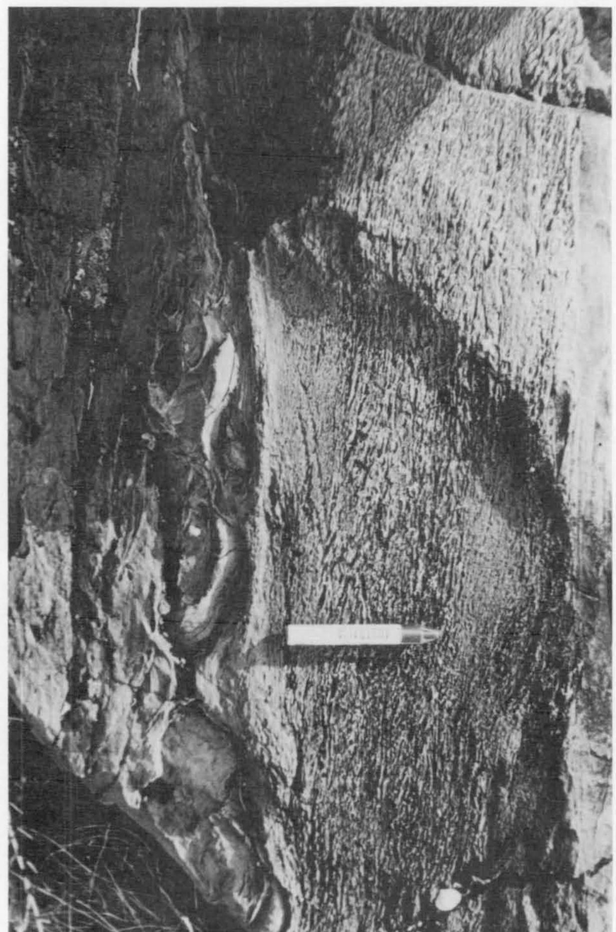

Fig. 54. Convolute bedding of recumbent-fold type in interbedded arenite and siltstone of the Staveley Formation 6 km southwest of Selwyn (at GR VB451146). (M2304/26)

1983), a low-angle unconformity is implied between the Staveley Formation and underlying rocks.

A possible unconformable contact between the Staveley Formation and the Kuridala Formation is exposed near GR VB457138; here little-metamorphosed rocks of the Staveley Formation appear to overlie finely crenulated schistose rocks of the Kuridala Formation which are cut by ptygmatically folded quartz veinlets, and conglomeratic beds in the Staveley Formation nearby contain schistose clasts possibly derived from the Kuridala Formation. The crenulated cleavage in the Kuridala Formation rocks here developed either during a tectonic event predating the deposition of the Staveley Formation, or during later faulting. Another possible unconformable contact occurs 7 km north of Kuridala, where small masses of Staveley Formation breccia appear to be discordant on steeply dipping Kuridala Formation schists (Donchak & others, 1983). To the south the Kuridala Formation forms two large second-generation synforms partly bounded by the Staveley Formation, but which is the older unit here is not clear. Several interpretations are possible from the available evidence: (1) the Staveley Formation may overlie the Kuridala Formation unconformably (the interpretation favoured at present) or conformably; (2) the two formations may be lateral equivalents; (3) the Staveley Formation may be the older unit; or (4) there may be two quite separate units mapped as Kuridala Formation, one older and the other younger than the Staveley Formation.

In the north the Staveley Formation is faulted against the Doherty Formation. These two formations are possible correlatives, as both contain bedded and brecciated calcareous rocks. However, the Staveley

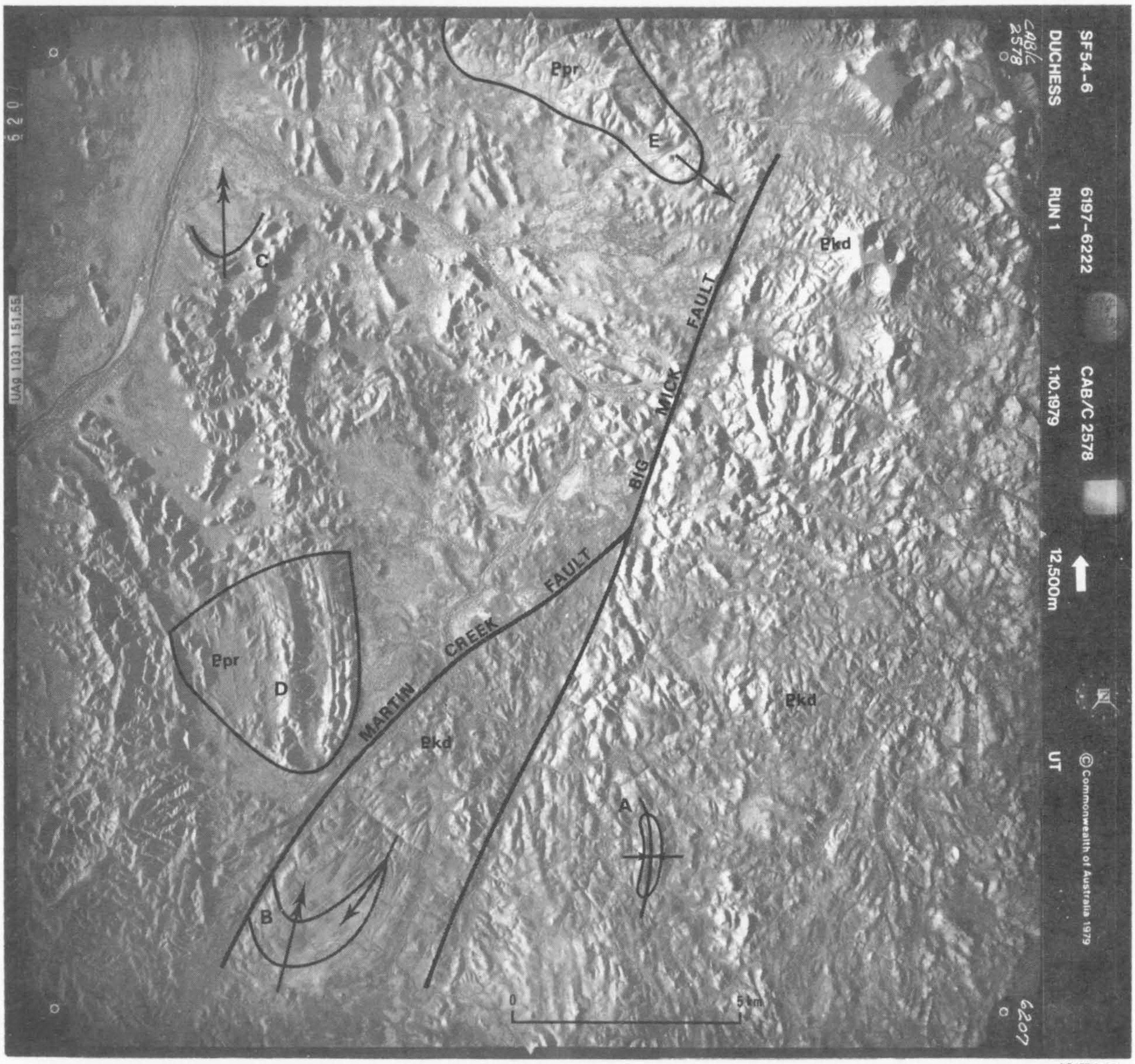

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Fig. 55. Infrared airphoto of the area centred about 25 km north-northeast of Kuridala. The Doherty Formation here (Ƥkd) displays tight to isoclinal first-generation folds (e.g., a tight synclinal basin outlined by a metadolerite sill at A) which in places are refolded by open north-plunging second-generation folds, as at B). Both folding episodes were associated with regional metamorphism and recrystallisation. Units to the west of the Doherty Formation, west of the postfolding Martin Creek and Big Mick Faults, are of lower metamorphic grade. Some second-generation folding is evident locally in the lower-grade rocks, as at C in the northwest, where a north-plunging second-generation fold has refolded the first-generation cleavage developed in the Marimo Slate. The Roxmere Quartzite? (Ƥpr) forms an isolated tilted block in the west (D) and a southeast plunging antiform, which is an overturned syncline, in the north (E).

Formation is a predominantly clastic unit, unlike the Doherty Formation, and is generally of much lower metamorphic grade. Consequently, it is considered to be the younger unit, and it may postdate an episode of deformation and regional metamorphism affecting the Doherty Formation.

The Staveley Formation is overlain, apparently conformably, by the Agate Downs Siltstone and Marimo Slate, and probably includes lateral equivalents of these two units. It is also overlain with apparent conformity by the Roxmere Quartzite?

Agate Downs Siltstone

This formation forms a north-trending belt 25 km long and up to 2.5 km wide in the central part of the area, on the west side of the Staveley Belt. It consists mainly of ridge-forming metasiltstone, fine-grained meta-arenite, and quartzite, together with less resistant phyllite, and appears to have been regionally metamorphosed only to the greenschist facies. Cross-bedding and ripple marks near the base of the Agate Downs Siltstone in the south indicate that the formation overlies the Staveley Formation and is preserved in a complex isoclinal syncline. The closure of the major fold is outlined in the south by a band of thin-bedded fine-grained quartzite and cherty metasiltstone.

The formation may be a facies equivalent of part of the Marimo Slate and the upper part of the Staveley Formation exposed to the northeast. Its top is not exposed.

Marimo Slate

The Marimo Slate forms low hills and ridges in the north of the Staveley Belt. Following Derrick & others (1977a), we have included in it ridge-forming feldspathic arenite and quartzite mapped as the *Toby Barty Sandstone Member*, but the relationship of this member to the remainder of the formation is uncertain because of faulting. The Marimo Slate consists mainly of carbonaceous slate and siltstone, which are cupriferous in places, and appears to be regionally metamorphosed to about the middle of the greenschist facies. The carbonaceous beds are commonly pitted, possibly owing to the leaching out of small pyrite cubes. Most of the non-carbonaceous rocks previously included within the formation (Carter & Öpik, 1963; Noon, 1978) are now placed in the Staveley Formation, which is probably a facies equivalent of part of the Marimo Slate. Open to tight large-scale folds and minor folds with axial planes parallel to the slaty cleavage are evident in places. The thickness of the Marimo Slate may range between 1000 and 2000 m; the uncertainty is because the formation shows widespread folding, and its top is not exposed.

TABLE 14. GRANITES OF THE WILLIAMS BATHOLITH, EASTERN AREA

Name of unit (reference to definition)	*Lithology*	*Relationships*
Foliated granites **Blackeye Granite** (Blake & others, 1981a)	Foliated leucocratic granodiorite and minor pegmatite	Intrudes Doherty Formation
Cowie Granite (Blake & others, 1981a)	Generally foliated biotite-bearing leucocratic granite, granodiorite, and tonalite; pegmatite	Intrudes Soldiers Cap Group and Doherty Formation; intruded by Squirrel Hills Granite
Maramungee Granite (Blake & others, 1981a)	Generally foliated biotite-bearing leucocratic granite, granodiorite, and tonalite; pegmatite	Intrudes Soldiers Cap Group; cut by dolerite dyke
Non-foliated granites **Wimberu Granite** (Carter & others, 1961)	Commonly porphyritic granite and granodiorite containing biotite and/or hornblende ± clinopyroxene; subordinate finer-grained non-porphyritic biotite granite; minor aplite and pegmatite	Intrudes Argylla Formation, Marraba Volcanics, Mitakoodi Quartzite, Overhang Jaspilite, Answer Slate, Doherty Formation, Staveley Formation, and metadolerite
Gin Creek Granite (Blake & others, 1981a)	Partly porphyritic biotite granite; subordinate slightly foliated fine to coarse leucogranite containing muscovite and tourmaline, and intensely foliated biotite granite with abundant inclusions mostly of gneiss and schist derived from the Double Crossing Metamorphics; minor biotite microgranite, aplite, and greisen	Intrudes Double Crossing Metamorphics, Answer Slate, Staveley Formation, Kuridala Formation, and metadolerite
Mount Angelay Granite (Blake & others, 1981a)	Partly porphyritic granite containing biotite and/or hornblende and/or clinopyroxene; minor leucogranite, porphyritic microgranite, contaminated grey granite, aplite, and pegmatite; xenoliths common near margins of granite	Intrudes Soldiers Cap Group and Doherty Formation; cut by dolerite dykes
Mount Cobalt Granite (Blake & others, 1981a)	Biotite granite and minor aplite	Intrudes Kuridala Formation and metadolerite
Mount Dore Granite (Blake & others, 1981a)	Biotite and hornblende-biotite granite, porphyritic in places; minor microgranite, aplite, pegmatite, and greisen	Intrudes Kuridala Formation and metadolerite
Saxby Granite (Blake & others, 1981a)	Biotite and hornblende-bearing granite; minor leucogranite, xenolithic diorite, monzonite, granodiorite, aplite, and pegmatite	Intrudes Soldiers Cap Group, Doherty Formation, and metadolerite; cut by dolerite dykes
Squirrel Hills Granite (Blake & others, 1981a)	Commonly porphyritic granite containing hornblende and/or biotite and locally clinopyroxene; minor aplite, porphyritic microgranite, monzonite, and granodiorite; rare pegmatite	Intrudes Soldiers Cap Group, and Kuridala, Doherty, and Staveley Formations, Cowie Granite, and metadolerite; cut by dolerite dykes
Yellow Waterhole Granite (Blake & others, 1981a)	Partly porphyritic biotite and hornblende-biotite granite; minor aplite	Intrudes Kuridala Formation
Undivided granite	Foliated leucocratic tonalite and pegmatite; biotite granite; minor hornblende-biotite tonalite	Intrudes Soldiers Cap Group, Kuridala Formation, and Doherty Formation

The Marimo Slate is similar in lithology to the Answer Slate, a possible correlative. However, the Marimo Slate is thought more likely to be a younger unit which, like the Staveley Formation, was deposited in mainly shallow water. The Toby Barty Sandstone Member may be a thick lens within the Marimo/Staveley sequence, or a younger unit, possibly equivalent to the Roxmere Quartzite?

Roxmere Quartzite?

Ridge-forming arenites mapped as Roxmere Quartzite? (Table 13) crop out within the Staveley Belt in the northern central part of the area, forming a partly fault-bounded block about 20 km north of Kuridala and a southeasterly trending ridge to the northeast (Fig. 55). The southern outcrop was mapped as Roxmere Quartzite by Carter & others (1961) and Carter & Öpik (1963), but both it and the northern outcrop are geographically separated from, and cannot be directly correlated with, the outcrop area containing the type section of the formation near Cloncurry. The northern outcrop is a southeasterly plunging antiform which is an overturned syncline bounded by breccia of the Staveley Formation. This antiform may be part of a large recumbent fold or nappe structure.

The arenites making up the unit are generally similar in lithology to those in the nearby Staveley Formation and Marimo Slate, and are considered to be part of the same, mainly shallow-water, sequence. They appear to have been regionally metamorphosed to about the lower greenschist facies.

Williams Batholith

The Proterozoic stratigraphic succession in the eastern area is intruded by a series of granitic plutons which collectively form the Williams Batholith (Table 14). Except for the most westerly intrusion, formed of Wimberu Granite, the plutons were previously mapped as Williams Granite (Carter & others, 1961; Carter & Öpik, 1963).

In the field the granites of the Williams Batholith can be divided into two main types. One type is recrystallised and foliated, leucocratic (pale pinkish), texturally heterogeneous (at any one exposure), and generally non-porphyritic. It forms small plutons in the east which have generally concordant and in places lit-par-lit intrusive contacts. The foliation in these granites is concordant with the foliation/metamorphic layering in adjacent country rocks. In some contact zones, migmatitic complexes are developed. The other type is mostly non-foliated, darker pink, and texturally homogeneous, and commonly contains plagioclase and microcline phenocrysts 1–5 cm across. It forms mainly large plutons and groups of plutons which have cross-cutting intrusive contacts. The foliated, heterogeneous granites may be syntectonic, and are inferred to be older than the non-foliated, homogeneous granites, which are post-tectonic. These younger granites were probably emplaced between 1500 and 1550 m.y. ago (Blake & others, 1983b).

Foliated granites

Northerly trending intrusions of fine-grained to pegmatitic, foliated granitic rocks cropping out along the eastern margin of the Williams Batholith are mapped as Blackeye, Cowie, and Maramungee Granites and unnamed granite. The intrusions are similar in composition and probably age. They typically contain up to 5 percent primary ferromagnesian minerals (amphibole ± biotite ± clinopyroxene), are commonly xenolithic, and have been regionally metamorphosed to the greenschist facies.

The *Blackeye Granite* forms a small but well-defined pluton 1.6 km long intruding the Doherty Formation in the southeast. The *Cowie Granite* forms a pluton 11.5 km long and up to 3 km wide 3 km to the west; it is intruded by non-foliated porphyritic microgranite probably related to the adjacent Squirrel Hills Granite. The *Maramungee Granite* forms a pluton 5 km long 12 km north of the Blackeye Granite; biotite from the Maramungee Granite has given a K–Ar age of 1400 m.y. (Richards & others, 1963, sample GA 134), but this is probably a cooling age rather than the age of granite emplacement.

Non-foliated granites

The voluminous non-foliated granites of the Williams Batholith, represented by the Wimberu, Gin Creek, Mount Angelay, Mount Cobalt, Mount Dore, Saxby, Squirrel Hills, and Yellow Waterhole Granites and some unnamed granite, are probably closely related to one another both magmatically and in age. They are mainly medium to coarse-grained, and typically consist of strained quartz, about equal amounts of slightly zoned oligoclase and commonly perthitic microcline, 5 to 15 percent of biotite and/or pale to dark green hornblende and/or pale green clinopyroxene, up to 5 percent magnetite and sphene, and accessory and secondary allanite, apatite, calcite, chlorite (mostly after biotite), epidote, fluorite, muscovite, sericite (mostly after plagioclase), sulphide minerals, and zircon. Micrographic quartz and microcline and myrmekitic quartz and plagioclase occur in some samples examined microscopically. Xenoliths and pegmatites are generally rare, but veins and patches of aplite are present at most exposures. Thin veins of hematite occur locally within the Mount Dore and Squirrel Hills Granites.

In detail the bodies of the non-foliated granites generally have sharp, commonly irregular intrusive contacts which cut across without obviously deflecting the bedding and foliation of the country rocks. However, some granite contacts, especially in the north, are broadly concordant with adjacent stratigraphic units. At many localities the country rocks appear to show no contact metamorphic effects, but metamorphic aureoles up to 100 m wide, consisting of hornfels, are present in places.

The field evidence indicates that the non-foliated granites were emplaced, probably by stoping, after the country rocks had been folded and regionally metamorphosed. However, petrographic evidence shows that most, if not all, these granites have been affected by a low-grade metamorphic event. Though termed 'non-foliated', the granites are sheared and foliated in places, mainly near faults.

The *Wimberu Granite* forms a large composite body, up to about 42 km across, which was emplaced within the major anticlinal structure in the northwestern part of the area, and it also forms some small intrusions, possibly connected to the main body at depth, to the east. The main intrusion contains several large pendants of country rocks and is partly concealed beneath Cambrian sediments of the Burke River Structural Belt. Two isotopic ages are available for the granite: a K–Ar biotite age of 1498 m.y. (Richards & others,

Fig. 56. Aerial view, from the northwest, of the small pluton of Mount Cobalt Granite intruding the Kuridala Formation 19 km south of Selwyn. (M2303/26)

1963); and an Rb–Sr total-rock age of 1530 m.y. (Richards, 1966) derived from a decay constant for Rb^{87} of $1.39 \times 10^{-11}y^{-1}$, or 1498 m.y. according to the current recommended decay constant for Rb^{87} of $1.42 \times 10^{-11}y^{-1}$.

The *Gin Creek Granite* crops out on the southwestern side of the Williams Batholith, forming a northerly trending composite body 24 km long and up to 6 km wide and also a few much smaller intrusions nearby. Unlike other named granites of the Williams Batholith, it includes both non-foliated and foliated types of granite.

The *Mount Angelay Granite* forms a north-northwesterly trending intrusion that crops out over an area of about 200 km^2 in the northeast on the western side of the Cloncurry Fault. It includes some heterogeneous pale to dark grey granitic hybrid rocks. Contaminated granite present in places adjacent to the Doherty Formation contains scapolite.

The *Mount Cobalt Granite* is exposed as a prominent stock about 1 km across (Fig. 56) at GR VB5100. The stock is surrounded by a metamorphic aureole about 100 m wide in which rocks of the Kuridala Formation and metadolerite have been metamorphosed to hornfels.

The *Mount Dore Granite* forms a northeasterly trending pluton 14 km long and 7 km wide intruding the Kuridala Formation between Selwyn and the Mount Cobalt Granite. It has been dated by Rb–Sr at 1509 ± 22 m.y. (Nisbet & others, 1983).

The *Saxby Granite* forms closely spaced, irregularly shaped plutons up to 10 km across in the northeast, mainly east of the Cloncurry Fault. It includes a complex body of xenolithic diorite, monzonite, and granodiorite near the headwaters of the Williams River.

The *Squirrel Hills Granite* forms a large composite body about 100 km long and up to 25 km wide trending north-northwest in the eastern half of the eastern area. Porphyritic microgranite associated with this granite intrudes the foliated Cowie Granite in the southeast.

The *Yellow Waterhole Granite* forms an east-trending intrusion 19 km long and up to 2.5 km wide in the southern central part of the eastern area. The intrusion cuts the surrounding northerly trending Kuridala Formation, which in a few places is metamorphosed to hornfels adjacent to the granite. A K–Ar biotite age of 1458 m.y. (Richards & others, 1963, sample GA 172) is regarded as a minimum age for the emplacement of this granite and probably also for the other non-foliated granites of the Williams Batholith.

Minor intrusions

Sills, dykes, and pod-like bodies of *metadolerite* and, in the east, *amphibolite* are widespread in the eastern area. They intrude most Proterozoic stratigraphic units, and range from less than a metre to several hundreds of metres in thickness. Many of the larger bodies are multiple sills in which some individual intrusions are separated from one another by thin screens of country rock.

The metadolerite and amphibolite intrusions predate the last major folding and metamorphic event affecting the area, and most are probably older than the granites of the Williams Batholith. Some, such as the sills at Kuridala (see below), postdate one folding event but were folded during a subsequent event. A small net-veined complex of granite and metadolerite at Boorama Waterhole (GR VB818316—shown incorrectly on the accompanying map as Boomerang Waterhole) indicates that at this locality the metadolerite is either similar in age or younger than the associated granite (Blake, 1981a).

Non-metamorphosed *dolerite* forms a series of widely spaced east-trending dykes up to about 50 m thick cutting granite and older rocks. The dolerite consists of ophitic pyroxene (augite ± hypersthene) + calcic plagioclase laths (commonly much altered) ± possible pseudomorphs after olivine + opaque minerals + apatite ± biotite ± interstitial and partly micrographic quartz and alkali feldspar. These dykes postdate the emplacement of granite and the last metamorphic event to affect the area. They are the youngest Precambrian rocks exposed in this part of the Mount Isa Inlier, and may be correlated with the Lakeview Dolerite to the north, which has been dated by the Rb–Sr whole-rock method at 1116 ± 12 m.y. (Derrick & others, 1978; Page, 1983b).

Structure

Folding

In the western part of the eastern area, the Argylla Formation to Overhang Jaspilite sequence has been folded into a large anticlinal structure about 50 km across. This structure, which corresponds to the Malbon Block, continues northwards into MARRABA as the northeasterly plunging Bulonga and Duck Creek Anticlines and intervening syncline (Derrick, 1980). Thin chert and jasper bands in the Overhang Jaspilite locally show related small-scale folds (Figs. 8c, 43). The eastern limb of the anticlinal structure in the north, north of the Malbon–Kuridala road, has been refolded to produce a series of large northeast-plunging, tight to isoclinal folds (Fig. 57): these differ in style, orientation, and possibly age from other folds in the region.

Immediately to the east of the major anticlinal structure there is a complex folded and faulted zone made up of the Answer Slate of the Malbon Block and the Staveley Formation, Agate Downs Siltstone, Marimo Slate, and Roxmere Quartzite? of the Staveley Belt. The Staveley Formation and Marimo Slate in the far north have been folded into north-plunging structures. The northernmost outcrop of the Roxmere Quartzite? is a southeasterly plunging antiform representing an overturned syncline (Fig. 55), possibly part of a nappe structure, surrounded by Staveley Formation breccias. This structure, as well as the partly fault-bounded block of Roxmere Quartzite? a few kilometres to the south, may have resulted from major overthrusting, shortly after lithification, along a decollement zone formed of breccia.

To the south, the Answer Slate, Staveley Formation, and Agate Downs Siltstone show tight to isoclinal folds with mainly gentle plunges. Many of the folds in the Answer Slate, an intensely cleaved unit, and also some in the Staveley Formation, are outlined by metadolerite sills (Fig. 44). The Agate Downs Siltstone defines a large isoclinal north-plunging syncline complicated by transcurrent and strike-slip faults.

The Kuridala Formation to the east, part of the Squirrel Hills Belt, is a sequence of complexly folded metapelites and meta-arenites. The metapelites have a well-developed schistosity which in places has been folded about open to tight major antiforms and synforms. Folds related to the early schistosity appear to be rare, but some examples of early major and minor folds have been found (Fig. 58), and larger folds may be inferred where bedding is clearly at a high angle to the schistosity; early open anticlines and tight synclines with wavelengths of up to several hundred metres have been described by Donchak (*in* Blake & others, 1983a) from a locality 9 km southeast of Mount Dore. A good example of a later fold is the tightly appressed north-trending 20-km-long structural basin outlined by dolerite sills near Kuridala (Donchak & others, 1983; Fig. 46). Small subsequent folds here may be related to movements along the Straight Eight Fault to the east. Near Mount Cobalt mine, southwest of Mount

Fig. 57. Infrared airphoto of the area centred about 10 km east of Malbon, showing tight to isoclinal northeast-plunging large-scale folds in ridge-forming Mitakoodi Quartzite on the eastern side of the Malbon Block. These folds appear to die out to the west, in the underlying Marraba Volcanics and Argylla Formation, and do not persist above the overlying Overhang Jaspilite to the east. They appear to fold pre-existing cleavages associated with the Duck Creek Anticline, and hence probably postdate this structure. No folds of this style and orientation have been found elsewhere in the region.

Dore, Nisbet & others (1983) have recognised two generations of tight to isoclinal folds and a later phase of more open folds.

To the east, tight to isoclinal early folds in the Doherty Formation have wavelengths ranging from several metres to several kilometres, steeply dipping axial planes, and moderate to steep plunges. These folds have been found only in thin-banded calc-silicate rocks in which an associated axial-plane cleavage is rarely evident. They are commonly refolded about steeply dipping axial planes (Fig. 59) to form north and south-plunging structures, including some basin-and-dome interference folds.

The easternmost Precambrian unit, the Soldiers Cap Group, is also multiply deformed. A well-developed early schistosity and metamorphic layering generally trend north, dip steeply, and are commonly parallel to boudinaged pegmatite and quartz veins. Compositional banding in the gneisses probably results from transposition of original bedding, locally enhanced by metamorphic differentiation. Recognisable bedding is generally parallel to the schistosity, except where shallowly plunging isoclinal and intrafolial rootless minor folds are present (Fig. 42). Large early folds related to the schistosity have been recognised only in the vicinity of the Fairmile prospect, where an isoclinal fold is outlined by a bed of banded iron formation. Later major tight folds, generally plunging north, and also some basin-and-dome-type folds occur sporadically in the eastern part of the Soldiers Cap Group (Fig. 60). Axial planes are mainly vertical and locally have an associated crenulation cleavage which in a few areas is defined by mica-rich bands that obliterate the earlier schistosity. A southeast-plunging younger antiform occurs in the far north, between Snake and Sandy Creeks (Donchak & others, 1983).

Faulting

In the eastern area the main faults, which include the Cloncurry, Straight Eight, Big Mick, Martin Creek,

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Fig. 58. Infrared airphoto of the area centred about 30 km south-southeast of Selwyn, showing outcrops of Kuridala Formation meta–arenites and metapelites. Ridge-forming quartzite bands in the circled areas show tight to isoclinal first-generation folds. Also shown is the cross-cutting Yellow Waterhole Granite (Pgiy).

and Happy Valley Faults, trend between northwest and northeast. The latest movements along these faults postdate folding, and some postdate the emplacement of the Williams Batholith. Some smaller faults, such as those in the Mitakoodi Quartzite east of Malbon, are aligned parallel to the axial planes of folds and were probably formed when ductile folding could no longer dissipate applied stresses. As in other parts of the region, many lithologic boundaries are marked by faults resulting from bedding-plane slip during deformation.

Metamorphic effects

The highest-grade regionally metamorphosed rocks of the eastern area are exposed in the southwest and far east (Fig. 9), as described by Jaques & others (1982).

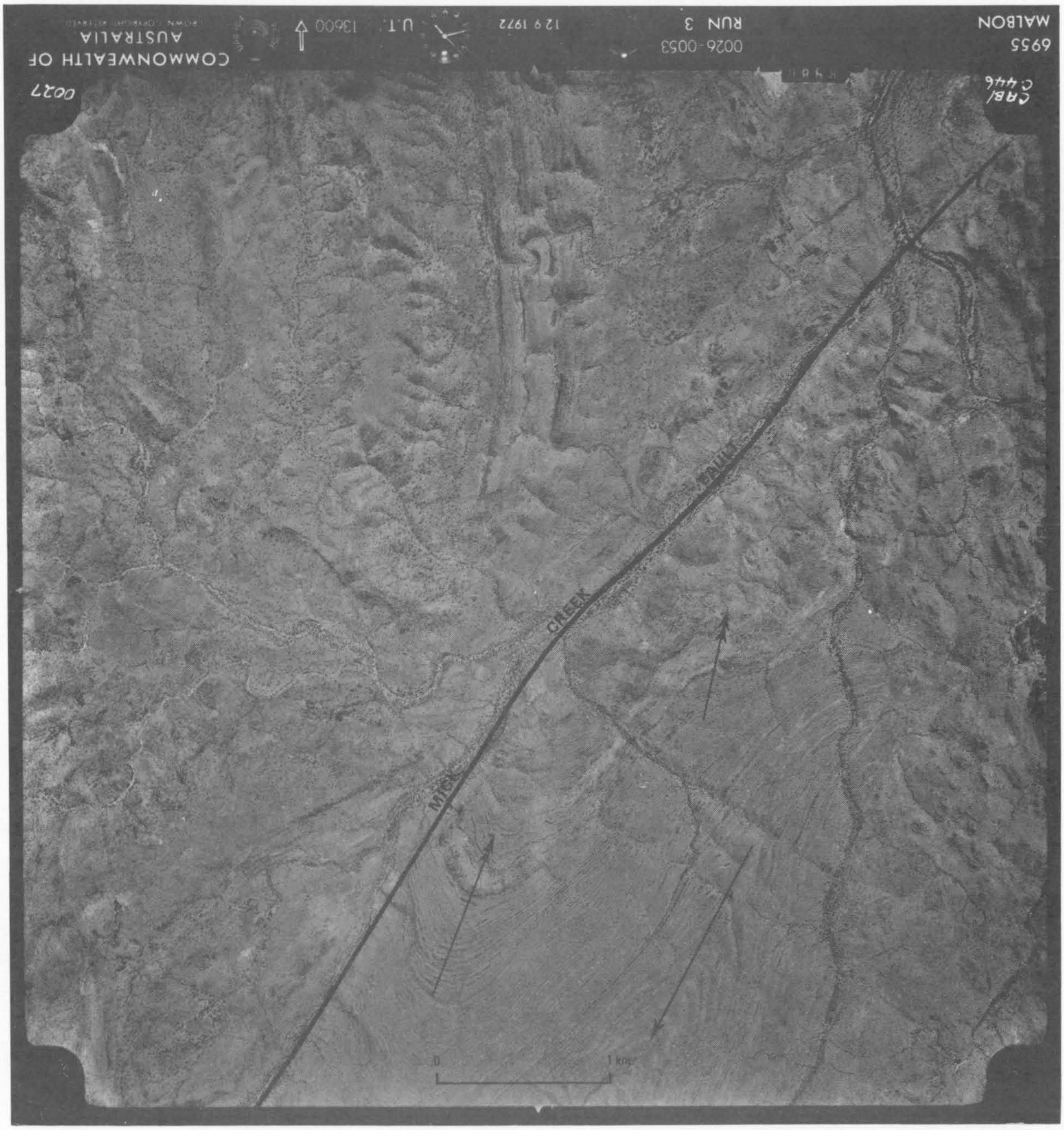

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Fig. 59. Airphoto of an area centred 22 km north of Kuridala, showing well-bedded calc-silicate rocks of the Doherty Formation in the south, the northeast-trending Mick Creek Fault, and north-trending ridges of westerly dipping Roxmere Quartzite? in the north and northwest. The bedded calc-silicate rocks show two generations of folding—a south-southwest-plunging first-generation fold (single arrowhead) and north-northeast plunging second-generation folds (double arrowheads). The hilly terrain to the east and northeast is formed of calc-silicate breccia.

In the north, west of the Doherty Formation outcrop, delicate primary structures and textures in sedimentary and igneous rocks are commonly well preserved, suggesting regional metamorphism to no more than the greenschist facies. However, rims of blue-green hornblende around cores of actinolite in some basaltic rocks of the Marraba Volcanics, and intensely recrystallised felsic volcanics at some exposures of the Argylla Formation, indicate that the lower amphibolite facies was reached in places.

To the south the Argylla Formation, Marraba Volcanics, and probably also the Mitakoodi Quartzite and Answer Slate consist predominantly of amphibolite-facies rocks, whereas the Staveley Formation and Agate Downs Siltstone to the east appear to have been metamorphosed mainly to the greenschist facies.

The Kuridala and Doherty Formations, east of the Staveley Formation outcrop, are formed of amphibolite-facies rocks. Pelitic schists and meta-arenites of the Kuridala Formation typically consist of quartz + biotite + muscovite ± alkali feldspar + porphyroblasts of andalusite, garnet, and less commonly staurolite, and associated metabasites contain hornblende and plagioclase more calcic than An_{17}; hornblende hornfels containing andalusite, cordierite, and fibrolitic sillimanite is present in metamorphic aureoles up to 100 m wide adjacent to some non-foliated granite intrusions of the Williams Batholith. Typical assemblages in the calc-silicate rocks of the Doherty Formation are calcite + sodic plagioclase (mostly albite) + microcline + quartz ± hornblende ± clinopyroxene (salitic) ± actinolite + epidote + sphene ± scapolite (rare); in the north the Martin Creek and Big Mick Faults separate these amphibolite-facies rocks from greenschist-facies arenites and breccias of the Staveley Formation to the west.

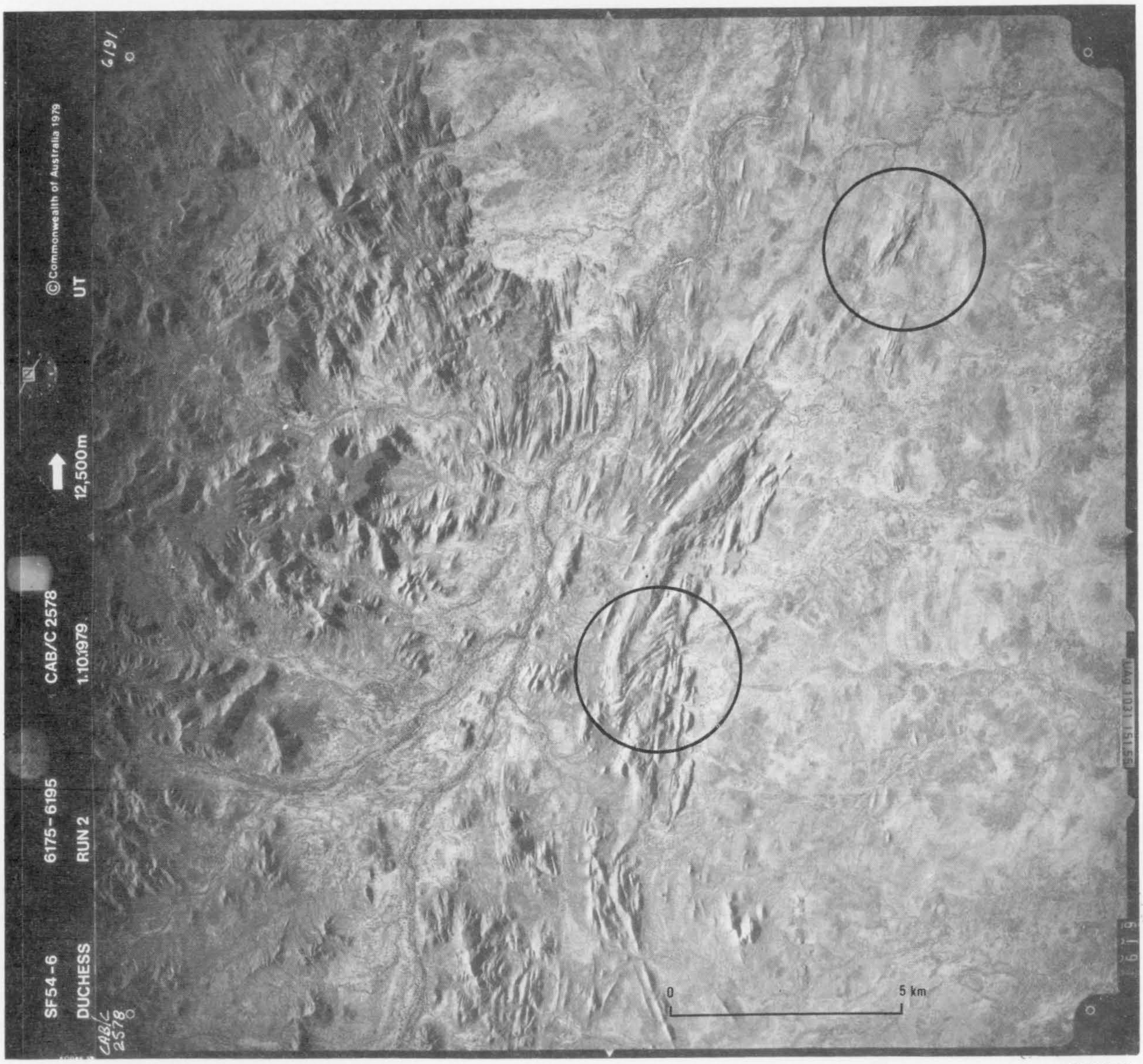

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Fig. 60. Infrared airphoto of Soldiers Cap Group and Saxby Granite outcrops centred about 35 km east-northeast of Kuridala, in the northeast of the region. The dominant trends in the metasediments represent bedding, which is generally parallel to the first-generation foliation. Tight major second-generation folds occur in the circled areas. A pluton of post-tectonic Saxby Granite occupies the general depression in the north. Mesas in the west are capped by flat-lying Mesozoic sediments of the Gilbert River Formation.

In the Soldiers Cap Group the metamorphic grade generally increases eastwards (Jaques & others, 1982), and in places the rocks probably reach the upper amphibolite facies. Partial melting is indicated by abundant veins and pods of leucogranite and pegmatite and the local development of migmatite (Fig. 42). Mineral assemblages include quartz + sodic plagioclase + microcline + biotite + muscovite ± garnet ± andalusite ± sillimanite in schist and gneiss, green hornblende + oligoclase/andesine in amphibolite, and amphibole + clinopyroxene + albite ± garnet ± scapolite in calc-silicate rocks.

The amphibolite-facies regional metamorphism may be related to the earliest major folding event recognised in the eastern area. The sporadic development of chlorite in the amphibolite-facies rocks may be related to a later, less intense, tectonic event.

GEOCHEMISTRY OF IGNEOUS ROCKS

The following account is mainly based on chemical analyses of 412 samples collected between 1975 and 1980. The samples were analysed for major elements at The Australian Mineral Development Laboratories (AMDEL), Adelaide. and for trace elements at BMR, mainly by X-ray spectrometry, though abundances of Co, Cr, Cu, Li, Zn, Ni, and V were determined by atomic absorption spectroscopy. Representative chemical analyses are listed in Tables 15–17, and variation diagrams for selected elements in felsic volcanics and granites are shown in Figures 61 and 62. Wyborn (in preparation) has compiled a complete list of analyses and sample localities, and separate publications discuss in more detail the geochemistry of

TABLE 15. REPRESENTATIVE CHEMICAL ANALYSES OF FELSIC VOLCANICS FROM THE DUCHESS–URANDANGI REGION
(from Bultitude & Wyborn, 1982)

	Leichhardt Volcanics		*Argylla Formation*		*Bottletree Formation*		*Corella Formation*		*Carters Bore Rhyolite*		
No. of samples or sample numbers*	34		13		19		15		7653–1143A	7653–1143B	7653–1143C
	$\overline{x}$	*s*	$\overline{x}$	*s*	$\overline{x}$	*s*	$\overline{x}$	*s*			
SiO_2	72.36	2.59	69.03	2.52	70.00	3.60	67.40	4.24	76.10	74.60	73.20
TiO_2	0.23	0.11	0.62	0.20	0.64	0.15	0.48	0.24	0.47	0.45	0.44
Al_2O_3	13.84	0.86	12.82	0.38	11.93	2.97	12.88	0.67	11.20	10.70	11.10
Fe_2O_3	1.19	0.50	3.04	1.24	2.71	1.34	3.23	2.13	0.49	3.75	3.88
FeO	1.18	0.86	2.05	0.81	3.19	0.80	1.64	0.95	0.24	0.35	0.35
MnO	0.03	0.02	0.04	0.03	0.06	0.02	0.05	0.08	0.01	0.01	0.01
MgO	0.45	0.31	0.56	0.36	0.45	0.26	0.61	0.28	1.02	0.13	0.13
CaO	1.60	0.64	1.68	1.14	2.43	0.98	1.74	1.13	0.24	0.09	0.09
Na_2O	2.90	0.58	2.55	0.95	2.10	0.81	1.67	1.00	0.20	0.10	0.16
K_2O	4.84	0.96	5.52	1.70	4.76	1.60	7.71	1.58	8.82	9.20	9.44
P_2O_5	0.06	0.03	0.15	0.09	0.14	0.06	0.11	0.06	0.15	0.06	0.07
Ba	817	318	856	503	1483	523	1194	332	210	200	170
Rb	197	53	190	53	175	50	241	64	100	130	140
Sr	152	60	89	58	180	74	40	28	24	14	13
Pb	26	23	7	5	18	10	3	3	5	3	<2
Th	29	6	30	6	26	4	33	14	34	26	30
U	6	2	8	3	5	3	10	6	12	4	10
Zr	212	99	607	86	566	143	311	107	480	430	450
Nb	13	4	41	10	27	5	26	6	32	30	30
Y	27	7	77	17	52	14	50	20	46	50	50
La	64	16	87	21	93	19	62	34	90	90	110
Ce	115	40	172	46	175	28	107	56	180	160	190

TABLE 15 *continued*

Plum Mountain Gneiss		*Mitakoodi Quartzite*		*Double Crossing Metamorphics*	*Undivided Tewinga Group*			*Sulieman Gneiss*		*Soldiers Cap Group*	*Doherty Formation*	
7920–5314	7753–2551	8053–0099	8053–2040A	7853–4709	7753–2013	5		7753–2364B	7853–2359	7853–1105	7853–0494	7853–0496
						$\overline{x}$	*s*					
65.10	69.70	70.90	75.70	68.90	64.70	70.62	2.22	74.00	75.50	67.80	78.30	75.00
0.79	0.39	0.54	0.50	0.47	0.48	0.54	0.14	0.43	0.28	0.67	0.17	0.13
14.50	14.50	10.60	8.95	11.80	14.90	12.90	·0.36	12.60	11.70	12.10	10.20	13.10
0.48	0.17	5.82	4.25	6.18	1.04	2.42	0.43	0.42	0.32	1.65	0.82	0.58
5.65	2.74	1.48	2.10	2.80	3.29	2.41	1.09	2.15	1.78	4.08	0.53	0.28
0.07	0.04	0.01	0.02	0.06	0.06	0.07	0.02	0.04	0.03	0.26	0.02	0.02
1.26	0.94	0.12	0.17	0.71	3.93	0.56	0.43	0.55	0.40	0.53	0.19	0.20
3.25	2.07	0.23	0.50	1.92	3.37	1.78	0.40	1.40	0.88	2.82	1.44	0.60
2.50	2.70	0 32	2.55	3.19	2.85	3.23	1.34	2.90	1.90	0.77	5.66	5.04
4.60	4.66	8.70	4.30	2.10	3.53	4.48	2.35	5.47	5.69	7.72	0.28	4.05
0.19	0.15	0.13	0.09	0.05	0.11	0.23	0.27	0.10	0.07	0.17	0.04	0.05
1300	600	1250	1100	580	450	1042	632	700	880	1100	30	250
170	250	140	55	46	190	200	102	230	210	280	2	90
200	160	11	22	140	160	164	53	85	75	46	20	17
19	19	<2	3	16	28	50	44	13	20	50	<2	<2
24	22	22	42	18	n.a.	31	2	30	42	n.a.	36	36
6	4	8	10	4	8	4	2	<4	4	n.a.	4	<4
350	200	560	760	1400	150	540	141	300	300	210	700	130
16	13	34	55	34	16	30	5	24	26	22	40	15
20	12	36	60	90	7	54	20	36	38	36	120	38
90	50	25	20	90	45	86	21	90	120	30	80	<20
130	92	75	25	200	70	166	47	160	220	60	160	20

Major oxides—wt%; trace elements—ppm.

* Where more than 4 samples from a formation have been analysed the mean ($\overline{x}$) of the analyses and standard deviation (*s*) are given. n.a. = not analysed.

igneous rocks in the region: volcanic rocks (Bultitude & Wyborn, 1982), granites of the Kalkadoon Batholith (Wyborn & Page, 1983), and dolerite and metadolerite samples collected before 1975 (Ellis & Wyborn, in press). Papers discussing the geochemistry of the other batholiths in the region are planned.

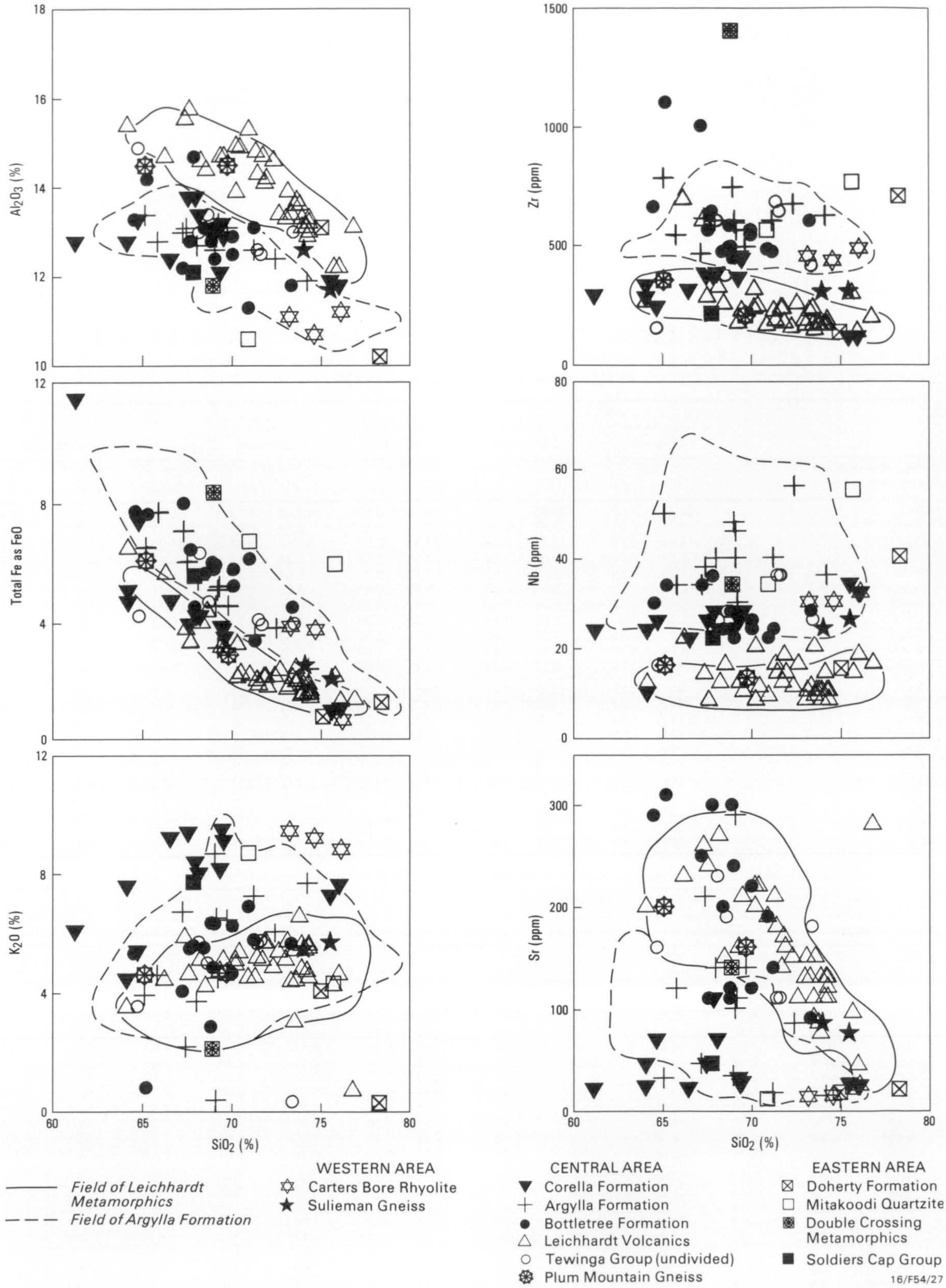


Fig. 61. Abundances of selected major oxides and trace elements plotted against SiO_2 for the felsic volcanics of the Duchess–Urandangi region. Also shown are the fields outlined by the Leichhardt Metamorphics (53 analyses) and Argylla Formation (79 analyses) from north of the region using data from Rossiter & Ferguson (1980) and Wyborn (in preparation).

Almost all the analysed rocks have been regionally metamorphosed to either the greenschist or amphibolite facies, and many are extensively recrystallised. However, as the various suites show generally consistent trends for most elements on variation diagrams, the majority of analysed samples are thought to be close to their original composition, rather than being extensively modified by metamorphism.

Silica values for the igneous rocks show a well-defined bimodal distribution (Fig. 63), and igneous rocks of intermediate composition are rare, as in other parts of the Mount Isa Inlier.

Felsic volcanics

Bultitude & Wyborn (1982) recognised five distinctive geochemical suites of felsic volcanics in the Duchess–Urandangi region: the Leichhardt suite, characterised by high Sr and low Zr, Nb, and Y abundances (relative to the other suites); the Argylla suite, which has low Sr and high Zr and Nb; the Bottletree suite, which has high Ba, Sr, Zr, and Nb; the Duchess–Corella suite, characterised by low Sr and Zr and high Nb and Y; and the Carters Bore suite, which has high K_2O and low Al_2O_3, Na_2O, CaO, Pb, Sr, and Ba. Some of these differences are illustrated in Figure 61. Each suite is thought to be derived from a chemically unique source.

Western area

The two analysed samples of felsic metavolcanics from the Sulieman Gneiss may belong to the Leichhardt suite, although they are anomalously high in Nb. No analyses are available for felsic volcanic rocks from the Saint Ronans Metamorphics. Three samples of the much younger Carters Bore Rhyolite have been analysed; these have the high K_2O contents characteristic of the Carters Bore suite, and their TiO_2 and MgO contents are notably high (Table 15) for rocks with high silica values (73–76 wt%).

Central area

The 34 analysed felsic volcanic rocks of the Leichhardt Volcanics show the typical features of the Leichhardt suite: low Y, Zr, Nb, TiO_2, and total Fe contents, relatively low K_2O, Th, and U abundances, and high Al_2O_3, Pb, Sr, Na_2O, and CaO contents. They are chemically and also isotopically identical with those of the Leichhardt Metamorphics north of the Duchess–Urandangi region (Wilson, 1978), and with the granites of the Kalkadoon Batholith (Wyborn & Page, 1983), their comagmatic intrusive equivalents.

The felsic volcanics of the Argylla Formation (13 analyses), like those to the north (Wilson, 1978; Rossiter & Ferguson, 1980), are distinguished by high Zr, Nb, Y, TiO_2, and total Fe contents, relatively high K_2O, Th, and U contents, and low CaO, Na_2O, Al_2O_3, Pb, Sr, and Zn contents, which are characteristic of the Argylla suite.

Felsic volcanics of the Bottletree Formation (19 analyses) belong to the Bottletree suite. They resemble the felsic volcanics of the Argylla Formation, except their CaO, Sr, and Pb contents are more similar to those of the Leichhardt suite.

Felsic volcanic rocks in the Corella Formation of the Duchess Belt (15 analyses) comprise the Duchess–Corella suite. They have high Nb and Y contents, like those of the Argylla and Bottletree Formations, but low Zr, TiO_2, and total Fe, as in the Leichhardt Volcanics. Sr, Pb, CaO, and Al_2O_3 values are low, and Th and U contents are high. Very low Na_2O and exceptionally high K_2O may be alteration effects.

Among the felsic volcanic rocks from the undivided Tewinga Group (6 analyses), one sample, which has also been isotopically dated (Page, 1983a), is indistinguishable in chemistry and age from the Leichhardt Volcanics; the other 5 samples resemble those of the Bottletree suite. Two analysed samples from the Plum Mountain Gneiss, both probably intrusive rather than extrusive, appear to belong to the Leichhardt suite.

Eastern area

The only analysed sample from the Double Crossing Metamorphics, a felsic gneiss thought to be a metamorphosed volcanic rock, is enriched in incompatible elements, like the Argylla suite. The two felsic volcanic samples analysed from the Mitakoodi Quartzite are typical Argylla suite rocks. Two samples of rhyolite from the Doherty Formation have been analysed: one, isotopically dated at about 1720 m.y. (Page, 1983a), is enriched in incompatible elements, whereas the other, from a separate but nearby body, is depleted in these elements. One sample of a possible felsic metavolcanic rock from the Soldiers Cap Group, a quartzofeldspathic gneiss, has low Sr, Y, Zr, and Al_2O_3, and high TiO_2, total Fe, and K_2O contents. This rock and the Doherty Formation rhyolites do not fit into any of the five main suites. No analyses of felsic volcanic rocks from the Kuridala Formation are available.

Granites

Parts of four major granitic batholiths are exposed in the Duchess–Urandangi region. From west to east these are the Sybella, Kalkadoon, Wonga, and Williams Batholiths. Each batholith is made up of several plutons, most of which have been foliated and/or recrystallised to some extent owing to postemplacement deformation and metamorphism, and each has its own particular chemical characteristics, some of which are illustrated in Figure 62.

The *Sybella Batholith* consists of northerly trending elongate plutons and some associated porphyry dykes, and is confined to the western area; it has no undoubted extrusive equivalents. Most of the plutons are intensely foliated and have been metamorphosed to at least the lower amphibolite facies. The main rock type is a biotite-bearing granite characterised by large K–feldspar augen and commonly containing deep blue-green hornblende and purple fluorite. Similar granite forms most of the plutons of Sybella Granite to the north of the Duchess–Urandangi region, in MOUNT ISA and KENNEDY GAP, where some of the granite has been dated at about 1670 m.y. (Page, 1981a). The main granite type has very high levels of incompatible elements, and has higher TiO_2, P_2O_5, La, Ce, and Pb and lower Al_2O_3 and Sr contents than most other granites of the Mount Isa Inlier. The batholith also includes one or more plutons of a petrographically and chemically distinct granitic type, here termed the Kahko type, which crops out mainly between Kahko and Jayah Bore Creeks. The Kahko type consists of biotite-rich granodiorite and subordinate granite. Compared with the main granite of the Sybella Batholith, it is mostly finer-grained, richer in plagioclase phenocrysts, and at similar silica values has less amphibole. It also has lower TiO_2, Zr, Y, and La, and higher Al_2O_3 and Sr contents; in these chemical features it

TABLE 16. REPRESENTATIVE CHEMICAL ANALYSES OF GRANITES FROM THE DUCHESS–URANDANGI REGION

	Sybella Batholith				Kalkadoon Batholith		Wonga Batholith				Williams Batholith							
	Main type		*Kahko type*				*Bowlers Hole type*		*Bushy Park type*		*Overlander type*		*Maramungee type*		*Wimberu type*		*Saxby type*	
Total number of samples analysed	48		13		50		3		9		19		4		25		6	
	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*
SiO_2	71.12	3.14	70.38	4.40	68.80	4.56	69.13	0.21	70.81	1.45	72.86	4.93	70.05	5.24	71.79	3.86	69.28	6.58
TiO_2	0.50	0.32	0.44	0.26	0.44	0.22	0.51	0.04	0.44	0.08	0.23	0.15	0.32	0.29	0.35	0.24	0.54	0.46
Al_2O_3	13.15	0.54	14.06	1.66	14.76	1.59	12.93	0.29	13.27	0.46	13.32	1.66	14.73	1.39	13.71	0.72	13.42	0.75
Fe_2O_3	1.22	0.78	1.02	0.65	0.76	0.37	1.86	0.82	0.94	0.18	1.04	0.53	1.94	1.90	1.33	1.31	1.86	1.50
FeO	2.31	1.35	2.36	1.19	2.81	1.35	3.65	0.43	2.82	0.67	1.26	1.36	1.39	1.52	1.07	0.67	2.79	2.26
Tot. Fe	3.41	1.62	3.28	1.57	3.50	1.50	5.32	0.33	3.66	0.74	2.20	1.42	3.13	3.21	2.26	1.40	4.47	3.27
MnO	0.05	0.02	0.05	0.02	0.05	0.02	0.09	0.01	0.04	0.01	0.04	0.03	0.05	0.05	0.03	0.01	0.06	0.04
MgO	0.61	0.41	0.77	0.60	0.98	0.61	0.27	0.09	0.56	0.07	0.29	0.23	0.66	0.36	0.67	0.47	0.82	0.82
CaO	1.92	1.03	2.14	1.06	2.74	1.35	2.12	0.36	1.50	0.39	1.05	0.60	2.31	1.86	1.66	1.01	1.91	1.59
Na_2O	2.69	0.57	2.79	0.70	2.88	0.80	2.65	0.28	2.60	0.29	3.80	1.10	4.45	1.10	3.87	0.98	3.67	0.32
K_2O	5.11	1.30	4.75	1.71	4.17	1.13	5.32	0.23	5.54	0.45	4.97	1.37	2.68	1.40	4.17	1.22	3.97	0.84
P_2O_5	0.13	0.10	0.14	0.09	0.11	0.07	0.09	0.01	0.11	0.04	0.06	0.05	0.10	0.09	0.13	0.11	0.19	0.14
Ba	656	393	711	275	793	426	880	72	861	250	369	388	343	192	761	488	465	384
Li	16	9(27)*	21	12	13	9(35)	14	(1)	22	9(7)	5	6(12)	6	4(2)	7	4(19)	9	3
Rb	263	103	248	104	172	57	299	18	261	30	236	95	100	71	176	67(24)	268	100
Sr	120	85	157	82	230	136	90	14	103	12	42	34	232	289	134	73	101	139
Pb	32	12	27	15	27	14	22	15	19	7	14	12	26	24	11	8	13	5
Th	53	29	45	32	24	8	31	3	32	3	54	27	32	34	51	31	41	23
U	10	7	6	4	4	3	5	9	5	1	12	6	7	8	10	5	15	12
Zr	354	136	247	100	218	87	557	112	255	52	239	167	157	47	206	90	242	162
Nb	31	9	21	7	11	4	35	6	14	4	30	17	9	3	24	7	33	12
Y	59	18	40	19	24	10	85	6	46	10	61	37	20	15	35	13	40	16
La	116	51	112	68	62	23	84	5	75	12	71	46	37	10	68	36	42	22
Ce	201	81	188	110	110	39	167	6	131	23	122	75	56	5	114	54	80	35
Nd	52	32(4)	n.a.		49	15(35)	75	(1)	61	12(7)	62	36(12)	28	16(2)	42	16(18)	39	18
Sc	4	(4)	n.a.		7	5(35)	6	(1)	7	11(7)	4	11(12)	11	10(2)	5	5(18)	11	17
V	25	24	26	26	35	23	19	12	21	12	22	40	14	13	28	31	45	55
Cr	9	3(4)	n.a.		17	12(35)	6	(1)	11	2(7)	8	4(12)	13	5	9	3(23)	10	6
Co	5	(4)	n.a.		9	5(28)	<5	(1)	6	2(7)	n.a.		8	(1)	4	4(8)	10	15
Ni	5	7	7	12	6	4(35)	2	(1)	4	1(7)	3	3(12)	8	9	4	4(23)	5	5
Cu	10	9	6	4	12	8	19	15	26	32	18	17	11	2	18	21(24)	8	6
Zn	41	21	43	17	48	20	69	10	29	15	13	12	23	19	14	7(24)	36	25
Sn	8	6	8	4	4	4	10	5	9	6	3	9	2	6	7	18(24)	5	6
Ga	18	3(4)	n.a.		17	2(35)	18	(1)	17	1(7)	19	4(12)	16	4(2)	16	1(18)	19	1
As	2	4(4)	n.a.		2	2(35)	1	(1)	2	2(7)	1	2(12)	1	(2)	2	3(18)	1	

Tot. Fe = total Fe as Fe_2O_3
$\bar{x}$ = mean; *s* = standard deviation
Major oxides—wt%; trace elements—ppm.
n.a. = not analysed
* Numbers in parentheses indicate number of samples analysed for a particular element where this number is less than the total number of samples analysed for that unit

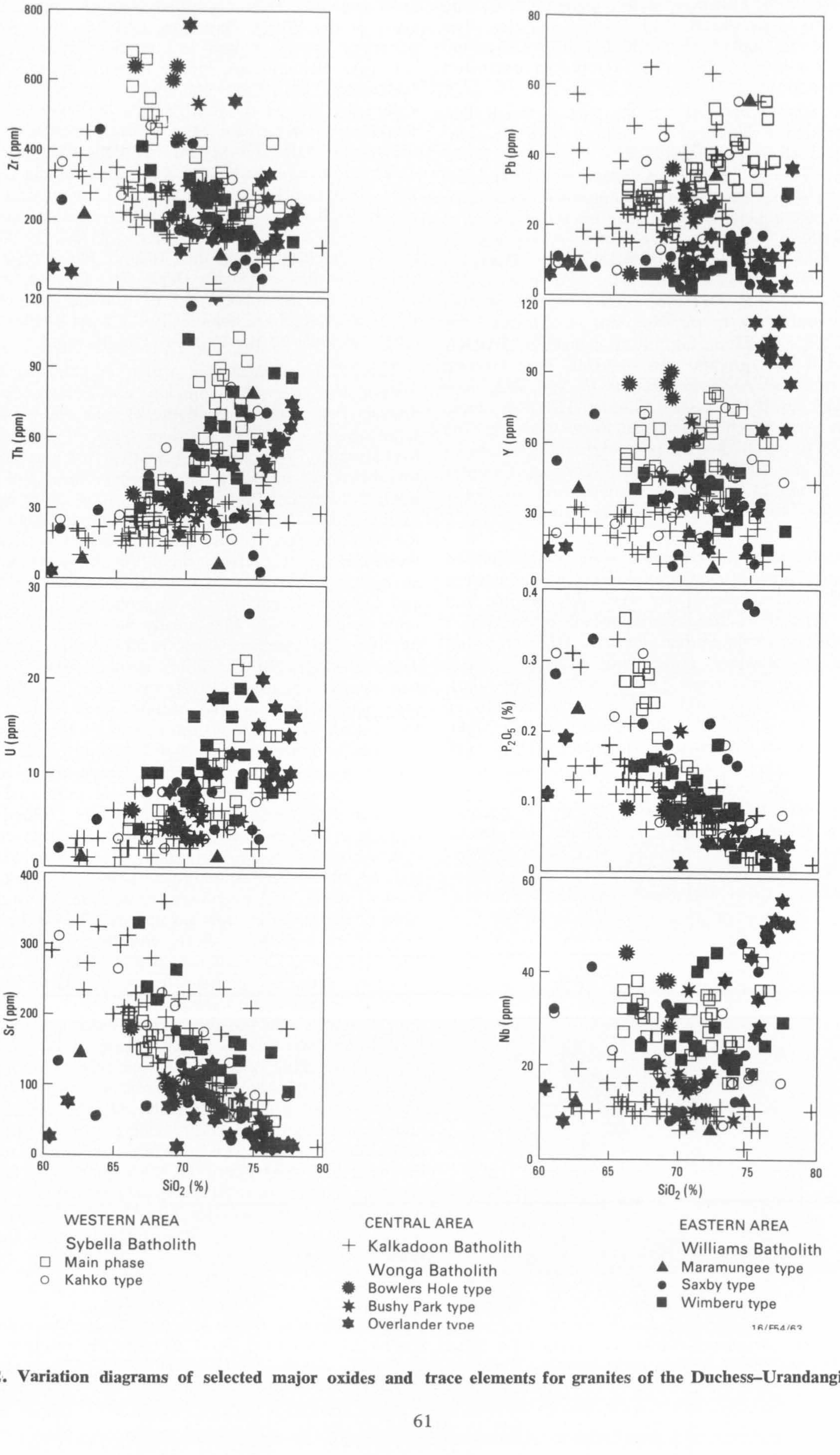


Fig. 62. Variation diagrams of selected major oxides and trace elements for granites of the Duchess–Urandangi region.

more closely resembles the granites of the Kalkadoon Batholith to the east than the main granite type of the Sybella Batholith. However, it has higher Th, U, and Nb contents than the Kalkadoon-type granites. The Kahko type may include the granodiorite of Kalkadoon type that Joplin & Walker (1961) reported northwest of Sulieman Bore.

The *Kalkadoon Batholith* forms part of the Kalkadoon–Leichhardt Block of the central area. It comprises the Kalkadoon Granite, which has been dated at 1865 $\pm^{11}_{9}$ m.y. (Wyborn & Page, 1983), and the One Tree, Wills Creek, and Woonigan Granites. Like the comagmatic Leichhardt Volcanics, the granites of the Kalkadoon Batholith have higher Al_2O_3 and Sr contents and lower levels of incompatible elements, especially Nb, TiO_2, Zr, and Th, than most other Mount Isa granites. Different plutons of the Kalkadoon Batholith show minor variations in chemistry; for example, the Kalkadoon Granite in central DAJARRA has lower TiO_2 contents, and the One Tree Granite has lower Sr and Al_2O_3 and higher Fe and TiO_2 contents, than typical Kalkadoon Granite. However, these variations are much less than those between the Kalkadoon Batholith and the other batholiths. Analysed samples of the Wills Creek and Woonigan Granites have more than 74 percent silica and cannot be readily distinguished from other high-silica granites of the region.

The *Wonga Batholith* comprises a series of deformed and metamorphosed elongate plutons in the eastern part of the central area. Three main petrographic and chemical types have been distinguished, all of which are enriched in incompatible elements. One type, that forming the Bowlers Hole and Mairindi Creek Granites, is characterised petrographically by dark blue-green amphibole and only minor amounts of plagioclase, and chemically by distinctively low MgO, P_2O_5, and Al_2O_3 contents. This Bowlers Hole type may be comagmatic with the 1780-m.y.-old felsic volcanics of the Argylla Formation. A second type, the Bushy Park type, is made up largely of gneisses containing K–feldspar augen. It includes the Bushy Park Gneiss, Birdswell Granite, and Saint Mungo Granite, which form intensely foliated plutons intruding the Magna Lynn Metabasalt, Argylla Formation, and Corella Formation. This granite type commonly contains blue-green hornblende and also some scapolite. It is generally coarser-grained than the other granite types of the Wonga Batholith, and has lower Nb and generally lower Th and U contents, although values for these elements are higher than in granites of the Kalkadoon Batholith. The third compositional type within the Wonga Batholith forms the Overlander and Revenue Granites and the granitic components of the Mount Erle and Myubee Igneous Complexes, all of which intrude the Corella Formation of the Duchess Belt. This Overlander type may be comagmatic with the Burstall Granite in MARRABA, which has been dated at 1720–1740 m.y. (Page, 1983b). It contains less plagioclase than the Bushy Park type, and chemically has unusually high Th, U, Nb, and Y contents. Of the three types of granite, those of the Bushy Park type are chemically the most similar to the felsic volcanics of the Duchess–Corella suite.

The *Williams Batholith*, which is confined to the eastern area, is petrographically and chemically more diverse than the other batholiths in the Duchess–Urandangi region. Three broad types of granite—the Maramungee, Wimberu, and Saxby types—can be distinguished, all of which have higher Na_2O and lower K_2O, Cu, Zn, and Pb contents than most other granites of the Mount Isa Inlier. The Maramungee type forms the Maramungee, Cowie, and Blackeye Granites, and numerous small plutons, including some mapped as Saxby Granite, which intrude the Soldiers Cap Group and Doherty Formation; it is probably either syntectonic or pretectonic. It is mostly fine-grained, non-porphyritic, and extensively recrystallised, and has lower TiO_2, P_2O_5, Zr, Nb, Ce, and V contents than the other two types and is also relatively low in Cr. The Wimberu type includes the Wimberu, Mount Cobalt, Mount Dore, and Yellow Waterhole Granites, part of the Gin Creek Granite, and perhaps most of the Squirrel Hills and Mount Angelay Granites. The granitic rocks of this type are generally massive, and were emplaced after the country rocks had been tightly folded and regionally metamorphosed. They typically contain yellow-brown biotite, some pale green clinopyroxene and/or blue-green amphibole, abundant dark red-brown sphene, and magnetite; muscovite is present in some of the more fractionated phases. Chemical characteristics are high MgO, P_2O_5, Ba, Rb, Sr, Th, U, Zr, Nb, Y, La, and Ce contents, and low Cu, Pb, and Zn contents. The Saxby type forms the large plutons mapped as Saxby Granite and also part of the Gin Creek Granite and possibly parts of the Squirrel Hills and Mount Angelay Granites. These mainly massive and post-tectonic plutons are characterised by the presence of dark blue-green hornblende, brown biotite, and muscovite, and by relatively low Al_2O_3, CaO, Ba, and Sr, and high Fe contents. One pluton of this type, that centred 15 km west of Maronan homestead, has distinctly high contents of Th (>70 ppm) and U (25–30 ppm). There are insufficient data available to determine whether any of the three granite types were comagmatic with the rhyolites of the Doherty Formation.

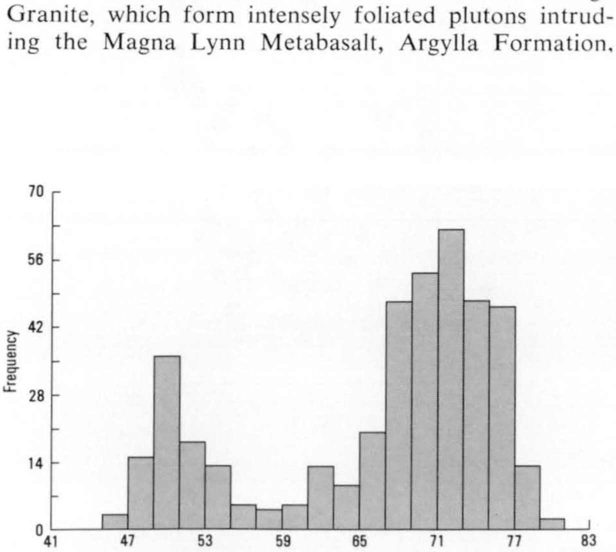


Fig. 63. Absolute frequency-distribution diagram for SiO_2 based on 412 analyses of igneous rocks from the Duchess–Urandangi region. Data from Wyborn (in preparation).

Mafic volcanics

Mafic volcanic rocks are present in the Sulieman Gneiss (1 analysis), Saint Ronans Metamorphics (1 analysis), Jayah Creek Metabasalt (3 analyses), Oroopo Metabasalt (2 analyses), and Eastern Creek

Volcanics (no analyses) of the western area; in the undivided Tewinga Group (1 analysis), Leichhardt Volcanics (no analyses), Magna Lynn Metabasalt (3 analyses), Argylla Formation (no analyses), Bottletree Formation (2 analyses), Eastern Creek Volcanics (5 analyses), and Corella Formation (1 analysis) of the central area; and in the Marraba Volcanics (1 analysis), Soldiers Cap Group (3 analyses), Kuridala Formation (1 analysis), Doherty Formation (2 analyses), and Argylla Formation, Double Crossing Metamorphics, Mitakoodi Quartzite, and Staveley Formation (no analyses) in the eastern area. The analysed samples (Table 17) are chemically similar to those of the Pickwick Metabasalt Member of the Eastern Creek Volcanics described by Derrick & others (1976b) and Glikson & Derrick (1978). As shown by Bultitude & Wyborn (1982), they are characterised by low and uniform contents of most incompatible elements (e.g., Ti, P, Zr, Y), and are similar to continental tholeiites of the Karroo province of southern Africa (Le Roex & Reid, 1978) and the Antrim Plateau Volcanics of northern Australia (Bultitude, 1976). The eastward progression from rocks of continental tholeiitic affinities near Mount Isa to rocks of ocean-floor tholeiitic affinities near Cloncurry, as recorded by Glikson & others (1976) and Glikson & Derrick (1978), is not apparent in the Duchess–Urandangi region. All mafic volcanics are magnetic, although those of the Soldiers Cap Group are only weakly so.

Dolerites

Several generations of metamorphosed and one or more of unmetamorphosed dolerite dykes are present in the region.

TABLE 17. REPRESENTATIVE CHEMICAL ANALYSES OF MAFIC VOLCANICS FROM THE DUCHESS–URANDANGI REGION
(from Bultitude & Wyborn, 1982)

	Eastern Creek Volcanics		*Bottletree Formation*		*Undivided Tewinga Group*	*Magna Lynn Metabasalt*			*Corella Formation*	*Oroopo Metabasalt*	
No. of samples or sample numbers[1]	5 $\bar{x}$	s	7653–5071	7653–5100	7753–0836	7753–0452	7753–2310	7753–5077C	7753–0148	7853–3020	7953–2376A
SiO_2	50.49	3.07	50.20	50.90	49.70	49.60	53.50	49.90	49.60	54.50	51.00
TiO_2	1.30	0.49	1.86	1.21	1.97	1.79	1.29	1.40	1.83	0.87	0.92
Al_2O_3	14.47	0.81	15.80	15.40	13.30	14.60	14.00	15.10	12.80	13.20	14.40
Fe_2O_3	4.99	0.79	6.12	3.14	4.65	3.11	4.07	3.81	5.52	2.51	4.93
FeO	6.71	2.10	6.78	8.55	10.30	10.30	6.69	8.08	9.88	7.67	6.18
MnO	0.19	0.01	0.19	0.20	0.24	0.23	0.29	0.35	0.18	0.17	0.14
MgO	6.62	1.95	2.62	5.92	5.70	6.04	6.20	7.04	4.40	6.61	6.14
CaO	9.51	2.29	11.70	10.80	8.73	10.00	5.99	7.97	8.06	10.70	9.06
K_2O	1.04	0.52	0.70	0.33	0.83	0.60	2.21	1.52	1.18	0.22	1.48
Na_2O	2.70	0.44	1.35	1.65	1.65	1.94	2.46	3.12	3.68	1.51	2.00
P_2O_5	0.13	0.07	0.53	0.20	0.19	0.20	0.18	0.20	0.23	0.10	0.16
Ba	239	109	380	170	310	140	520	330	210	55	350
Rb	30	23	26	3	22	11	65	70	24	2	32
Sr	181	55	390	260	130	130	180	160	120	120	230
Pb	37	33	380	160	38	280	140	75	60	65	5
Zr	120	63	280	170	140	150	160	180	120	70	130
Nb	6	4	22	14	14	16	18	18	14	8	8
Y	26	11	34	26	28	30	32	32	26	17	26
La	38	25	40	35	15	50	30	30	30	30	20
Ce	42	19	180	55	30	40	80	70	90	20	30

TABLE 17 *continued*

Jayah Creek Metabasalt			*Saint Ronans Metamorphics*	*Sulieman Gneiss*	*Soldiers Cap Group*			*Marraba Volcanics*	*Kuridala Formation*	*Doherty Formation*	
7853–2405D	7853–2408A	7853–3035	7953–2034	7953–2477	7853–0166A	7853–4666	7853–4365	7853–4346A	7853–0821	7853–0065F	7853–0072C
52.80	52.40	56.70	51.40	49.60	48.30	48.80	49.30	51.10	50.80	49.20	50.10
1.02	1.21	1.25	0.92	1.56	2.85	1.62	1.43	2.03	1.42	2.23	1.59
14.30	14.30	13.90	14.90	15.10	12.90	13.70	13.90	12.80	13.70	12.10	12.50
3.84	6.43	4.36	3.61	6.65	0.48	5.26	0.34	5.95	4.73	6.01	7.55
6.67	5.29	7.33	7.43	5.39	14.10	10.00	11.20	9.37	7.14	9.02	6.65
0.20	0.17	0.14	0.18	0.19	0.49	0.21	0.24	0.21	0.47	0.15	0.12
6.10	4.60	5.65	6.49	6.80	5.85	5.40	6.50	5.14	5.87	4.96	5.20
9.48	9.61	3.95	9.55	10.20	9.10	8.25	11.20	7.83	8.67	8.78	8.80
1.32	0.54	0.85	0.65	0.36	1.72	0.61	0.73	0.54	0.49	0.81	1.12
1.70	3.34	2.86	2.20	1.88	1.03	3.77	2.66	2.20	4.12	3.89	4.90
0.14	0.17	0.14	0.13	0.19	0.30	0.17	0.15	0.19	0.12	0.19	0.18
460	360	460	240	170	200	140	100	150	780	410	150
34	17	48	22	10	85	16	20	15	7	26	24
130	230	110	190	190	70	60	150	110	300	120	95
120	60	36	150	13	5	<2	<2	22	38	36	26
140	160	130	110	100	170	120	95	140	80	150	140
16	16	14	14	16	7	5	5	14	12	16	6
22	26	22	18	24	38	36	18	36	26	34	28
60	30	20	30	20	<20	<20	<20	15	40	25	40
70	60	50	60	20	20	20	20	35	50	60	75

1. Where more than 4 samples from a formation or member have been analysed the mean ($\bar{x}$) of the analyses and standard deviation (s) are given.

In the western area, metamorphosed dolerites intrude the basement and older cover rocks, and a few also intrude granite of the Sybella Batholith.

At least four groups of metadolerite intrusions occur in the central area. One group forms a swarm of north-trending sheets intruding the older cover rocks of the Dajarra Belt. Another forms a conjugate swarm, trending north-northwest and north-northeast, intruding the undivided Tewinga Group, Leichhardt Volcanics, and granites of the Kalkadoon Batholith; the dykes of this group are much less magnetic than other dolerite intrusions in the region, and do not give rise to anomalies on aeromagnetic maps. A third group forms relatively large doleritic to gabbroic bodies intruding the Corella Formation, and is associated with granite in net-veined complexes of the Mount Erle and Myubee Igneous Complexes; this group may be related to the Lunch Creek Gabbro associated with the Burstall Granite to the north, in MARRABA, which has been dated at about 1740 m.y. (Page, 1983b). The fourth group forms elongate bodies mainly intruding the Argylla Formation and Corella Formation.

In the eastern area, metadolerite forms folded sills and northerly trending dykes and pod-like bodies. These intrude the Mary Kathleen Group and older rocks, but predate most of the Williams Batholith.

Unmetamorphosed dolerite dykes are rare in the western and central areas, but are relatively common in the eastern area, where they form several widely spaced easterly trending dykes.

All analysed samples of dolerite, plotted on the conventional total alkalies–silica diagram, fall in the subalkaline field. The majority are hypersthene-normative, and on an AFM diagram show the tholeiitic trend of iron-enrichment with increasing differentiation. Most dolerites have <53 percent SiO_2 and comparatively low total alkali contents (<4%). Like the mafic volcanics of the region, they can be classified as continental tholeiites with generally atypically low contents of incompatible elements such as Ti, Y, Zr, and P. The unmetamorphosed dolerites tend to be richer in K, Ti, Zr, Ba, Rb, Y, and Cu than the metamorphosed dolerites.

Discussion

The Kalkadoon Batholith and comagmatic volcanics of the Leichhardt suite have lower levels of incompatible elements than younger felsic rocks in the region. As shown by Wyborn & Page (1983), they represent a remarkably uniform melt emplaced between 1840 and 1870 m.y. ago and covering at least 5000 km^2 of the Mount Isa Inlier. The source of this melt is thought to have formed between 1900 and 2000 m.y. ago during a major differentiation event from the mantle. This mantle event may have been at least continent-wide, as granites of similar age and composition, and probably source, are widespread in other Proterozoic terrains of northern Australia. The rocks of the Kalkadoon Batholith and Leichhardt suite belong to the I-type of Chappell & White (1974), as they contain primary amphibole (now mostly pseudomorphed), have molecular ratios of Al_2O_3 to Na_2O + K_2O + CaO of < 1.1, and have low initial $^{87}Sr/^{86}Sr$ values (about 0.704). The absence of associated large ore deposits may be a consequence of the volcanism being subaerial and the granite having crystallised by restite unmixing (following the model of White & Chappell, 1977), resulting in a decreasing concentration of metallic elements with increasing SiO_2 content (Whalen & others, 1982).

The next igneous event to affect the region may have been the emplacement of the weakly magnetic dolerite which forms the conjugate dyke swarms intruding the Kalkadoon Batholith, Leichhardt Volcanics, and undivided Tewinga Group. These dykes are unlikely to be feeders for basalt lavas of the Eastern Creek Volcanics and Magna Lynn Metabasalt, which are invariably strongly magnetic.

Widespread igneous activity took place from about 1810 to about 1770 m.y., during what was probably a period of crustal extension in the region. Representatives of this activity include the volcanics of the Bottletree and Argylla Formations and those of other older cover formations, some of the metadolerite intrusions, and probably the granite of the Bowlers Hole type of the Wonga Batholith. The felsic volcanics of the Bottletree and Argylla Formations are classified as A-type, as they have low MgO and high Na_2O + K_2O contents and also high levels of Zr, Nb, and Y (Loiselle & Wones, 1979; Collins & others, 1982). If the model of Collins & others (1982) is valid—i.e., A-type magmas are derived by partial melting of the residue remaining in the lower crust after production of a previous felsic melt—then the Bottletree and Argylla felsic rocks may represent high-temperature melts derived from a near-anhydrous granulitic source left behind after the removal of the Kalkadoon–Leichhardt melt. The addition of large volumes of mafic magma from the mantle to the crust during the period of crustal extension and accompanying crustal thinning probably resulted in higher heat flow, facilitating the formation of felsic melt. The source that gave rise to the felsic volcanics of the Bottletree Formation presumably had more residual plagioclase than that of the Argylla Formation. Some of these felsic volcanics may be subaqueous, and copper orebodies present in the upper part of the Argylla Formation, adjacent to sedimentary rocks, could represent exhalative deposits.

Some igneous activity also occurred between about 1740 m.y. and 1720 m.y. ago, when granites of the Overlander type and possibly the Bushy Park type of the Wonga Batholith were emplaced in the central area, and rhyolite of the Doherty Formation was extruded in the eastern area. Some plutons of the Williams Batholith (the Maramungee type?) may also be of this age. The Overlander Granite and related granites are A-type, but the Bushy Park type has both A-type and I-type characteristics. The granite of the Overlander type and associated mafic intrusions are of economic importance, as there are several copper deposits—including those at the Duchess and Trekelano mines—related to them, and they are rich in uranium, like the probably comagmatic Burstall Granite to the north, so may have given rise to some uranium deposits—as yet undiscovered—possibly like that at Mary Kathleen.

A later major period of igneous activity took place in the western area between about 1670 m.y. and 1680 m.y., when the Carters Bore Rhyolite was extruded and the uranium-rich main phase of Sybella Granite was emplaced. These units represent A-type melts, and either or both may be comagmatic with the potassium-rich tuffs in the Mount Isa Group.

The main regional metamorphism and deformation event recognised in the region is thought to have taken place between 1640 and 1550 m.y. This metamorphism does not appear to have been synchronous with any major igneous activity, although the Saxby Granite of the Williams Batholith may have been intruded during this interval. The main metamorphism was probably responsible for the migration of metals into favourable sites to form economic mineral deposits such as the Mary Kathleen uranium deposit (Page, 1983b) and the copper orebodies at the Mount Isa mine (Perkins, 1981).

The last major episode of granite plutonism was the emplacement in the eastern area of the Wimberu-type and possibly the Saxby-type granites of the Williams Batholith about 1520 m.y. ago (the main phase of the Wimberu Granite has been dated at about 1520 m.y. by R. W. Page, BMR, personal communication 1983). These are A-type granites which, although rich in uranium, are considered to be less prospective for uranium than the Overlander and Sybella Granites because they postdate the main metamorphism.

The final igneous event recorded in the region was the emplacement of the unmetamorphosed potassium-rich dolerite dykes. These may be comagmatic with the 1116 ± 12-m.y.-old Lakeview Dolerite to the north.

Several of the extrusive and intrusive igneous rocks exposed in the region have not been placed in the above chronological scheme, principally because of considerable doubts regarding possible correlations. In the western area they include the felsic volcanics of the Sulieman Gneiss and Saint Ronans Metamorphics, and the Kahko type of the Sybella Batholith. These units may be similar in age to the Big Toby Granite pluton, dated at about 1800 m.y. (Page, 1981a), or to the Yaringa Metamorphics, dated at over 2000 m.y. (Page & others, 1982), both of which crop out to the north of the region.

CORRELATIONS OF PRECAMBRIAN UNITS

Because of many uncertainties regarding stratigraphic positions and relative ages of units in the southern part of the Mount Isa Inlier, there are several possible correlation schemes for the Precambrian units exposed in the Duchess–Urandangi region. To date, two general interpretations have been proposed: one by Carter & others (1961), partly modified by G. M. Derrick and his co-workers (e.g., Derrick & others, 1977b; Plumb & others, 1980, 1981; Derrick & Wilson, 1981b); and the other by Blake (1980, 1981b).

The interpretation that we favour is summarised diagrammatically in Figure 64 (see also the Duchess–Urandangi region map), and mainly follows Blake (1980). In this interpretation the Saint Ronans Metamorphics, Kallala Quartzite, and Sulieman Gneiss of the western area, most of the undivided Tewinga Group, the Plum Mountain Gneiss, and perhaps at least part of the Corella Formation of the central area, and possibly the Double Crossing Metamorphics of the eastern area are considered to be broadly equivalent basement units which were first deformed and regionally metamorphosed before 1870 m.y. Possible correlatives north of the region include the Yaringa Metamorphics west of Mount Isa, which are probably at least 2000 m.y. old (Page & others, 1982), and part of the Leichhardt Metamorphics to the east. The Leichhardt Volcanics, isotopically dated at about 1870 m.y., are older than most but not all granitic plutons of the probably comagmatic Kalkadoon Batholith, phases of which have been dated at around 1860 m.y. (Page, 1978; Page & Wyborn, 1983). Granite emplacement at this time may have been accompanied by local (but not region-wide) deformation, as the Leichhardt Volcanics generally appear to be no more deformed or metamorphosed than immediately overlying much younger Precambrian units.

We do not correlate the ~1800-m.y.-old Bottletree Formation (Page, 1983a) and conformably overlying Mount Guide Quartzite in the west of the central area with any other units in the region. However, Derrick & Wilson (1981b) regard the Bottletree Formation as broadly equivalent to the ~1780-m.y.-old Argylla Formation and Magna Lynn Metabasalt to the east. Another possibility, though considered unlikely, is that the Sulieman Gneiss and Kallala Quarzite are correlatives of the Bottletree Formation and Mount Guide Quartzite, respectively. The undivided Tewinga Group may also include some Bottletree Formation (and Leichhardt Volcanics) equivalents.

The basaltic Eastern Creek Volcanics, the formation succeeding the Mount Guide Quartzite, is tentatively correlated with the Jayah Creek Metabasalt and Oroopo Metabasalt of the western area, and with the Magna Lynn Metabasalt to the east. It is thought to be older than the basaltic Marraba Volcanics of the eastern area—not a lateral equivalent, which Derrick (1980), for example, suggested. The Argylla Formation, a unit of felsic volcanics which overlies the Magna Lynn Metabasalt in the central area and underlies the Marraba Volcanics in the eastern area, may be correlated with the Judenan beds of the western area: north of the Duchess–Urandangi region the Judenan beds are correlated with the Myally Subgroup of the Haslingden Group (Derrick & others, 1976b), and Blake (1980, 1981b) has suggested that this subgroup may be a lateral equivalent of the Argylla Formation. The Argylla Formation is dated at about 1780 m.y. (Page, 1983a).

In the central area the Argylla Formation is overlain concordantly by the Ballara Quartzite and Corella Formation?, two units which may be correlatives of the Stanbroke and Makbat Sandstones and also of rocks mapped as Surprise Creek Formation?. The contact between the Argylla Formation and Ballara Quartzite is considered by Derrick and his co-workers (e.g., Plumb & others, 1980; Derrick & Wilson, 1981b) to be a major unconformity representing not only the period during which the Haslingden and Malbon Groups were laid down but also a metamorphic episode; however, Blake (1980, 1981b) contends that this interpretation is highly unlikely, and suggests that the contact represents a negligible time interval. The rocks mapped as Corella Formation? may be equivalent to those mapped as Corella Formation to the east, or they may be much younger—the former view is favoured by Derrick and his co-workers and the latter view is favoured by Blake (1982).

Like the Ballara Quartzite, the Marraba Volcanics to the east are concordant on, and probably similar in age to, the Argylla Formation. Hence the conformable Ballara–Corella? sequence of the central area and the Marraba–Mitakoodi–Overhang–Answer sequence of the eastern area are regarded as probable lateral equivalents. Other correlations with these sequences are more tentative: the Soldiers Cap Group farther east contains basaltic metavolcanics which may be similar in age to those of the Marraba Volcanics (e.g., Plumb & others, 1980). The Kuridala Formation appears to grade laterally eastwards into the Soldiers Cap Group and westwards into the Answer Slate, and it may be partly equivalent to the Doherty Formation, which has concordant and possibly conformable contacts with the Soldiers Cap Group.

Of the other stratigraphic units in the eastern area, the Staveley–Agate Downs–Marimo–Roxmere? sequence is tentatively correlated with the ~1600–m.y.–old rocks in the Tommy Creek area in MARRABA (Page, 1983a), and hence may be appreciably younger than the youngest units exposed in the central and western areas—the 1680-m.y.-old Carters Bore Rhyolite, the 1670-m.y.-old Mount Isa Group and its correlative the McNamara Group, and possibly the Surprise Creek Formation?

At least two—and possibly as many as four—region-wide periods of deformation and regional metamorphism may be recognised, as suggested in Figure 64. The earliest predates the Leichhardt–Kalkadoon igneous event, and affected much of the undivided Tewinga Group and correlatives. A possible second period may have occurred shortly after the 1670-m.y.-old Mount Isa Group was deposited and perhaps before the deposition of the Staveley–Roxmere? sequence. Most of the Sybella Batholith may have been emplaced at about this time (Page, 1981a). Before this possible second deformation period some local folding, faulting, and regional metamorphism may have accompanied the emplacement of the Wonga Batholith between 1740 and 1720 m.y. ago. A subsequent period of major deformation resulted in the Staveley–Roxmere? sequence and older rocks being tightly folded and metamorphosed, probably between about 1600 m.y. and 1550 m.y. ago. The foliated granites of the Williams Batholith may have been intruded at this time or earlier. A postulated later deformation is presumed to have caused the post-tectonic non-foliated granites of the Williams Batholith to be weakly metamorphosed sometime after about 1500 m.y. ago and before the intrusion of the non-method at about 1116 m.y.; Page, 1983b) north of the metamorphosed dolerite dykes, which may be similar in age to the Lakeview Dolerite (dated by the Rb–Sr Duchess–Urandangi region.

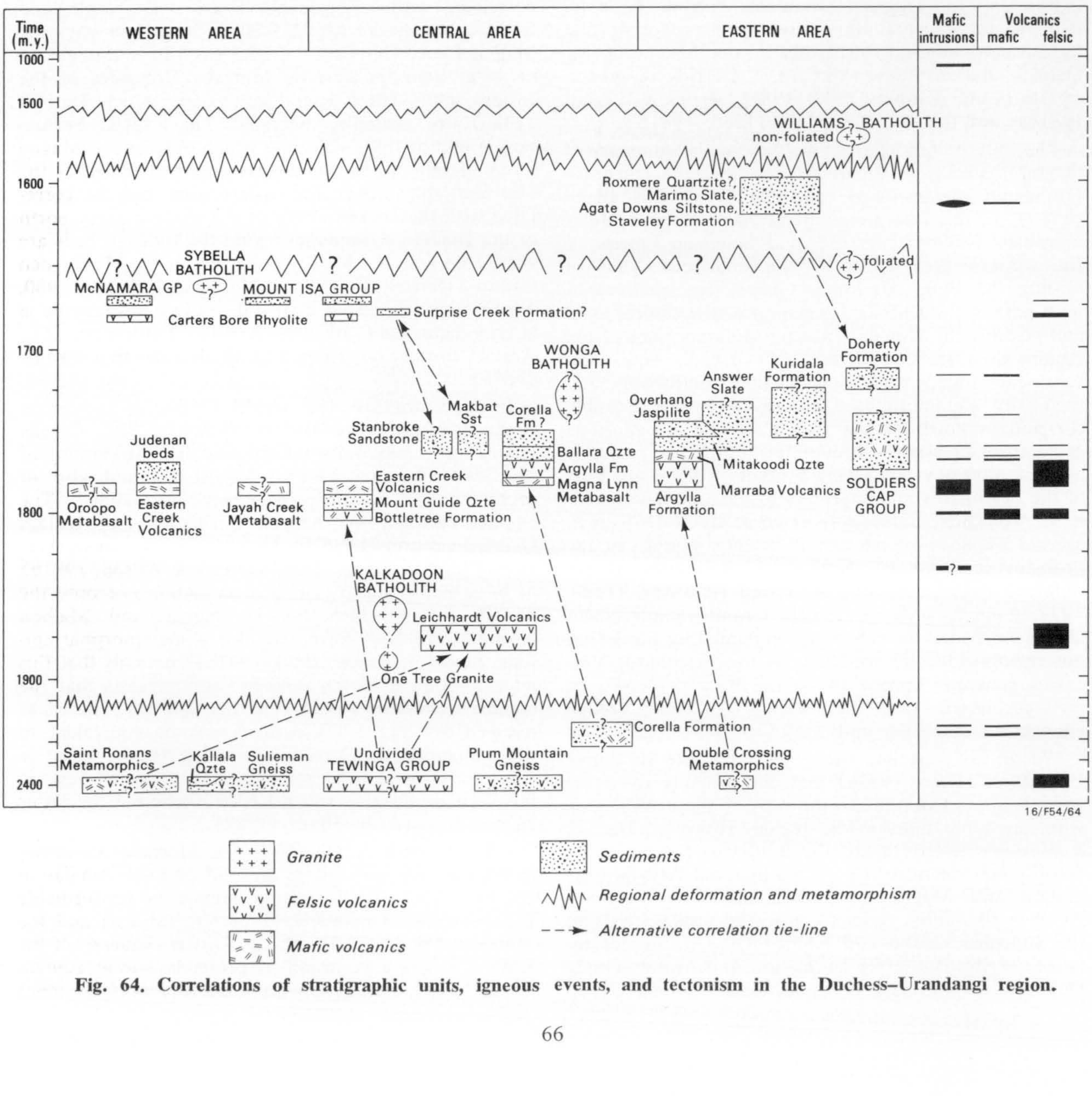


Fig. 64. Correlations of stratigraphic units, igneous events, and tectonism in the Duchess–Urandangi region.

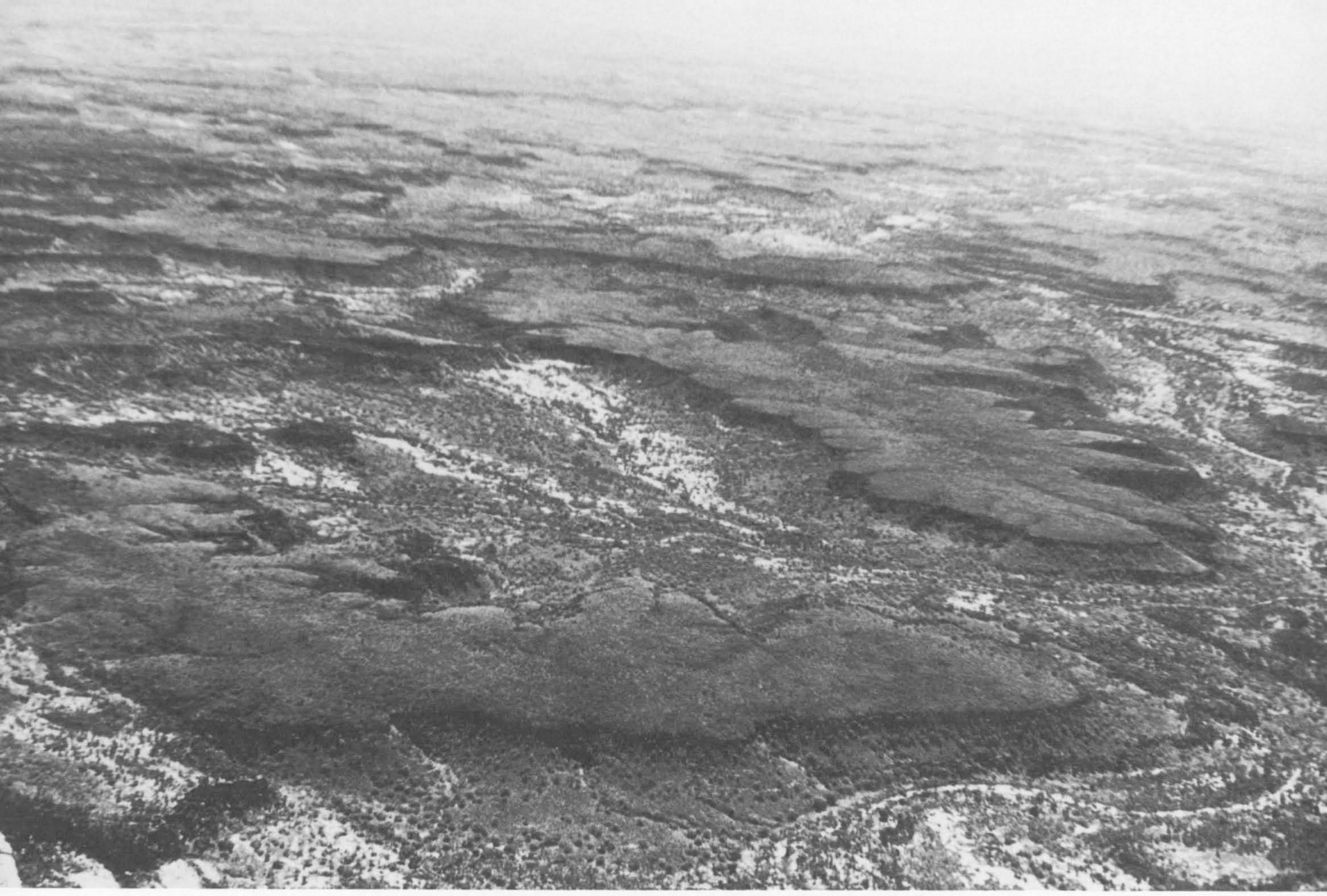


Fig. 65. Mesas formed of flat-lying Mesozoic Gilbert River Formation overlying the Squirrel Hills Granite of the Williams Batholith east of Selwyn. (M2303/34)

SEDIMENTARY ROCKS OVERLYING THE MOUNT ISA INLIER

Late Proterozoic and early Palaeozoic rocks of the Georgina Basin

Sedimentary rocks of the Georgina Basin succession crop out in the Burke River Structural Belt, mapped in 1967 by de Keyser and others (de Keyser, 1968), and in the far west, where they were mapped in 1969 by de Keyser & Cook (1972). There are also some small scattered outcrops, remnants of a formerly more extensive cover, between the two main outcrop areas. The succession is mostly flat-lying, and rests with a marked angular unconformity on the rocks of the Mount Isa Inlier. It contains several phosphate deposits, mostly in the Middle Cambrian Beetle Creek Formation; the main phosphate deposit is near The Monument, 45 km south of Duchess (Russell & Trueman, 1971).

The Georgina Basin succession in the region has been described recently by Shergold & Druce (1980). The oldest unit is the upper Adelaidean *Little Burke Tillite* exposed 9 km east-northeast of Duchess. It is up to 34 m thick and consists of tillite capped by dolomite. The younger units of the succession range in age from late Early Cambrian or early Middle Cambrian to Early Ordovician They consist of clastic, calcareous, dolomitic, and cherty sedimentary rocks, which are mainly shallow marine, and may reach a maximum thickness of about 1000 m. The succession contains several disconformities and diastems. Further details are given on the Duchess–Urandangi region map, in DUCHESS REGION, DAJARRA, ARDMORE, and SELWYN REGION map commentaries (Bultitude & others, 1982; Blake & others, 1982; Bultitude, 1982; Blake & others, 1983), in the paper by Shergold & Druce (1980), and in works referred to in these publications. Details of macrofossil localities in the Burke River Structural Belt are given by Carter & Öpik (1963), de Keyser (1968), and Shergold (1980); lithologic logs of stratigraphic holes penetrating the Cambrian units are summarised by de Keyser (1968), Shergold & Walter (1979), and Simpson (1980).

Mesozoic rocks of the Eromanga Basin

A flat-lying cover of sediments may have been deposited over the whole region during the Mesozoic, but only remnants are now preserved, generally as cappings on summit surfaces (Fig. 65). The most extensive remnants are in the east, where they are mainly mapped as the *Gilbert River Formation*—a partly fluvial and partly shallow-marine clastic unit of Late Jurassic to Early Cretaceous age; plant fossils have been recorded from this unit about 6.5 km north of Selwyn (Carter & Öpik, 1963). Probable equivalents to the west are mapped as unnamed Mesozoic rocks. These Mesozoic sediments are generally much weathered, and so are the immediately underlying Precambrian rocks; all this weathering may postdate the Mesozoic sedimentation. Three other Mesozoic formations are exposed in the southeast: the Cretaceous *Wallumbilla Formation*, *Toolebuc Formation*, and *Allaru Mudstone*, which represent shallow-marine, partly calcareous sediments. These units, and the Gilbert River Formation, are part of the Eromanga Basin succession (Senior & others, 1978); the Gilbert River Formation also forms part of the Carpentaria Basin succession (Smart & others, 1980).

Cainozoic

Four Cainozoic units have been distinguished on the Duchess–Urandangi region map. *Leached bedrock* consists of bleached to ironstained, highly weathered rock which has pre-weathering textures and structures partly preserved. It forms cappings up to 10 m thick on summit surfaces, especially on granite, and is part of a deep-weathering profile which is at least partly Cainozoic and may be Tertiary. *Laterite and lateritic rubble* also form cappings, and probably represent part of the same weathering profile as the leached bedrock; they show no pre-weathering textures or structures. *Limestone and minor chalcedony* of probable Tertiary age form low mounds in broad drainage depressions. They may represent modified lacustrine sediments (Hutton & Dixon, 1981) or chemical deposits resulting from the evaporation of groundwater (Goudie, 1972). Alluvial, colluvial, and residual *unconsolidated sediments*, in places over 15 m thick, overlie older rocks on gently undulating plains, broad alluvial fans, and river flood plains, and also occur as a thin patchy cover on many areas mapped as bedrock. They are probably mainly Quaternary.

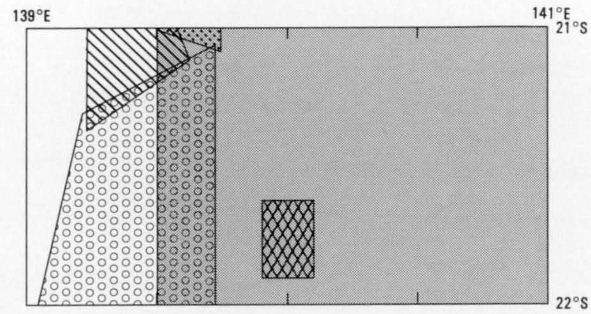
REGIONAL GEOPHYSICS

This account is based on the results of regional gravity, airborne magnetic and radiometric, and detailed metalliferous ground surveys carried out by BMR in the Duchess–Urandangi region.

The regional gravity was determined between 1957 and 1966 from surveys in which stations on a grid spacing of about 11 km (plus some fill-in stations) gave an average density of one station every 90 km^2. Maps showing contoured Bouguer anomalies at 1:250 000 scale (Urandangi) and 1:253 440 scale (Duchess) are available through the Australian Government Printer Copy Service.

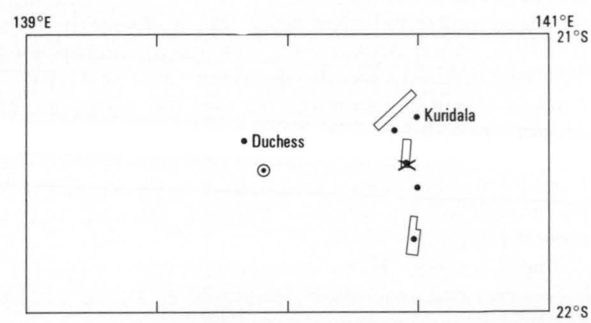
Wells & others (1966) described the results and presented profiles of alternate lines of an aeromagnetic survey of the Georgina Basin, including the Urandangi 1:250 000 Sheet area, in which east-west lines were spaced 3.2 km apart 600 m above mean sea level; BMR (1966) published a contour map of the magnetic field at a scale of 1:250 000. An airborne magnetometer and gamma-ray spectrometer survey was carried out over the Duchess 1:250 000 Sheet area in 1975 along east–west flight lines 1.5 km apart 150 m above ground level; the data are presented at 1:250 000 scale as (1) contours and stacked profiles of the magnetic and total-count radiometric results, (2) stacked profiles of the potassium, uranium, and thorium channels, and (3) stacked profiles of the ratios uranium: thorium, uranium:potassium, and thorium:potassium (BMR, 1978b), and at 1:100 000 scale as contour maps of the magnetic field (BMR, 1978c)—all of which can be obtained from the Australian Government Printer Copy Service. Airborne scintillograph surveys made in 1958–60 in the west along east–west flight lines 300–500 m apart 60 m above ground level are reported on by Gardener (1961) and Mulder (1961a,b). In 1969, a detailed airborne gamma-ray spectrometer survey was made along lines 320 m apart 80 m above ground level over phosphate deposits in the Burke River Structural Belt (Waller & others, 1971). Areas covered by airborne radiometric surveys are shown in Figure 66.

Several detailed metalliferous ground surveys made in the 1950s were reported on by Horvath (1952, 1955), Horvath & Tate (1954), and Howard (1960). Earlier ground geophysical investigations were conducted by the Aerial, Geological and Geophysical Survey of Northern Australia southwest of Duchess (Rayner & Nye, 1936). Figure 66 shows locations of detailed metalliferous surveys.



AIRBORNE RADIOMETRIC SURVEYS

Survey area	Instrument	Flying height (a.g.l.)	Line spacing (m)	Reference
(circles)	*Scintillograph*	*60m*	*400*	*Gardener (1961)*
(diagonal hatching)	*Scintillograph*	*60m*	*300-500*	*Mulder (1961a)*
(dots)	*Scintillograph*	*60m*	*320-480*	*Mulder (1961b)*
(cross-hatching)	*Spectrometer*	*80m*	*320*	*Waller & others (1971)*
(grey shading)	*Spectrometer*	*150m*	*1500*	*BMR (1978b–c)*



DETAILED METALLIFEROUS SURVEYS

Location	Reference
⊙	*Rayner & Nye (1936)*
•	*Horvath (1952)*
×	*Horvath & Tate (1954); Horvath (1955)*
▭	*Howard (1960)*

16/F54/65

Fig. 66. Areas covered by airborne radiometric surveys and detailed metalliferous surveys.

Rock density

Although insufficient samples were measured to adequately represent the densities of all rock units exposed in the region, Tables 18 and 19 provide the best available guide for estimating bulk rock densities (for more details see Hone & others, in preparation). The measured densities are consistent with those of rocks from other parts of the Mount Isa Inlier. The results are summarised diagrammatically in Figure 67.

Porosity measurements show that weathered rocks in the Mount Isa Inlier have porosities of up to 27 percent, whereas fresh drillhole samples have porosities between 0 and 2.6 percent, and fresh surface rocks have recorded porosities between 0 and 2.0 percent. The rock densities in Tables 18 and 19 are based on assumed porosities of 2 percent or less for sedimentary rocks, and 0.5 percent or less for igneous rocks.

TABLE 18. SUMMARY OF DENSITY MEASUREMENTS (GROUPED BY ROCK UNIT AND ROCK TYPE)

Rock unit	*Lithology*	*No. samples*	*Wet density (t/m^3)* *Range*	*Mean*	*SD*
McNAMARA GROUP					
Gunpowder Creek Formation*	sandstone	3	2.62–2.69	2.66	0.04
	dolomitic siltstone	15	2.65–3.03	2.77	0.09
	shale	3	2.61–2.66	2.63	0.02
MOUNT ISA GROUP					
Moondarra Siltstone*	siltstone	1		2.72	
MARY KATHLEEN GROUP					
Marimo Slate*	siltstone, shale, slate, chert	8	2.30–2.72	2.55	0.15
Staveley Formation	basalt	1		2.94	
Kuridala Formation	banded iron formation	2	3.13–3.20	3.17	
Overhang Jaspilite*	shale, jaspilite	9	2.77–3.46	2.93	0.22
Corella Formation west of Wonga Belt*	shale, quartzite	13	2.63–2.82	2.70	0.05
	marble	1		2.79	
	granofels	2		2.71	
in Wonga Belt*	metaconglomerate, metavolcanics	2		2.75	
	marble	1		2.76	
	calc-silicate rock, amphibolite, granofels	5	2.77–3.08	2.92	0.14
	schist	1		2.69	
	skarn	2	3.48–3.63	3.56	
east of Wonga Belt*	shale, siltstone, quartzite	6	2.61–2.69	2.64	0.03
	metasiltstone	3	2.71–2.80	2.75	0.05
	limestone, calc-silicate	25	2.64–3.06	2.81	0.12
Ballara Quartzite	conglomerate	1		2.90	
MALBON GROUP					
Mitakoodi Quartzite*	meta-arenite	1		2.63	
	siltstone, shale	3	2.79–2.83	2.81	0.02
	basalt	2	2.84–2.87	2.86	
Marraba Volcanics*	mafic schist, metabasalt	2	2.78–2.84	2.82	
SOLDIERS CAP GROUP					
Undivided	amphibolite	2	3.00–3.10	3.05	
	garnetiferous gneiss	1		2.78	
Toole Creek Volcanics*	dolerite, metabasalt, amphibolite	5	2.80–3.11	3.03	0.13
	quartzite	3	2.67–3.02	2.89	0.19
Mount Norna Quartzite*	metasediments	10	2.63–2.78	2.68	0.05
	rhyolite	2	2.57–2.60	2.59	
	metadolerite	1		3.05	
	banded iron formation	3	3.14–3.73	3.48	0.30
HASLINGDEN GROUP					
Eastern Creek Volcanics*	basalt	6	2.87–3.07	2.99	0.07
	chlorite–albite–quartz rock	2	2.70–2.77	2.74	
Yappo Member (Mount Guide Quartzite	conglomerate	1		2.78	
Bottletree Formation	metadacite	1		2.65	
TEWINGA GROUP					
Argylla Formation	felsic metavolcanics	2		2.68	
	amphibolite	1		2.95	
Leichhardt Volcanics	ignimbrite	2		2.64	
	quartz–feldspar porphyry	2	2.63–2.69	2.66	
	quartz–feldspar porphyry dyke	1		2.66	
Undivided	gneiss	9	2.58–2.72	2.64	0.05
	metagreywacke conglomerate, meta-agglomerate	3	2.72–2.79	2.75	0.04
WONGA BATHOLITH					
Mount Erle Igneous Complex	dolerite, metadolerite	2	2.98–3.04	3.01	
WILLIAMS BATHOLITH					
Wimberu Granite		4	2.64–2.67	2.65	0.01
Gin Creek Granite	granite	1		2.58	
Unnamed granite		1		2.65	
Mount Dore Granite		1		2.64	
KALKADOON BATHOLITH					
Wills Creek Granite		1		2.65	
One Tree Granite	granite	5	2.66–2.73	2.69	0.03
Woonigan Granite		1		2.60	
Kalkadoon Granite		10	2.67–2.80	2.74	0.04
Dolerite, gabbro, metadolerite dykes		5	2.96–3.03	3.00	0.03
Mount Philp Breccia		1		2.62	

Note that densities of sedimentary rock samples with porosities of over 2 percent have been corrected to densities for porosities of 2 percent, and densities of igneous rock samples with porosities of over 0.5 percent have been corrected to densities for porosities of 0.5 percent.
* Samples from north of the Duchess-Urandangi region.

TABLE 19. SUMMARY OF DENSITY MEASUREMENTS (GROUPED BY ROCK TYPE ONLY)

Rock type	*Number of samples*	*Wet density (t/m³)* *Range*	*Mean*	*SD*
skarn	2	3.48–3.63	3.56	
banded iron formation	2	3.13–3.20	3.16	
mafic igneous rocks	15	2.84–3.10	2.98	0.08
granofels	3	2.77–2.87	2.82	0.05
conglomerate, metaconglomerate	5	2.75–2.90	2.79	0.06
metavolcanics	1		2.75	
calc-silicate rocks	3	2.66–2.79	2.73	0.07
meta-agglomerate	1		2.72	
mafic schist	1		2.71	
granite	24	2.64–2.80	2.69	0.05
gneiss	12	2.58–2.78	2.66	0.06
felsic volcanics	4	2.63–2.68	2.65	0.02
breccia	1		2.62	

Basement rocks, mainly felsic gneiss and granite, are generally of low to medium density (<2.74 t/m³), but intrusions of high-density mafic rocks increase the overall density of the basement. The Proterozoic older and younger cover sequences contain rocks ranging in density from over 3.1 t/m³ (skarns and banded iron formations) to about 2.6 t/m³ (some shale, arenite, and felsic volcanics). Measured granite samples have mean densities of 2.58 to 2.74 t/m³. Mafic dykes have densities of about 3.0 t/m³.

Densities of some Palaeozoic sediments cropping out near the Mount Isa Inlier have been reported by Gibb (1967). Only two of the formations mentioned in his report crop out in the Duchess–Urandangi region—the Ninmaroo Formation and the Chatsworth Limestone, which have densities of 2.69 t/m³ and 2.71 t/m³ respectively.

Regional gravity characteristics

Bouguer anomaly values over outcropping rocks of the Mount Isa Inlier form the Cloncurry Regional Gravity High of Fraser & others (1977). This regional high extends well to the south of the exposed limits of the Mount Isa Inlier, where it is considered to delineate the concealed southerly extension of the inlier.

North of the Duchess–Urandangi region the gravity anomalies trend north, while to the south they trend north-northwest (Fig. 68). These trends are regional geological trends. West of the Rufus Fault Zone and extending far westwards into the Georgina Basin, the regional gravity anomalies trend northwest.

Alignment of gravity contours, anomaly truncations and offsets, and significant changes in anomaly amplitude appear to define a set of lineaments trending roughly northeast; the more conspicuous of these possible lineaments are shown in Figure 68. An apparently less well-defined set of complementary lineaments trends about northwest to north-northwest. The lineaments, if real, must mark abrupt changes in the geology—i.e., faults and fault zones.

Bouguer gravity values in the region have a range of over 500 μm.s^{-2} (Fig. 69). The highest values occur over metasediments and mafic rocks, and the lowest values are over granite. Bouguer anomaly profiles and interpreted geological cross-sections, grossly simplified, along 21°45′S (line AB in Fig. 69) and 22°S are shown in Figure 70.

The Corella Formation is considered to be the major contributor to Bouguer anomaly values of over 100 μm.s^{-2} aligned along longitude 139°55′E. High gravity values to the south, over the Burke River Structural

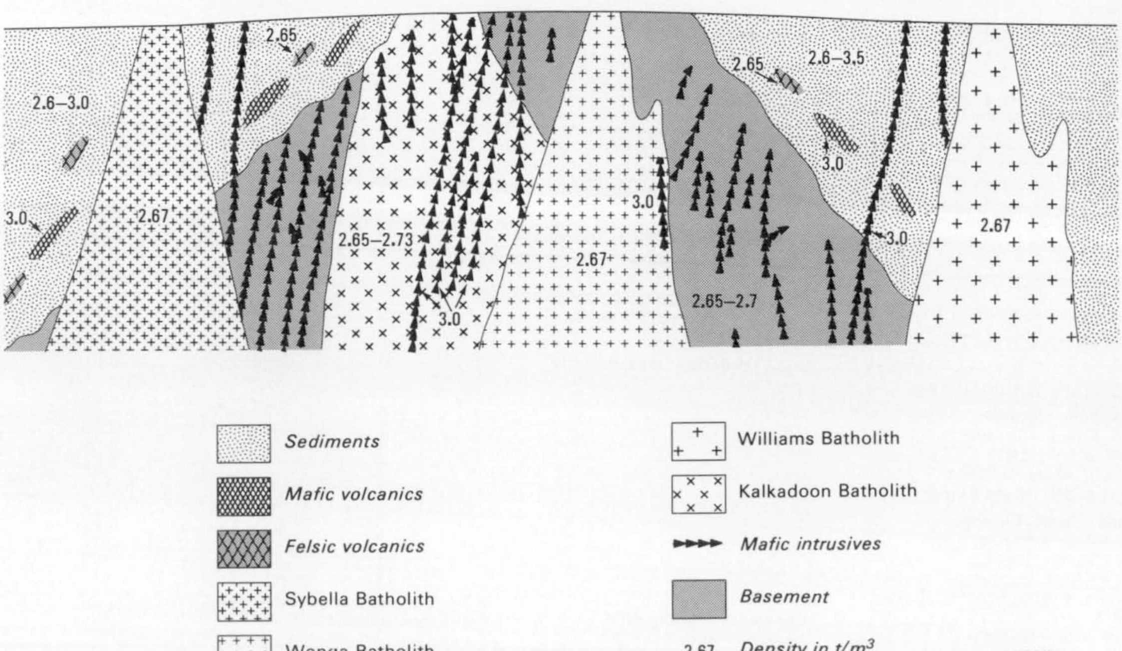


Fig. 67. Density model for the Proterozoic rocks in the Duchess–Urandangi region.

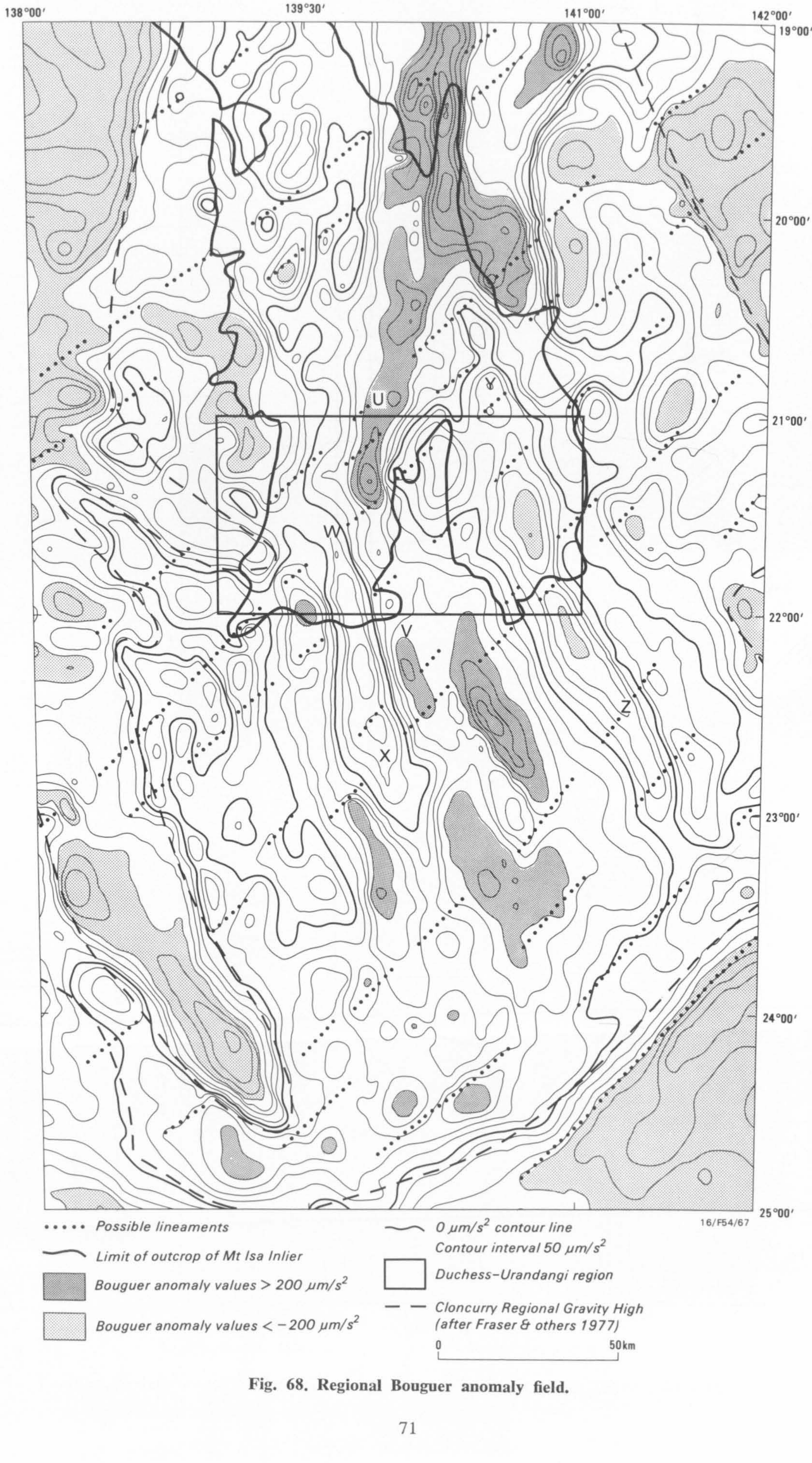
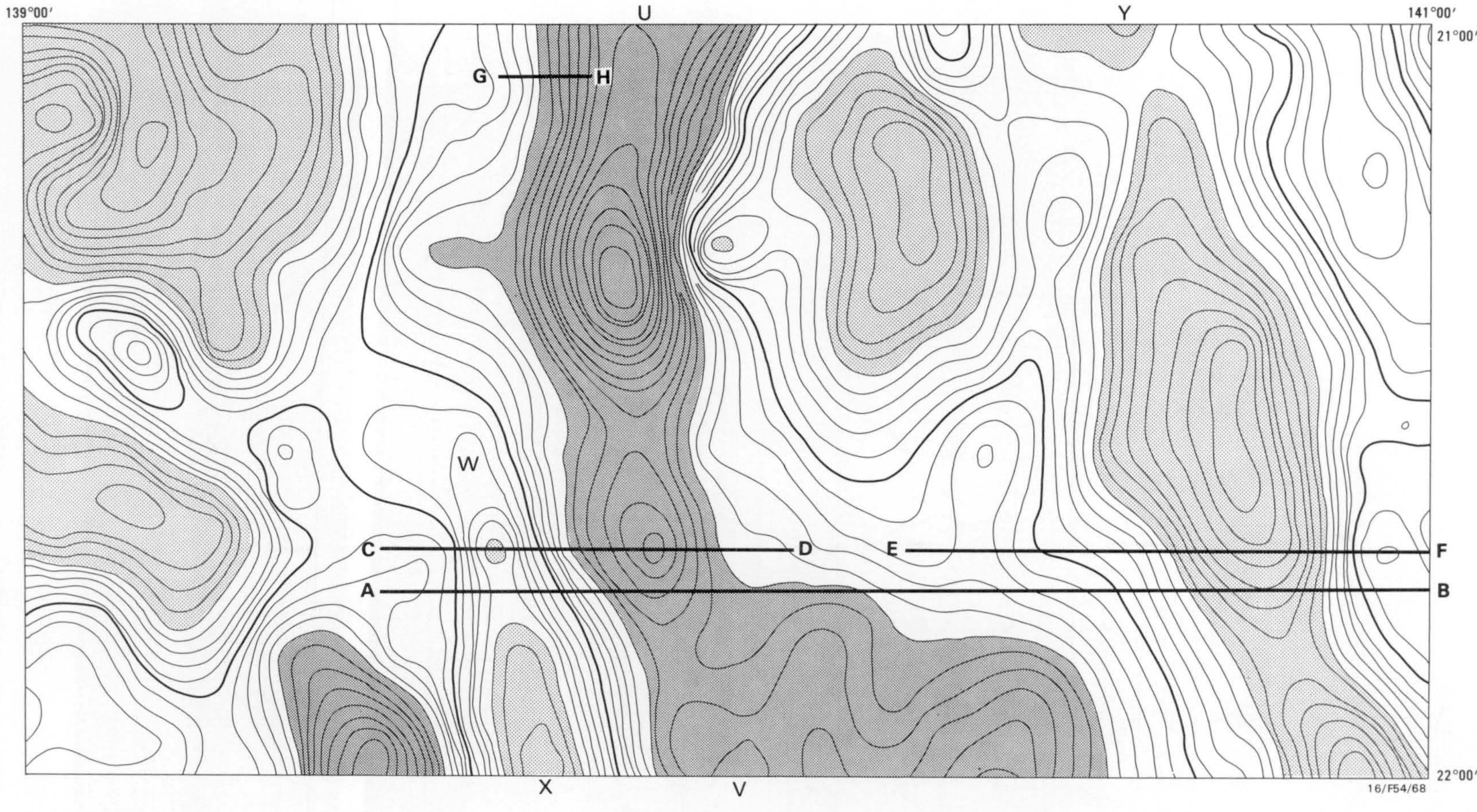


Fig. 68. Regional Bouguer anomaly field.



Bouguer anomaly values > 100 µm/s²

Bouguer anomaly values < − 100 µm/s²

0 µm/s² contour line
Contour interval 20 µm/s²

Bouguer reduction density: 2.67 t/m³

Letters refer to features and profiles mentioned in text.

0 50km

Fig. 69. Bouguer anomaly map of the Duchess–Urandangi region.

Belt, are considered to be due to underlying Proterozoic rocks of Corella Formation type. A small area of high Bouguer values in the south, along longitude 139°30′E, is mainly over the Eastern Creek Volcanics and Jayah Creek Metabasalt, and is attributed to the basaltic component of these formations.

Medium Bouguer anomaly gravity fields (between –100 and 100 $\mu m.s^{-2}$) in the east are considered to be caused by the exposed rocks of the Soldiers Cap Group and Staveley Formation. Those over the Burke River Structural Belt are interpreted as being caused by underlying Proterozoic older and younger cover rocks.

The sources of most low Bouguer anomaly gravity values (less than –100 $\mu m.s^{-2}$) are considered to be granites of the Williams and Sybella Batholiths.

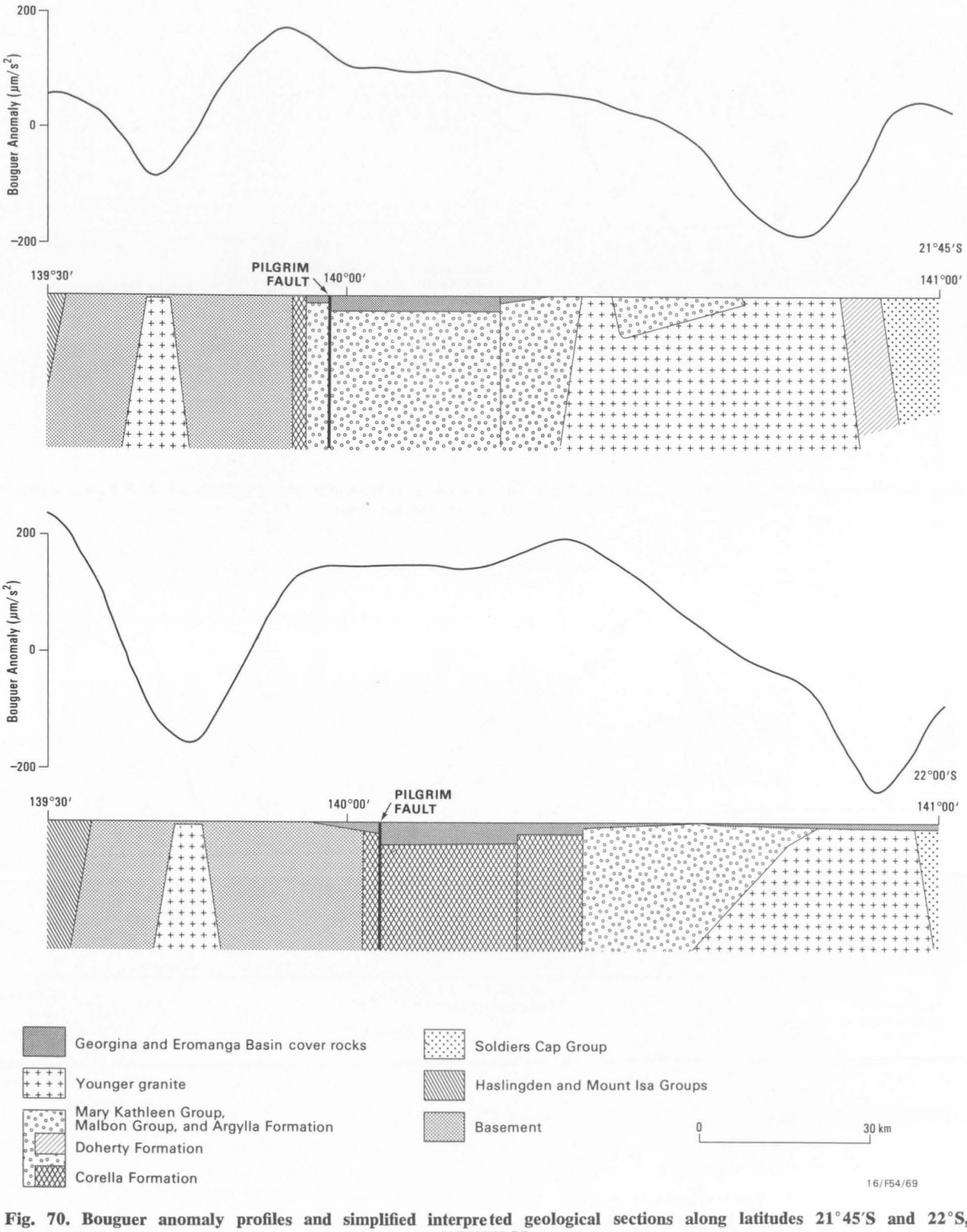


Fig. 70. Bouguer anomaly profiles and simplified interpreted geological sections along latitudes 21°45′S and 22°S, DUCHESS.

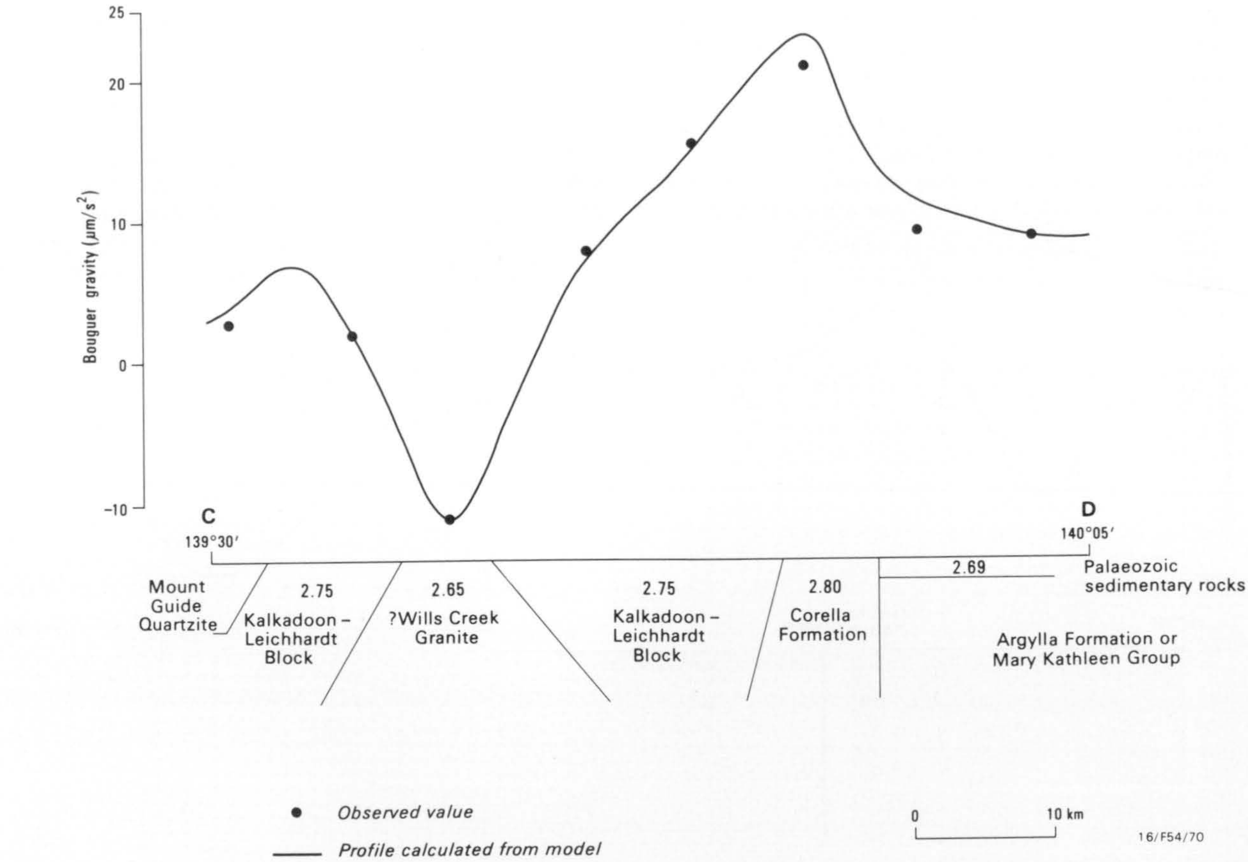


Fig. 71. Observed Bouguer gravity values and modelled Bouguer gravity profile along latitude 21°42′S between points C and D (see Fig. 69 for location).

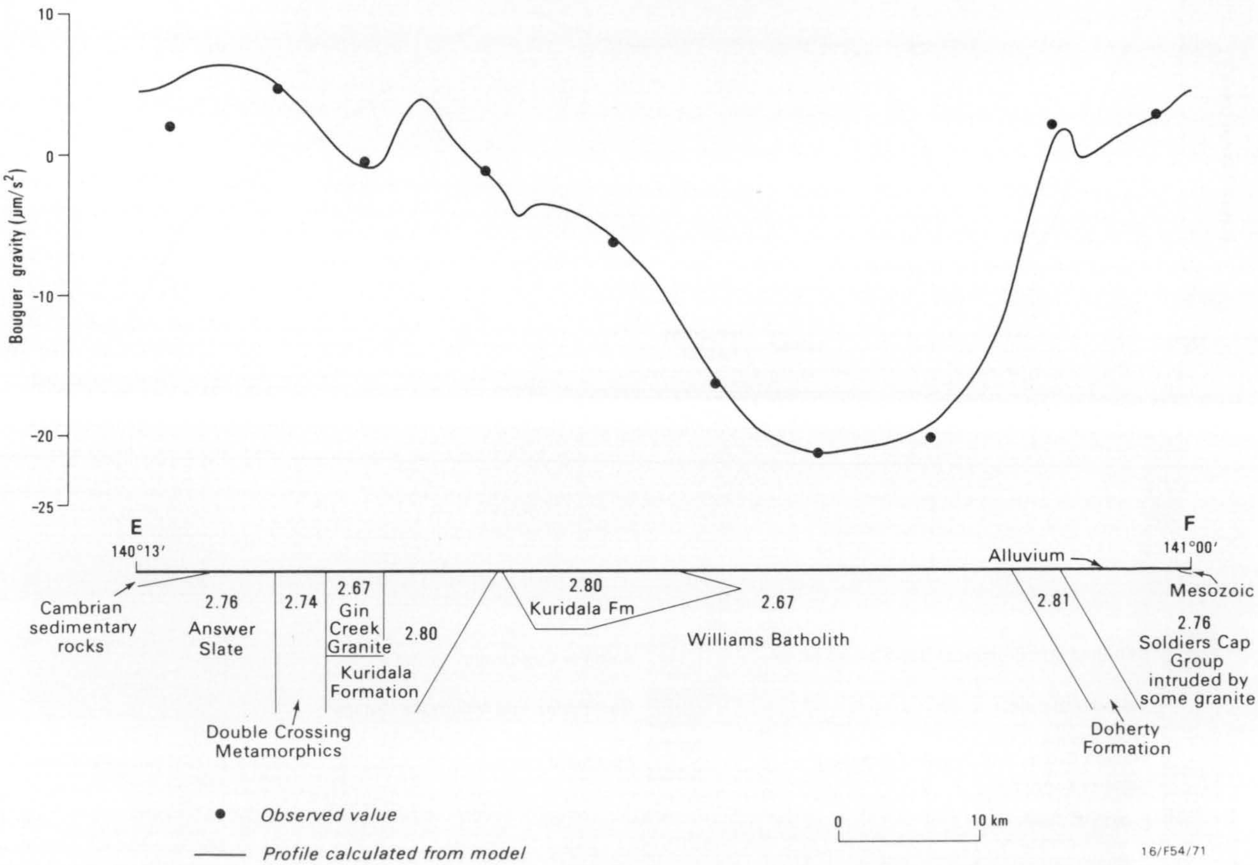


Fig. 72. Observed Bouguer gravity values and modelled Bouguer gravity profile along latitude 21°42′S between points E and F (see Fig. 69 for location).

The wide spacing of the gravity stations in the region precludes definition of the gravity field over units of limited areal extent, such as the Overlander Granite and other small granite bodies of the Wonga Batholith. Local anomalies of over 100 μm.s^{-2} amplitude such as some of those reported by Smith (1966a, b, 1968) from the Dobbyn, Cloncurry, and Mount Isa 1:250 000 Sheet areas would not be detected by the regional survey.

Quantitative interpretation of major features of the gravity field

Three major features of the Bouguer gravity map of the region and surrounds are the long gravity high labelled UV and the elongate gravity lows labelled WX and YZ in Figures 68 and 69. The western flank of the gravity high, UV, lies partly over the Kalkadoon–Leichhardt Block, which—being granitic—would be expected to generate a gravity low. The gravity low, WX, is located in the southwest in an area of sparse outcrop. The other gravity low, YZ, which is associated with the Williams Batholith, has a gentler gravity gradient on its western flank than on its eastern flank. To try to explain the sources of these gravity features, a quantitative interpretation was carried out along latitude 21°42′S (lines CD and EF in Fig. 69). The observed gravity values and the profiles calculated from interpreted generalised densities along lines CD and EF are shown in Figures 71 and 72.

The gravity high, UV, peaks over the Corella Formation (Fig. 71), and its western flank is over the Kalkadoon–Leichhardt Block. The measured average density of Corella Formation rocks, around 2.8 t/m^3, is consistent with the modelling calculation, which shows the Corella Formation as the main cause of the anomaly. Yet the average density of granite and gneiss of the Kalkadoon–Leichhardt Block ($\leqslant$2.74 t/m^3) is too low to account for the western flank of the anomaly. Measurements on samples of Kalkadoon and One Tree Granites indicate that the density of granite and gneiss under the western flank could be about 2.72 t/m^3—too low by 0.03 t/m^3 to account for the feature. However, if—for example—10 percent of the volume of the rock corresponding to the western flank of the anomaly were to comprise mafic dykes (average density of 3.0 t/m^3) and the other 90 percent granite (density 2.72 t/m^3), the bulk average density would be about 2.75 t/m^3. This speculation may be close to the truth, as the 1:100 000-scale geological maps of the southern part of the Mount Isa Inlier show that mafic dykes form a significant component of the Kalkadoon–Leichhardt Block; being readily eroded, and hence often not exposed, such dykes may be more voluminous than mapped. In contrast, the presence of gravity lows over the Williams and Sybella Batholiths is consistent with their composition of low-density granite intruded by only sparse mafic dykes.

The northern part of an elongate gravity low in the south along longitude 139°45′E (WX, modelled in Fig. 71) occurs partly over outcrops of the Wills Creek Granite. This granite (or another granite), intruded by few mafic dykes, is suggested to be the source for most of this gravity low.

Modelling of the gravity field over the Williams Batholith along line EF (Fig. 72), in order to interpret the cause of anomaly YZ, indicates that the batholith has a complex western boundary. The gravity field can be accounted for by supposing that metasediments form a wedge in the granite, and that the granite contact dips westwards at a low angle.

Magnetic properties of Proterozoic rocks

The results of laboratory magnetic susceptibility and remanence measurements made on surface samples of rocks collected during the 1975–1980 geological mapping program, and on surface and drillhole samples from north of the region, are summarised in Table 20. The rocks measured exhibit a wide range of susceptibilities, and the mean value is high—more than 0.01 (SI). The strengths of measured remanences, and the Koenigsberger ratio (Q, the ratio of the effect of remanence to that of susceptibility, calculated for an ambient field strength of 50 000 nT), also have a wide range. The measurments show that many of the Proterozoic rocks are magnetic. The most magnetic samples (based on a combination of susceptibility and remanence) were basalts from the Eastern Creek Volcanics and a sample of banded iron formation from the Kuridala Formation (Table 20). Other very magnetic samples came from the Corella Formation, Overhang Jaspilite, and Mount Norna Quartzite (banded iron formation). Of the granite samples measured, all but one (the only sample of Gin Creek Granite) from the Williams Batholith were magnetic, whereas all those from the western part of the region were non-magnetic.

Regional magnetic characteristics

The total magnetic field over the Duchess–Urandangi region (Fig. 73) was compiled from the results of two surveys. A change in style of the anomalies across longitude 139°30′E is due to the use of different survey parameters and contouring methods. The survey in the Duchess 1:250 000 Sheet area was flown at a line spacing of 1.5 km and an altitude of 150 m above ground level, whereas for the Urandangi 1:250 000 Sheet area the line spacing was 3.2 km and the flying height 600 m above mean sea level—that is, 180 m above ground level in the northeast and 400 m above ground level in the south. The results from Duchess were contoured by computer, whereas those from Urandangi were hand-contoured.

The total magnetic field strength is about 51 500 nT, the inclination is −52°, and the declination is 6°E (Finlayson, 1973). Narrow sources with an east-west strike, or small sources with a roughly equidimensional horizontal cross-section, produce an induced magnetic anomaly with a high to the north and a low to the south of the source. The strength of the induced magnetic field across a north–south striking vertical source is symmetrical.

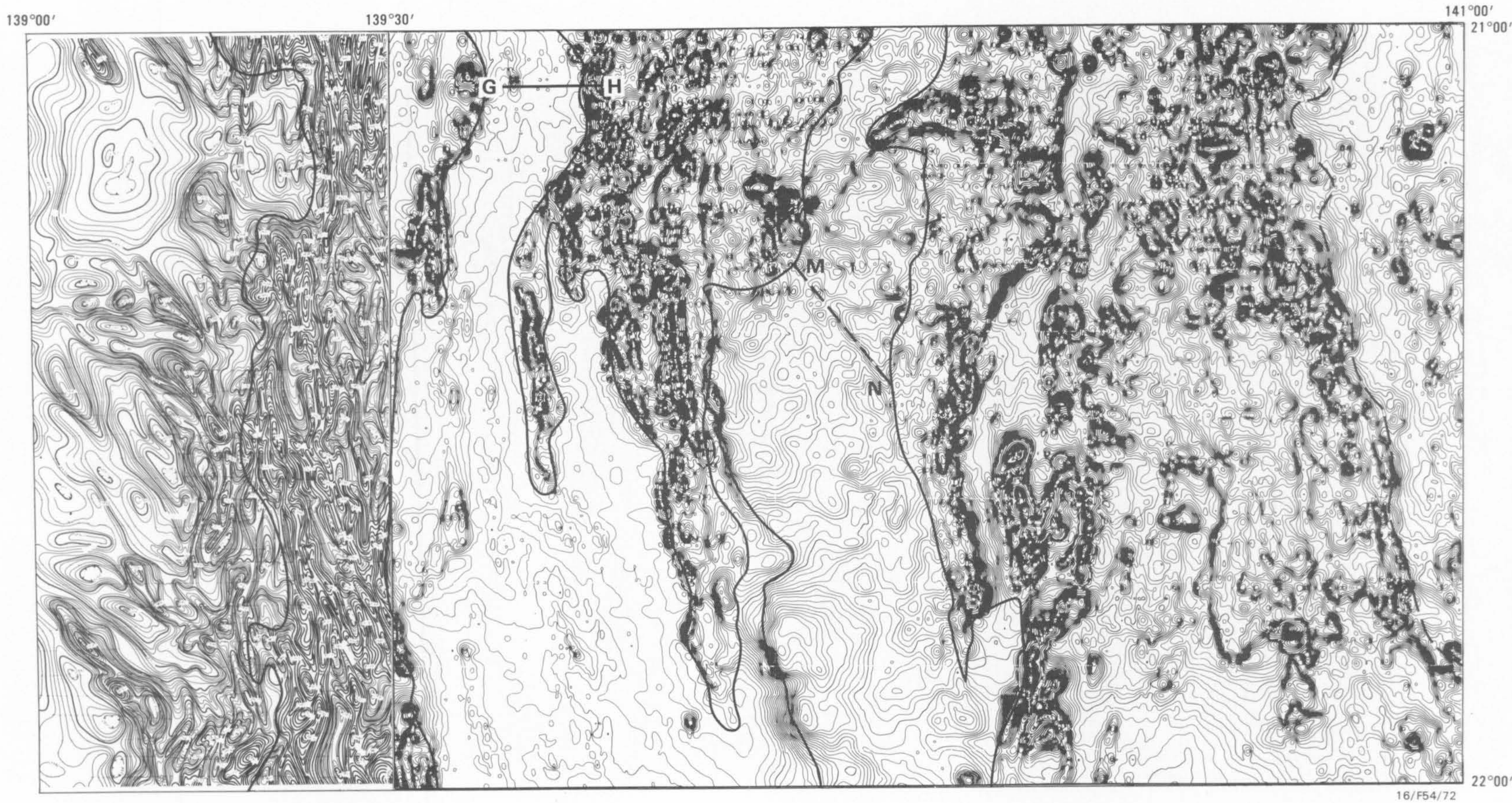
The region can be divided into seven broad magnetic areas (Fig. 73) which correlate well with gross geological divisions. These areas are divided into zones (Fig. 74) on the basis of changes in anomaly trends, anomaly shapes, magnetic field level, and degree of magnetic disturbance. The zones outline areas of consistent magnetic properties, and can be used to assist mapping and structural interpretation.

In the westernmost area, magnetic anomalies are elongate and generally trend northwest, parallel to regional gravity trends. They are interpreted as arising mainly from mafic rocks in the Oroopo Metabasalt, Sulieman Gneiss, and Saint Ronans Metamorphics, and from mafic intrusions. The magnetic anomalies in the far west indicate places where mafic rocks underlie

TABLE 20. SUMMARY OF MAGNETIC SUSCEPTIBILITY AND REMANENCE MEASUREMENTS

Unit	*Lithology*	*N*	*Susceptibility (SIx10⁻⁵)* *Range*	*Median*	*Mean*	*N*	*Remanence (mA/m)* *Range*	*Median*	*Mean*	*N*	*Koenigsberger ratio* *Range*	*Median*	*Mean*
McNAMARA GROUP*													
Gunpowder Creek Formation	dolomite	4	5–1634	22	421	4	0.1–290	1.0	73	4	0.01–0.45	0.11	0.17
	sandstone, siltstone, dolomitic siltstone, shale	17	0–38	13	19	17	0.1–10	0.7	1.2	16	0.02–0.66	0.08	0.13
MOUNT ISA GROUP*													
Moondarra Siltstone	siltstone	1			0	1			1				
MARY KATHLEEN GROUP													
Staveley Formation	basalt	1			678	1			100	1			0.37
Kuridala Formation	banded iron formation	2	88–1005		547	2	12400–102700		57550	2	257–354		306
Overhang Jaspilite*	shale, jaspilite	181	100–32794	106	2011	9	0.2–1700	50	410	9	0.01–6.68	0.20	1.15
Corella Formation													
west of Wonga Belt*	quartzite, shale, marble, granofels	218	0–1767	75	104	15	0.05–340	10	43	15	0.002–17.0	0.56	2.03
	amphibolite, calc-silicate rock metavolcanics, granofels	11	0–151	88	262	11	0.1–1300	3	203	10	0.002–87	0.24	9.70
east of Wonga Belt*	calc-silicate rock, siltstone, limestone, metasediments, amphibolite, granofels, shale	126	0–13210	76	356	11	0.1–560	10	122	10	0.08–8.30	0.45	1.75
Ballara Quartzite	conglomerate	1			12692	1			2750	1			0.54
MALBON GROUP													
Mitakoodi Quartzite	shale	40	30–5958	3309	3052	2			20	2	0.001–0.003		0.002
	basalt	2	4700–5200		4450								
Marraba Volcanics*	mafic schist, basalt	2	251–1200		726	1			1050	1			10.5
SOLDIERS CAP GROUP													
undivided	amphibolite	2	75–94		85	2			1	2			0.03
	garnet gneiss	1			18850	1			2400	1			0.32
Toole Creek Volcanics*	amphibolite, metabasalt, quartzite, dolerite	8	6–580	112	166	1			2	1			0.02
Mount Norna Quartzite*	banded iron formation	3	210–22000	15000	12403								
	sedimentary rocks, rhyolite, meta-dolerite	13	2–3600	78	405								
HASLINGDEN GROUP													
Eastern Creek Volcanics	basalt	5	792–10681	6723	6436	6	2500–390000	48735	132261	6	0.72–173	16.66	59.80
	chlorite–albite–quartz rock	2	36–261		149	2	30–300		165	2	2.07–2.90		2.49
Yappo Member (Mount Guide Quartzite)	conglomerate	1			50	1			10	1			0.50
Bottletree Formation	metadacite	1			5027	1			580	1			0.29
TEWINGA GROUP													
Argylla Formation	gneiss, amphibolite	3	50–2199	189	813	3	15–6000	60	2025	3	0.75–6.86	0.80	2.80
Leichhardt Volcanics	porphyry, meta-ignimbrite	3	38–1583	201	607		2–1700	460	721	3	0.12–5.75	2.70	2.86
undivided	meta-ignimbrite	1			2890	1			20500	1			17.83
	conglomerate	2	2890–6660		4775	2	160–420		290	2	0.14–0.16		0.15
	gneiss	9	0–182	25	48	9	0.3–2950	7	337	8	0.03–65.56	0.92	10.45
WONGA BATHOLITH													
Mount Erle Igneous Complex	dolerite, metadolerite	2	31–75		53	2	1–40		21	2	0.08–1.33		0.71
WILLIAMS BATHOLITH													
Wimberu Granite		4	113–4147	201	1166	4	20–4300	48	1104	4	0.33–2.61	0.66	1.06
Gin Creek Granite		1			0	1			0.2				
unnamed granite	granite	1			5027	1			1400	1			0.70
Mount Dore Granite		1			1005	1			40	1			0.10
KALKADOON BATHOLITH													
Wills Creek Granite		6	0–38	22	21	6	0.1–15	1.3	3.8	5	0.01–1.2	0.1	0.31
One Tree Granite	granite	5	25–31	25	27	5	0.2–9	3	3.8	5	0.02–0.72	0.24	0.33
Kalkadoon Granite		6	13–38	28	26	6	0.4–2	0.5	0.7	6	0.03–0.40	0.05	0.10
mafic intrusives		5	50–4926	316	1840	5	20–12000	860	3215	5	0.44–31.6	1.75	8.09
Mount Philp Breccia		1			50	1			7100	1			355

N Number of samples measured.
* Includes some samples from north of the Duchess–Urandangi region.



0 50km

G H *Magnetic profile shown in figure 75*

M N *Feature mentioned in text*

Contour interval 10 nT

Fig. 73. Total magnetic field contours, Duchess–Urandangi region.

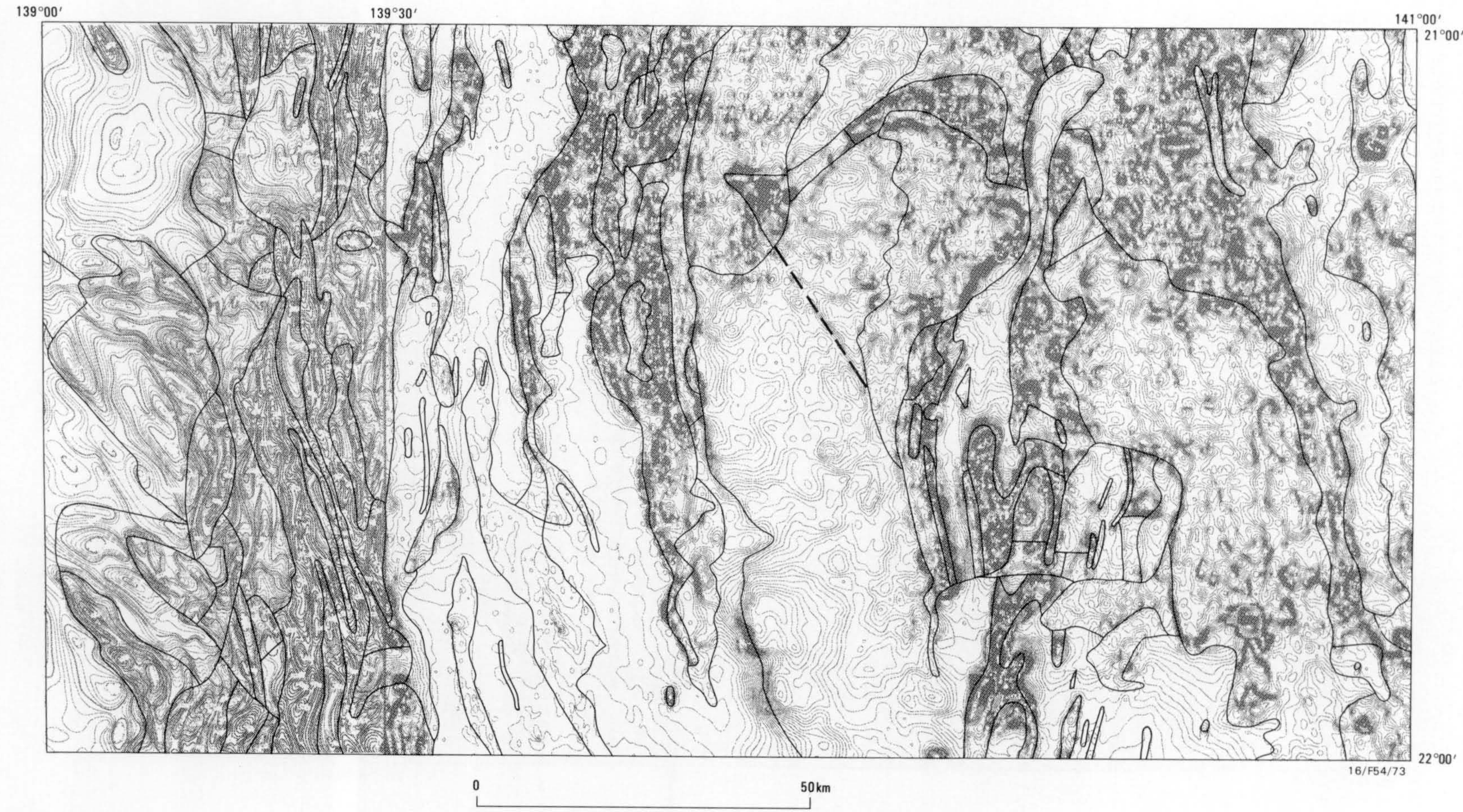


Fig. 74. Zones defined from characteristics of the total magnetic field.

the essentially non-magnetic sediments of the Georgina Basin.

Immediately to the east, a magnetic area characterised by many short-wavelength high-amplitude complex magnetic anomalies mainly overlies the Dajarra Belt. The anomalies form long narrow zones which have north-northeast to north-northwest trends. Most of the anomalies arise from basalts of the Eastern Creek Volcanics and Jayah Creek Metabasalt, and from mafic intrusions. Zones of low magnetic intensity occur over Mount Guide Quartzite and Mount Isa Group rocks.

The area of generally quieter and lower magnetic field farther east mainly overlies the Kalkadoon–Leichhardt Block. Although many mafic intrusives are mapped in this block, most do not produce noticeable magnetic anomalies in the regional contours. A profile between G and H in northern DUCHESS REGION (Fig. 73) reveals magnetic anomalies that are of much smaller amplitude over mafic intrusives in the Kalkadoon–Leichhardt Block than over nearby Eastern Creek Volcanics, Magna Lynn Metabasalt, and Argylla Formation (Fig. 75).

Many high-amplitude short-wavelength magnetic

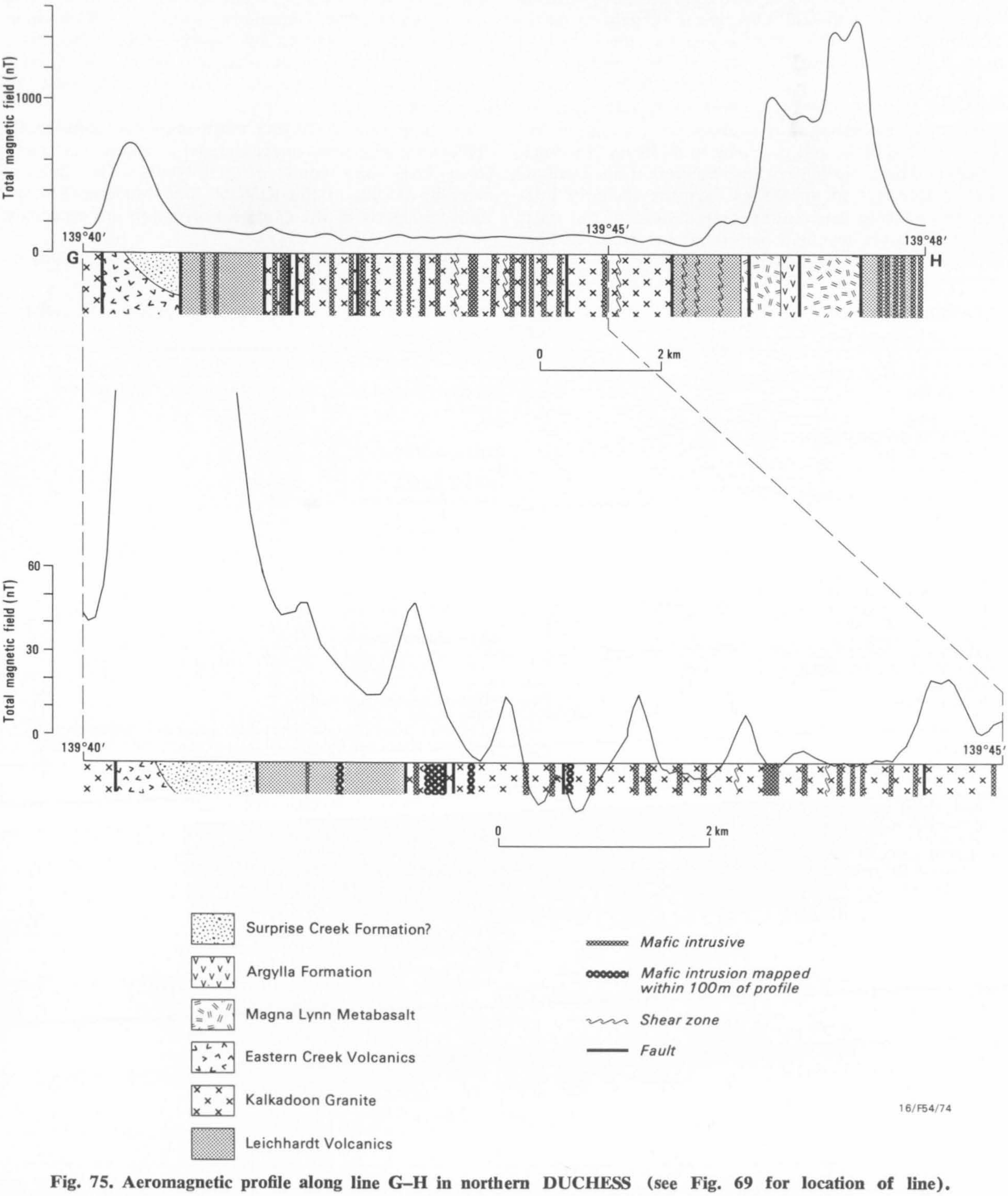


Fig. 75. Aeromagnetic profile along line G–H in northern DUCHESS (see Fig. 69 for location of line).

anomalies occur over the Duchess Belt and the western part of the Malbon Block. They result from magnetic rocks in the Corella Formation, Argylla Formation, and Wimberu Granite.

The magnetic background over the Burke River Structural Belt is higher than that over the Kalkadoon–Leichhardt Block. The magnetic anomalies are smooth, and arise from sources in the Proterozoic basement underlying the Georgina Basin sediments. The north-westerly trending dashed line (MN) in the area corresponding to the Burke River Structural Belt (Fig. 73) marks a break in magnetic characteristics: southwest of this line the anomalies are broader and of lower amplitude than those to the northeast, indicating deeper sources to the southwest. This line is thought to represent a fault along which the basement to the south has been displaced downwards several hundred metres.

East of the Burke River Structural Belt, as to the west, the magnetic field is dominated by intense short-wavelength anomalies. The sources are granites of the Williams Batholith, and magnetic units in the Tewinga, Malbon, Mary Kathleen, and Soldiers Cap Groups. High amplitudes of anomalies over the Doherty Formation outcrop, and lower amplitudes to the east, reflect the more magnetic nature of the Doherty Formation relative to the Soldiers Cap Group.

Stratigraphic locations of magnetic sources

Stratigraphic locations of magnetic anomaly sources are summarised in Table 21, which lists the typical maximum anomaly recorded in the airborne data. In some rock units, more than one distinct source is apparent. Where multiple sources are evident, because of either multiple layering of sources or repetition of sources by faulting or folding, only the most intense source has been identified.

Few high-amplitude magnetic anomalies occur over basement rocks of the Plum Mountain Gneiss, Kalkadoon and One Tree Granites, Leichhardt Volcanics, and undivided Tewinga Group. Some anomalies appear to be caused by mafic intrusions, often along faults, and some anomalies over the Kalkadoon Granite may be caused by ingested rocks. However, most of the mafic rocks intruding the basement units produce only low-amplitude anomalies, unlike many of those elsewhere in the region.

In the older and younger cover sequences most mafic volcanics and intrusives are magnetic, and so are many felsic lavas and some metasediments. The quartz–hematite bodies in the Kuridala and Staveley Formations and parts of the Corella Formation are especially magnetic.

Of the granitic rocks, only those of the Williams

TABLE 21. AIRBORNE MAGNETIC ANOMALIES FROM ROCK UNITS OF THE DUCHESS–URANDANGI REGION

Rock unit	*Anomaly amplitude (nT)*
Metadolerite	500, −300 (western area); 500, 20 (central area); 2000 (eastern area)
Dolerite dyke	400
WILLIAMS BATHOLITH	
Wimberu Granite	100(a), 400(b)
Gin Creek Granite	0
Mount Dore Granite	100(a), 300(b)
Yellow Waterhole Granite	100(a), 300(b)
Squirrel Hills Granite	400(a), 600(b)
Mount Angelay Granite	200(a), 600(b)
Saxby Granite	300(a), 600(b)
Maramungee Granite	0
Unnamed granite	0
WONGA BATHOLITH	
Birds Well Granite	0
Saint Mungo Granite	0
Garden Creek Porphyry	100 (mafic margins)
MOUNT ISA GROUP	0
MARY KATHLEEN GROUP	
Marimo Slate	50
Staveley Formation	5800 (quartz–hematite body)
Doherty Formation	1600
Kuridala Formation	500 (schist), 200 (graphitic slate), 5400 (quartz–hematite body)
Corella Formation	3800, 1000 (felsic volcanics), 100 (metabasalt), 300 (calc-silicate rock)
Overhang Jaspilite	800
SOLDIERS CAP GROUP	
Toole Creek Volcanics	100
Mount Norna Quartzite	1000
undivided	40 (metabasalt), 200, 400, 900
MALBON GROUP	
Mitakoodi Quartzite	1200 (upper part), 200 (lower part)
Marraba Volcanics	100 (mafic schist), 1400, 1000
Double Crossing Metamorphics	1200 (quartz–hematite body?)
HASLINGDEN GROUP	
Eastern Creek Volcanics	1000 (western area), 1400 (central area)
Bottletree Formation	600 (metabasalt?)
Oroopo Metabasalt	500
Jayah Creek Metabasalt	−200, 1000
TEWINGA GROUP	
Argylla Formation	2100 (eastern area), 400 (central area)
Magna Lynn Metabasalt	2400?
Leichhardt Volcanics	100
undivided	40 (quartzite), 600? (rare)
KALKADOON BATHOLITH	
Woonigan Granite	0
Wills Creek Granite	0
Kalkadoon Granite	0
One Tree Granite	0
Plum Mountain Gneiss	0

(a) short-wavelength anomalies; (b) long-wavelength anomalies.
NOTE: Amplitudes of 0 indicate no anomalies attributable to the rock unit. Negative amplitudes indicate reversely magnetised sources.

Batholith are characteristically magnetic. These granites generate a distinctive pattern of complex anomalies in which randomly oriented short-wavelength anomalies with amplitudes of 100 nT to 400 nT are superimposed on longer-wavelength anomalies with amplitudes of 300 to 600 nT. Other granites are non-magnetic or only weakly magnetic.

The Phanerozoic rocks in the region do not appear to contain magnetic sources.

Regional radiometric characteristics

Total-count and spectral data are available for the Duchess 1:250 000 Sheet area, but not for the Urandangi 1:250 000 Sheet area. Detailed or quantitative interpretation of BMR spectrometer data is plagued by uncertainties owing to the small detector crystal used and the lack of quantitative calibration data. The small detector results in low count rates, so the statistical accuracy of data collected over small areas is poor, but the data collected are useful in regional reconnaissance where large areas of similar rock type are sampled. Over much of the Duchess–Urandangi region, however, there are marked changes in rock type over distances too short to give meaningful results. The regional interpretation presented here is therefore, by necessity, broad.

The Duchess 1:250 000 Sheet area can be divided into five broad zones of radioactivity. From west to east these are classed as of low, moderate, low, high, and low activity (Fig. 76). The zones correlate broadly with structural groupings, and their shapes and radioactivity characteristics are strongly influenced by the presence or absence of granite and its radioactivity. Not surprisingly, the granites with the highest uranium contents (see section GEOCHEMISTRY OF IGNEOUS ROCKS) generate the highest count rates.

In the westernmost low zone the total count rate is less than 75 cps. The zone lies mainly over the Dajarra Belt, in which the main rock units belong to the Haslingden Group and, in the south, the Mount Isa Group. Haslingden Group rocks generate very low count rates except in the extreme northwest, where part of the Mount Guide Quartzite generates count rates of over 100 cps.

In the moderate zone, which covers most of the Kalkadoon–Leichhardt Block, the Duchess Belt, and the western part of the Malbon Block, the total count rate is mainly in the range 50–150 cps. Higher count rates occur over the Overlander (up to 350 cps), Revenue (up to 200 cps), and Bowlers Hole (over 175 cps) Granites, part of the Wimberu Granite (up to 250 cps), parts of the Argylla Formation, and also the phosphate deposits at Phosphate Hill, DAJARRA, where counts of up to 175 cps were recorded. The Birds Well and Mairindi Creek Granites are not quite as radioactive, and the Saint Mungo Granite, Bushy Park Gneiss, and granites of the Kalkadoon Batholith —which yield total-count recordings usually less than 125 cps—are even less so.

In the central low zone the count rate is mostly

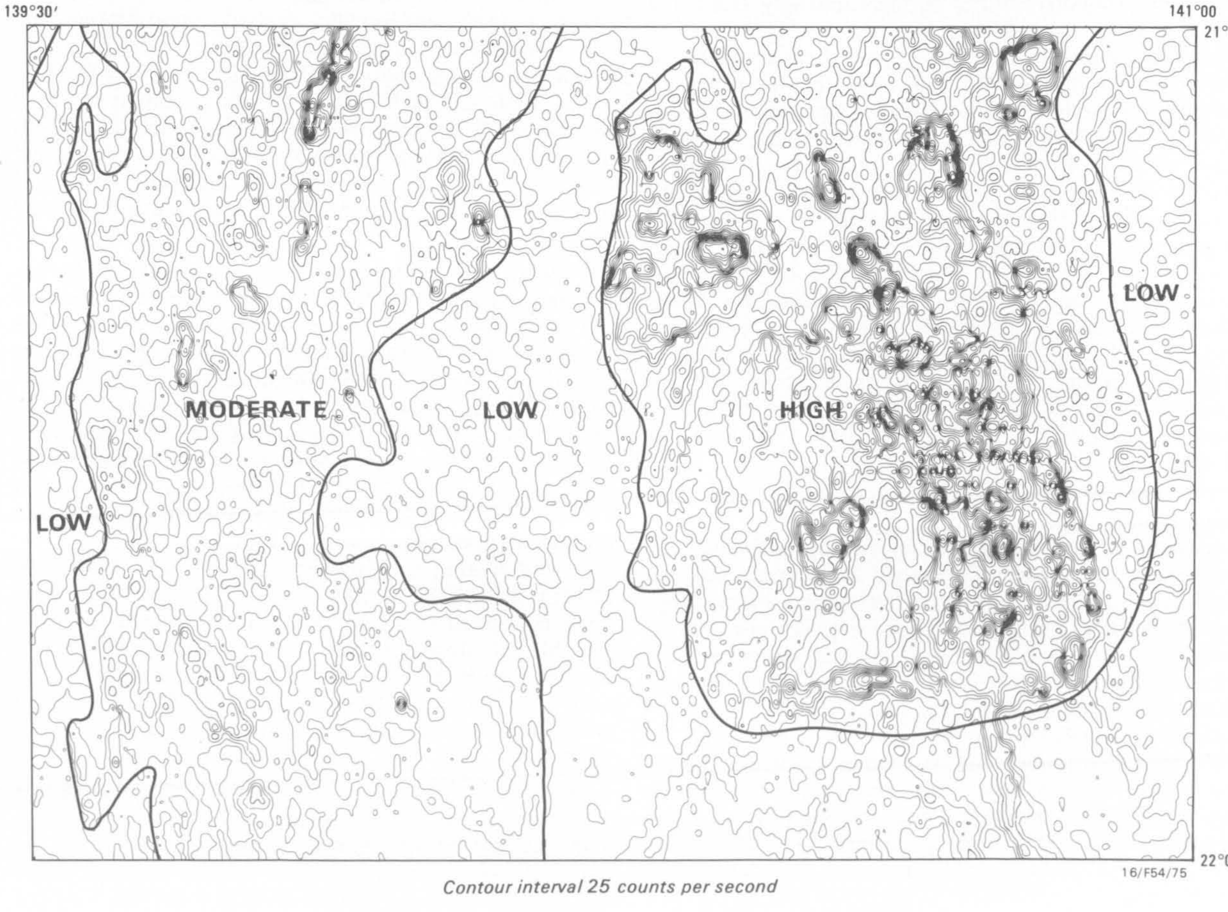


Fig. 76. Total-count radiometric contours, DUCHESS.

in the range 25–75 cps. The zone corresponds largely to the area occupied by Palaeozoic sedimentary rocks of the Burke River Structural Belt, but it also covers small parts of the Corella Formation in the west.

The high zone to the east is dominated by high count rates: values of over 300 cps have been recorded over non-foliated granites of the Williams Batholith. The Mary Kathleen, Malbon, and Soldiers Cap Groups in this zone generate mainly moderate count rates.

In the eastern low zone, which in the south joins with the central low zone, the count rate is usually in the range 25–75 cps. Higher count rates occur over watercourses, such as those of the Fullarton River, Sandy Creek, and Bustard Creek, which drain granites of the Williams Batholith. Most of the zone is covered with Cainozoic sediments, although there are some outcrops of Soldiers Cap Group, Kuridala Formation, and Phanerozoic sedimentary rocks.

Spectral results

In the Duchess 1:250 000 Sheet area, profiles are available for thorium and stripped uranium and potassium channels, and for thorium:potassium, uranium: potassium, and uranium:thorium. In addition, spectral results in the form of contours are available from a detailed airborne survey covering 640 km^2 in the south of the Sheet area (Waller & others, 1971). The data show that the high total count rates over the Williams Batholith and the Overlander and Revenue Granites are accompanied by high count rates in each of the thorium, uranium, and potassium channels, suggesting that these granites are enriched in all radioactive elements. Granites with a lower total count rate appear to have a lower enrichment. Exceptionally large thorium-channel anomalies (well over 50 cps), accompanied by high thorium:potassium and uranium: potassium ratios, occur over parts of the Williams Batholith where weathered granite and, in places, Mesozoic sedimentary rocks form mesa cappings, and may be attributed to surface concentration of thorium and uranium during lateritic weathering processes.

Uranium-channel anomalies, often unaccompanied by anomalies in other channels, occur over some Cambrian outcrops, mainly the Beetle Creek Formation, and may overlap onto adjacent formations. Some also occur over parts of the Staveley Formation, Marimo Slate, Overhang Jaspilite, and Doherty Formation. Uranium:thorium ratios typically appear to be inversely proportional to the total count rate, except over the Cambrian Beetle Creek Formation, where they are high and the total count rate is moderate to high.

MINERAL RESOURCES

Mining history

The Duchess–Urandangi region contains what were the most productive mines of the Cloncurry Gold and Mineral Field during the early part of this century. Significant numbers of miners were first attracted to the region in the 1860s, following the discovery of rich alluvial gold deposits at Top Camp on the Cloncurry River east of Malbon. However, within a decade most of the gold reserves were exhausted. The prospectors then extended their searches farther south and west, and by 1900 most of the major copper deposits in the region had been discovered. In 1906, large-scale mining operations were initiated by two companies which were soon to dominate the field—Mount Elliott Ltd and Hampden–Cloncurry Copper Mines Ltd. The latter's operations were centred on the Hampden group of mines and its associated service township of Kuridala, whereas the former's operations were concentrated at the Mount Elliott mine, 28 km to the south, near Selwyn.

In 1906, Hampden–Cloncurry Copper Mines Ltd acquired the Duchess copper mine, which had been discovered in 1897 by Jack Kennedy, son of the pioneer pastoralist Alexander Kennedy. This mine was to become the richest producer in the Duchess–Urandangi region. By 1912, Hampden–Cloncurry had also gained control of the rich Trekelano copper mine and the smaller Mount Mascotte and Answer copper mines. However, its rival, Mount Elliott Ltd, achieved a business coup in 1912 by purchasing the richest mine of the Hampden group, the Hampden Consols. Within the region at that time, only one copper mine with any significant output, Saint Mungo, remained in independent hands. This mine produced over 6700 t of ore averaging 23 percent Cu between 1910 and 1918 (Table 22).

From 1911, ore obtained from the mines operated by the two major companies was processed at their respective smelters at Kuridala (Fig. 77) and Mount Elliott, both now in ruins. The blister copper was transported to Cloncurry and then to Townsville via the newly completed railway. Despite industrial disputes, inefficient smelter designs, breakdowns, and the rapid depletion of the high-grade oxidised ore in most of the operating mines (ore grades fell from about 12% Cu in the oxidised zones mined in 1910 to about 4% in the primary zones mined in 1918), the copper smelting operations on the field remained profitable, and the smelters were the most important producers of blister copper in Australia during World War I.

However, in 1918 continued labour troubles, breakdowns, and fires in the Hampden Consols mine, and the exhaustion of the high-grade oxidised ore, together with a drastic postwar drop in world copper prices, forced the closure of the Duchess, Hampden, Mount Elliott, Mount Mascotte, and Answer mines. After a brief rally in 1919, copper prices fell once more in 1920, and the low prices then persisted for more than a decade. As a result, by 1920, the Hampden, Mount Elliott, and Duchess mines had closed, after each had produced more than 200 000 t of copper ore (Table 22), and mining activities in the Cloncurry Gold and Mineral Field had almost ceased. Only the Trekelano mine continued to be worked, and it closed in 1922. The Mount Mascotte mine was reopened in 1927, but closed again in 1928. In that year, Trekelano mine was sold to an independent syndicate, and was worked profitably until labour problems forced its closure in 1943.

During the first half of this century the only major non-cupriferous mining operation in the region took place at the Mount Cobalt mine, 50 km south of Kuridala. Here cobalt ore was mined between 1920 and 1934, and hand-picked or milled on the site for shipment. The mine closed because of decreasing ore grades and prolonged drought.

During the last 20 years, intermittent small-scale

Fig. 77. Ruins of the smelter for the Hampden group of copper mines at Kuridala. Photograph taken in 1975. (GB 2906).

operations have taken place at the Hampden, Trekelano, Answer, and Mount Mascotte mines, and open-cut mining has been carried out at the Mount Hope mine (north of Duchess) and the Young Australia mine (southwest of Kuridala). The Mount Hope mine produced over 300 000 tonnes of cupriferous silica flux and about 10 000 tonnes of copper ore between 1967 and 1973, and more than 170 000 tonnes of low-grade (2.2%) copper ore was extracted from the Young Australia mine (Fig. 78) in 1967. Since the closure of these two mines, only intermittent small-scale gouger activity has been recorded in the region, except for the open-cut mining of phosphate ore in Cambrian rocks at Phosphate Hill, south of Duchess, between 1975 and 1978.

Recorded production data for many of the mines in the region (Table 22) have been obtained from Mines Department Annual Reports, Queensland Government Mining Journals, Carter & others (1961), Krosch & Sawers (1974), Brooks (1977), and Noon (1978). Descriptions of the most productive mines are contained in map commentaries (Blake & others, 1982a, 1983a; Bultitude & others, 1982; Bultitude, 1982; Donchak & others, 1983) and in BMR Records (e.g., Bultitude & others, 1978; Mock, 1978).

Ore distribution, controls, and associations

Copper

Copper has been by far the most abundant and economically significant base-metal resource in the region. Copper ore has been won from a great number of widely scattered and mostly small mines which generally extended no deeper than the zone of secondary enrichment.

Some deposits are broadly stratabound, but no syngenetic stratiform types are known. Almost all of the deposits are localised along faults, shear zones, or tension cracks. These sites probably acted as channels for circulating metal-rich solutions moving in response to deformational stresses and/or thermal gradients associated with igneous intrusions. Dolerite intrusions, in particular, are very commonly associated with the ore deposits. The intrusions may have either contributed directly to the metal content of the deposits, or set up convection cells involving metal-concentrating meteoric waters. The highest metal concentrations are generally developed in, or derived from, rocks which probably had high primary base-metal contents. Particularly favourable rock types are carbonaceous black shales (deposited in euxinic environments), calc-silicate rocks, and metabasalt.

Fig. 78. Open cut of the Young Australia copper mine, 5 km southwest of Kuridala (at GR VB383403). The lode was situated in a steeply dipping, north-trending, kaolinised fault zone, and contained malachite, chalcocite, cuprite, tenorite, and hematite (Donchak & others, 1983). Photograph taken in 1980. (M2491/3A)

The mineral deposits at the *Mount Elliott*, *Tip Top*, *Labour Victory*, *Occidental*, and *Mount Dore* mines, and at the *Hampden* group of mines, are in carbonaceous black slate of the Kuridala Formation. The *Answer* and *Young Australia* deposits occur in faulted carbonaceous rocks of the Answer Slate. Black shale or slate units within predominantly calc-silicate sequences are almost invariably mineralised. In the Doherty Formation, for example, copper and minor silver minerals at the *Two Bobs* mine, 13 km north of Kuridala, occur in fracture zones in quartzite adjacent to carbonaceous and sulphide-bearing shales of the 'Bipygo Basin', and copper ore containing minor molybdenum occurs in black shale at the *Mount Arthur* mine, northeast of Kuridala. Minor copper deposits are present in faulted lenses of black shale within the Corella Formation at the *Pelican* leases about 33 km north-northeast of Duchess (near GR UB920690).

Calc-silicate rocks of the Corella Formation are hosts to copper deposits at several mines. For example, in the north, at the *Overlander* group of mines, fault-controlled and possibly stratabound copper deposits occur in calc-silicate rocks adjacent to felsic metavolcanics. The *Duchess* mine, the most productive in the region, is located on a shear zone cutting thin-banded calc-silicate rocks, and metadolerite and granite of the Mount Erle Igneous Complex. Similar amounts of copper and gold ore were recovered from the *Trekelano* mine, to the south, where a shear zone cuts schistose amphibolite and calc-silicate granofels. Smaller copper deposits in the Corella Formation are located in fissure veins along faults, shears, and tension cracks at, for example, the *Revenue* and *Mount Mascotte* mines.

In the eastern area, minor copper deposits are common in the Marraba Volcanics, especially where shear zones cut mafic volcanics. Examples include those at the *Quark*, *Deadlock*, *Hugarty*, and *Just-in-Time* mines. In the north of the central area, at the *Lady Fanny* and *Mount Hope* mines, the copper orebodies are located in fissure veins in faulted amphibolite and felsic and mafic volcanics of the Magna Lynn Metabasalt and Argylla Formation. At the *Saint Mungo* mine, south of Duchess, the copper ore is at faulted contacts of Saint Mungo Granite and amphibolite dykes.

South of Kuridala, ridge-forming banded quartz–hematite bodies within the Mitakoodi Quartzite, Answer Slate, Staveley Formation, and Kuridala Formation, and in screens of country rock within intrusions of metadolerite and Gin Creek Granite (Blake & others, 1983a), have anomalously high copper and gold contents. Some of these bodies, which are thought to be epigenetic (Blake & others, 1983a), have economic potential.

In the western part of the region, minor copper deposits are known in metabasalt of the Eastern Creek Volcanics, in shale and siltstone of the Mount Isa Group, and in some metadolerite intrusions. The main mines here are located near major fault zones.

Gold

The two main mines worked primarily for gold are the *Last Call* and *Top Camp* mines in the north of the eastern area. The *Last Call* mine produced a few hundred grams of gold between 1880 and 1894 from small lenses of black shale and impure limestone in calcareous breccias of the Staveley Formation. *Top Camp* was a more prolific producer during the latter part of the last century, but no production figures are available; here alluvial gold was recovered from valleys cutting through hills of calcareous siltstone, phyllite, and quartzite of the Overhang Jaspilite.

Silver

Silver ore has been produced mainly from O'Briens Soak, a small but very rich fissure vein deposit with calcite gangue in undivided Tewinga Group gneiss west of Bushy Park homestead in the west of the central area, and from the *Silver Phantom* mine in the eastern area, where the ore is present in a pendant of Mitakoodi Quartzite in the Wimberu Granite.

Lead, zinc

Stratiform lead, zinc, and copper deposits are known within the Kuridala Formation and Soldiers Cap Group. At the best known prospect, *Pegmont*, lead, zinc, and subordinate copper are contained in banded iron formation within the Kuridala Formation. Accounts of this deposit have been given by Löcsei (1977), Stanton & Vaughan (1979), Orridge (1980), Stanton (1982), and Taylor & Scott (1982). Almost identical deposits are present in similar banded iron formation within the Soldiers Cap Group at the *Cowie Maramungee*, and *Dingo* prospects (Nisbet & Joyce, 1980), and the *Black Rock* and *Fairmile* prospects. These deposits are considered to be essentially syngenetic. The banded iron formation at all the prospects is possibly at the same stratigraphic level, and may be an exhalative deposit related to contemporaneous volcanism, perhaps associated with mafic and/or felsic volcanics in the Soldiers Cap Group and Kuridala Formation.

TABLE 22. RECORDED PRODUCTION DATA FOR MINES IN THE DUCHESS–URANDANGI REGION

"ppt" refers to production of copper cement from leaching operations

Mine	*Grid reference*	*Ore t*	*Copper t*	*Gold g*	*Silver g*	*1958–80 production*
Answer	VB340035	10826	1023	11090		1967–76, 78, 79
		25.44 (ppt)				1974–76
Ardath	UB786520	58.91	1.49			1979
Bald Hills	UB241234	244.97	27.43			1961, 63–65
Beauty	UB782610	63.91	1.73	224		1969
Belgium	VB432120	359.68	90.12			
Burke and Wills	UB732492	685.02	88.29	367		1968
Chum Victoria	UB735523	74.23	3.84	9		1976–77
Deadlock	VB268746	202.04	34.85			1965, 73
Duchess	UB818374	204865	25155	76141	61833	
Edgarda (Crown)	UB784503	312.45	20.23			1968, 69, 73–79
Empress	UB801347	5.56	0.2			1971
Green Valley	VB375609	65.54	2.34			1969–70
Hampden Group (includes Hampden, Hampden Consols, Hampden Queen)	VB487465	214852	15114	376096	173619	1973–77, 79, 80
		8.4 (ppt)	5.1			1974–76
Hampden West	VB438479	43.7	8			
H.B.	UB904253	257.26	11.07			1968, 69
Horse Creek	VB299326	125.89	40.38			1967, 68
Hugarty	VB228671	143.85	8.69			1969, 70, 72
Just-in-Time	VB244686	604.55	133.20	196		
Labour Victory	VB445281	1367.66	260.79	606		1959–62
Lady Barbara	UB829341	94.59	4.27			1968–70
Lady Fanny (including Lady Fanny North)	UB737493	4673.06	460.93	1676		1966, 67, 69, 70, 73, 74
		3.99 (ppt)	1.23			1974
Lady Maria	UB736458	168.46	10.97	(also limestone flux)		1966–67
Last Call	VB526702	130		445		
Little Bit (includes Big Bit)	UA762868	1654.55	154.83			1961–65, 80
Little Monastry	?UB811036	43.69	2.13			1971
Lotta Coppa	VB517496	192.03 (hand-picked)	11.78			1967
Malbon	VB238683	520.22	110.24	563		
McPhail	VB349585	18.29	3.45	31		
Mount Agate	VB305352	87.90	3.36			1970, 71, 73
Mouth Arthur (Lanham Shaft)	VB600534	11.68	1.12			1964
Mount Birnie	UB872097	13.21	1.63	22		
Mount Cobalt	VA474960	3286.92 (hand-picked ore and concentrates)		(778.69 t cobalt)		
Mount Devoncourt (Kangaroo)	VB358437	432.73	32.51			1966–68
Mount Dore	VB472043	16.26	5.99			
Mount Elliot	VB485178	268201	24862	1054698		
Mount Hope Group (includes Mount Hope; Mount Hope North, South, and West; Greens Creek; Binna Burra; The Stubbie)	UB765582	11962	657.8	109		1959–61, 66–70, 72, 74
		309175 (silica flux)	5874			1967–73
Mount Kalkadoon	VB699541	214.69	40.13			1960, 62–66, 68–69
Mount McCabe	VB467702	4.06	1.22			
Mount Mascotte	UB812574	5154.93	889.55	7037		1967, 68, 70
Myubee	UB728479	25.20	1.02			1970, 71
Nil Desperandum (includes Nil Desperandum Nos. 2 and 3)	UB728461	1790.03	81.48	9		1967, 71, 73, 75
O'Briens Soak	UB546523	8.84			314891	
Occidental	VB446258	13.02	0.49			1969
Overlander (includes Overlander Nos. 1 and 4)	UB862722	913.23	44.91			1966–68, 70
Oxford	UB802306	170.09	17.58			1966, 68
Pindora Group (includes Pindora Nos. 1 to 5)	UB956706	1039.95	77.59	174		1969–74
		1822.12 (silica flux)				1971, 72
Pokara	VB281620	53.55	2.95	16		1967, 68
Quark	VB238765	6.08	0.42			1970
		1998.96 (silica flux)				1977
Rainbow Ridge	VB029465	8.03	0.51			1972
Revenue Group (includes Revenue, Revenue Central, Revenue Extended, Lucky Revenue)	UB790452	4957.99	302.44	311		1964, 67–77
[Lucky Revenue]	[UB791454]	[9.54]			[1240]	[1975]
Saint Mungo	UB809080	6701.87	1561.67			
Silvèr Phantom	VB377427	98.42			435387	1967, 77, 78
Sinking Sun	VB388570	295.69	17.64			1968–73
Southern Cross	VB380758	319.34	56.59	361		1968–70
Squirrel Hill	?	8.74	1.12			1968
Straight Eight	VB528485	439.85	22.56			1966–69
Stuart 186	VA454917	1607.24	84.74			1968–70, 76, 79–80
Sweet William	VB428770	783.61	61.51	202		1968, 71, 75
Tip Top	VB437310	44.71	13.72			
Trekelano	UB859238	187939	20472	423236	338560	1971
True Blue	UA892930	209.92	36.58	31		1966, 69, 71
Trump	VB382563	3.05	1.22			
Two Bobs	VB480597	272.29	22.44	68	5089	1968–70, 72, 74, 76
Vulcan	VB529719	284.49	11.89	19		
Young Australia	VB383403	1182.46	135.66			1959–66
		173151.2	3775.6			1967

Cobalt

The one major cobalt deposit in the region is at *Mount Cobalt* mine, south of Kuridala. The lode here, situated along a shear zone at the contact between a metadolerite sill and metasediments of the Kuridala Formation, also contains minor copper and traces of gold, silver, and tungsten (see below).

Calcite, silica

Substantial amounts of calcite and silica are required as fluxes in smelting operations by Mount Isa Mines Ltd at Mount Isa. Large near-vertical lenses of coarsely crystalline calcite (marble) suitable for flux occur within the Corella Formation north and south of Duchess (Bultitude & others, 1982). The lenses formed as fissure fillings, and are generally oblique to bedding in the surrounding calcareous metasediments. Significant producers include the *Revenue*, *Lady Maria*, *Lucky Chance* (GR UB730480), *Semigem* (GR UB775350), *Atina* (GR UB813610), *Lime King* (GR UB805600), *Big Chance* (GR UB845735), and *Mount Morah* (GR UB846607) mines.

Cupriferous silica flux has been obtained from three deposits in the region. These are at the *Mount Hope* mine, 20 km north of Duchess, where silicified faults cut mafic schist and amphibolite of the Magna Lynn Metabasalt and felsic gneiss and granite of the Bushy Park Gneiss; at the *Pindora* mine, to the northeast, where a silicified shear zone cuts schist and felsic volcanics of the Argylla Formation; and at the *Quark* mine, north of Malbon, where a silicified shear zone cuts metabasalt of the Marraba Volcanics.

Phosphate

Extensive deposits of sedimentary phosphorite (rock phosphate) are present in the Middle Cambrian Beetle Creek Formation at *Phosphate Hill* (Russell & Trueman, 1971), in the Burke River Structural Belt. The ore is mainly pelletal, although some laminae of collophane mudstone are also present. Open-cut mining of the phosphorite began at Phosphate Hill in 1975, but was suspended for economic reasons in mid-1978, by which time more than one million tonnes of marketable phosphate rock had been produced.

Subeconomic phosphate deposits have also been found in the Beetle Creek Formation in the Ardmore Outlier (GR UA2295) in the west (Thomson & Russell, 1971; de Keyser & Cook, 1972).

Notes on selected mines

Duchess mine (Broadhurst, 1953; Carter & others, 1961)

The Duchess orebody was situated on a steep westerly dipping shear zone at the northern end of the north-northeast-trending Juenburra Fault (Bultitude & others, 1982). The country rocks are granite and dolerite of the Mount Erle Igneous Complex, and mica schist and calc-silicate rocks of the Corella Formation. The lode in the upper levels of the mine consisted of bornite and subordinate chalcocite, malachite, and cuprite in a calcite gangue, but at deeper levels chalcopyrite with quartz gangue was dominant. The mine was worked to a depth of 259 m, below which the ore showed an abrupt decrease in grade. The main shaft extended to a depth of 326 m.

Mount Elliott mine (Nye & Rayner, 1940; Sullivan, 1953b; White, 1957; Carter & others, 1961)

The ore at Mount Elliott mine occurred in a shear zone cutting andalusite-bearing graphitic slate of the Kuridala Formation adjacent to a metadolerite sill with dyke-like offshoots to the east. The shear zone trends north-northwest and dips steeply to the east, subparallell to bedding. Four en-echelon orebodies were worked. In the oxidised zone (down to about 75 m) the ore minerals were malachite, cuprite, and subordinate tenorite, azurite, chrysocolla, and native copper, whereas chalcopyrite, magnetite, pyrite, and pyrrhotite occurred in the primary zone. Calcite, diopside, scapolite, gypsum, apatite, sphene, and prehnite were gangue minerals.

Trekelano mine (Shepherd, 1953; Carter & others, 1961)

Trekelano mine is situated about 14 km south of Duchess, where a steep westerly dipping shear zone cuts hornblende–biotite schist, amphibolitic granofels, red and grey banded calc-silicate rocks, and scapolite–pyroxene granofels of the Corella Formation, and aplitic granite of the Mount Erle Igneous Complex. The mine was worked to a depth of 263 m. The ore consisted mainly of chalcopyrite and pyrite/marcasite in calcite gangue, but also contained some chalcocite, malachite, chrysocolla, and tenorite.

Hampden group of mines (Broadhurst, 1936; Sullivan, 1953a; Carter & others, 1961; Brooks, 1977)

The orebodies at the Hampden group of mines occur along a north-trending shear zone, the Hampden Fault, which is up to 60 m wide and cuts slate of the Kuridala Formation and metadolerite forming the elongate structural basin centred on Kuridala. Ore shoots are up to 12 m wide in the oxidised ore, but average less than 1 m wide in the primary zone. The oxidised ore—consisting mainly of malachite, chrysocolla, tenorite, and chalcocite—is reported to extend to a depth of 107 m. The primary ore zone, containing mainly chalcopyrite, marcasite, and pyrite, was worked to a maximum depth of 183 m. Quartz and kaolin are gangue minerals.

Recent small-scale open-cut operations, described by Brooks (1977), have exposed veins of chalcocite, malachite, cuprite, and hematite in kaolinised slate. The main lode is reported to dip 75° to the east, and a secondary ore shoot exposed in the open cut dips about 25° to the east.

Saint Mungo mine (Carter & others, 1961)

The Saint Mungo orebody was situated in a narrow fissure vein at the contact between the Saint Mungo Granite and an amphibolite dyke. The main ore shoots, as described by Carter & others (1961), occurred at the intersections of horizontal and vertical faults or fracture planes. In the lower workings, one ore shoot was at right-angles to the northerly trend of the main deposit. The mine was worked to a depth of 116 m, but the main shaft extended to a depth of 137 m. The main ore mineral appears to have been chalcopyrite.

Mount Mascotte mine (Carter & others, 1961)

The copper deposit at the Mount Mascotte mine, 20 km north of Duchess, was a narrow fissure vein in a north-northeast-trending fault cutting fine-grained quartz–biotite schist and amphibolite of the Corella Formation. The oxidised ore consisted of malachite, chalcocite, and minor cuprite in a gangue of quartz and calcite. Primary sulphides included bornite and chalcopyrite. Ore shoots of massive sulphide 30 cm to 1 m thick were reported.

Answer mine (White, 1957; Carter & others, 1961; Brooks, 1977, 1979b)

The Answer lode is situated along a shear zone parallel to bedding in black and grey carbonaceous slate and minor phyllite of the Answer Slate. Almost all the ore mined came from the oxidised zone, above the 30.5-m level, and consisted mainly of chalcocite, bornite, chalcopyrite, and pyrite in a quartz gangue. The highly pyritic primary sulphide lode was exposed at the 61-m level. Profitable small-scale copper leaching has been practised since 1974, using scrap iron (to fix the copper) and the highly acidic mine water.

Mount Cobalt mine (Reid, 1921; Rayner, 1938, 1953; Honman, 1941; Brooks, 1960, 1979a; Carter & others, 1961; Croxford, 1974; Nisbet & others, 1983).

The Mount Cobalt lode occurs in a shear zone at the contact between a metadolerite sill and steeply dipping schist, metagreywacke, and meta-arenite of the Kuridala Formation. The lode is up to 9 m wide, and has been worked over a length of 220 m and to a depth of 34 m. The cobalt ore consists of hypogene cobaltite and supergene erythrite and black oxide, together with minor galena, pyrite, chalcopyrite, sphalerite, and traces of gold, silver, and scheelite. The gangue minerals include quartz, calcite, magnetite, siderite, and biotite. Small amounts of copper ore consisting of chalcopyrite, pyrite, and supergene chalcocite, covellite, cuprite, malachite, azurite, and chrysocolla were also produced. Indicated reserves from diamond and percussion drilling are 60 000 t of 1.25 percent Co (Nisbet & others, 1983).

Mineral potential

Perhaps the most obvious exploration targets in the region are shales and slates, many of which—especially those that are carbonaceous and pyritic—were probably deposited in euxinic basins and hence originally may have been anomalously rich in base-metals, precious metals, uranium, and sulphur.

One of the most productive cupriferous areas in the region in the past has been the Corella Formation north and south of Duchess. This predominantly calc-silicate sequence has been intruded by numerous granite and dolerite bodies which may have contributed copper by hydrothermal processes or may have promoted convective movement of copper-scavenging sodium and chloride-rich solutions. Numerous faults provide good structural traps for mineral-bearing solutions, and many contain cupriferous vein calcite and silica. The Corella Formation can therefore be considered prospective for both small-scale epigenetic medium to high-grade and large-scale low-grade copper deposits, and also for calcite and silica flux. Favourable sites for possible syngenetic sulphide accumulation within the Corella Formation may be located near interlayered felsic metavolcanics, such as those recorded near the Overlander group of mines (Bultitude & others, 1982).

In the east, similar calc-silicate rocks intruded by dolerite and granite occur in the Doherty Formation. However, three criteria imply that the mineral potential of this formation is less significant: (1) the unit has a poor record as an ore producer; (2) few interlayered volcanic rocks have been found within it; and (3) much of the granite intruding it postdates the main deformation and regional metamorphism. Nevertheless, the formation does host low-grade copper–molybdenum deposits in black shales interbedded with calc-silicate rocks north and south of Mount Arthur, and can still be considered prospective, as exploration has been discouraged by the rugged terrain.

Other areas of economic interest in the east include the northern part of the Staveley Formation, where halite casts indicate a shallow-water evaporitic depositional environment in which intrastratal brines may have been active in concentrating and depositing copper minerals during sedimentation and diagenesis; black slate of the Marimo Slate, in which traces of copper minerals have been found in shear zones; and metabasalt of the Marraba Volcanics, which remain prospective for small-scale copper deposits, particularly where cut by cross-faults.

Within the Kuridala Formation and Soldiers Cap Group, several low-grade lead–zinc–copper deposits are associated with stratiform syngenetic banded iron formation, the best-known prospect being *Pegmont* (mainly lead–zinc). Prospecting for similar bodies has been undertaken in recent years throughout most of the Soldiers Cap Group and Kuridala Formation outcrop areas, and it is considered unlikely that more prospects will be located in areas of reasonable outcrop. However, some potential still exists in the far south and east, where the sequences are either intensely weathered and leached or are concealed beneath superficial sediments.

Similar prospecting targets occur in a north-trending zone west of Selwyn, where some essentially concordant ridge-forming quartz–hematite bodies (Fig. 79), mainly in the Kuridala Formation, are anomalously rich in copper and gold (Blake & others, 1983a); Donchak & others, 1983). These iron-rich bodies appear to be epigenetic, perhaps formed by hydrothermal replacement of readily altered grains and matrix during the intrusion of nearby granite. Many of them have been evaluated during recent exploration, but there is still scope for further exploration.

Granites, quartzofeldspathic gneisses, and felsic volcanic units within the region generally show little evidence of mineralisation, and are considered prospective for base-metals only where they are cut by mafic dykes. The uranium-rich granites of the region, however, especially those of the Sybella and Wonga Batholiths, which have been regionally metamorphosed, and adjacent country rocks, are potential hosts for economic uranium deposits (see section GEOCHEMISTRY OF IGNEOUS ROCKS).

The outcrop areas of Mount Isa Group sedimentary rocks in the west of the region have considerable potential for Mount Isa-type copper deposits, and also some potential for Mount Isa-type lead–zinc deposits, although no equivalents of the Urquhart Shale, the host rock at Mount Isa mine, appear to be present.

Classification of mineral deposits and metallogenesis
by **D. J. Perkin**

Two main types of metalliferous mineral deposits can be recognised in the Duchess–Urandangi region. One of these is the Duchess-type copper–gold (± cobalt, tungsten, molybdenum, uranium, silver) *stratabound deposit* into which most of the known economic deposits fall. The other is the Pegmont-type lead–zinc–silver *stratiform deposit* (Mount Isa shale-hosted style). However, tectonic, metamorphic, and metasomatic overprinting has caused the original characteristics of the deposits to be blurred, and has led to a great diversity in the present form of these two main types.

Fig. 79. Concordant quartz–hematite body within the Kuridala Formation forming a wall more than 2 m high on a ridge crest 15 km southwest of Kuridala (at GR VB405332). (GB 2326)

Characteristics of Duchess-type stratabound deposits

- — disseminated ore minerals within a distinctive lithologic unit, commonly concentrated where there is enhanced shearing, faulting, and metasomatism
- — diagenetic through to late metamorphic mineralisation
- — generally high gold contents and appreciable amounts of cobalt, tungsten, molybdenum, silver, or uranium
- — associated iron oxide facies rocks uncommon
- — some evidence of hypersaline sedimentary environment: e.g., high potassium and/or sodium contents, presence of scapolite and/or barite, presence of pseudomorphs after evaporite minerals.

Characteristics of Pegmont-type stratiform deposits

- — banded to massive sulphides of lead, zinc, and iron in thinly bedded metasediments
- — syngenetic mineralisation
- — generally minor copper and only traces of gold
- — sulphides invariably associated with bedded iron oxide facies rocks which in the unoxidised zone comprise mainly magnetite
- — evidence in host rocks of hypersaline and/or alkaline depositional environment

Discussion

The Duchess-type stratabound deposits are considered to have resulted from the leaching of copper from mafic igneous rocks into sulphur-bearing black shale, dolomite, calc-silicate rock, or arenite at some stage between early diagenesis and the end of regional metamorphism. Basaltic volcanics were probably the ultimate source for most of the copper and other metals, although doleritic dykes, sills, and other intrusions may have contributed copper to some of the deposits, such as those of the Hampden group at Kuridala, through hydrothermal leaching; however, metamorphic convergence (Walker & others, 1960) obscures the identity of the protoliths of many amphibolite bodies close to the mineral deposits. Favourable zones for copper ore deposition are where reactive rocks such as carbonates are located near permeable zones connected with nearby mafic rocks; the permeable zones may be faults, breccia zones, or conglomerate bands. Most copper is thought to have been originally deposited during late diagenesis in a sabkha or rift–shelf (shallow-lacustrine) environment in an intracratonic tectonic setting. However, much of the copper was remobilised and concentrated during subsequent tectonism and metamorphism.

The Pegmont-type stratiform deposits, like the Mount Isa lead–zinc ores, were probably originally shale-hosted and are of exhalative origin. Subsequent metamorphism and metasomatism has effectively masked the original textures and mineralogy of the host sedimentary rocks. The source of the metals is envisaged as lead–zinc-rich brines or exhalites derived from hydrothermally leached felsic volcanics, rather than mafic volcanics. The chemical precipitation may have taken place in a fault-controlled local basin or rift.

The Duchess-type deposits bear some resemblance to portions of the Bushmanland copper deposits of the Okiep district in northwest Cape Province, South Africa, described by Lombaard & Schreuder (1978). Both the Duchess-type and Okiep-type deposits may be regarded as examples of metamorphosed, metasomatised, and remobilised Zambian-type copper deposits. The Pegmont-type deposits, on the other hand, are similar to the Broken Hill lode in New South Wales, and also to the Broken Hill lead–zinc–copper deposit at Aggeneys, 120 km north of Okiep (Ryan, 1982), to the nearby zinc deposit at Gamsberg, South Africa (Rozendaal, 1978), and to the lead-zinc deposits of Ducktown, Tennessee (Nesbitt, 1982); I consider that these deposits are metamorphosed and metasomatised equivalents of shale-hosted stratiform lead-zinc (± copper) deposits.

SUMMARY OF GEOLOGICAL HISTORY

In accord with the correlation scheme favoured for the Duchess–Urandangi region, the geological history outlined below generally follows the interpretation of Blake (1980, 1981b, 1982), rather than that proposed by Carter & others (1961) and Derrick and his coworkers (e.g., Plumb & Derrick, 1975; Plumb & others, 1980, 1981; Derrick, 1980; Derrick & Wilson, 1981b), for the evolution of the Mount Isa Inlier. The geochronological framework is based on U–Pb zircon and Rb–Sr dating by Page (1978, 1980, 1981a, 1981b, 1983a,b; Page & others, 1982). The main periods of sedimentation, volcanism, igneous intrusion, regional metamorphism, and deformation are shown in Figure 64. The tectonic setting throughout the Proterozoic is considered to be intracratonic or ensialic (Wyborn & Blake, 1982).

Pre-1900 m.y.?

Volcanism. Thick sequences of felsic volcanics, predominantly pyroclastic flows (ignimbrites) but including some lavas, and minor basaltic lavas were extruded over much of the region. These volcanics, together with associated volcaniclastic and other sediments, are represented by the older basement rock units—probably the Sulieman Gneiss and Saint Ronans Metamorphics of the western area, the Plum Mountain Gneiss, much of the undivided Tewinga Group, and probably part of the Corella Formation of the central area, and possibly the Double Crossing Metamorphics of the eastern area. The abundance of ignimbritic deposits in the undivided Tewinga Group indicates that much of the volcanism was subaerial.

Sedimentation. Fluvial and shallow-marine sediments of mainly volcaniclastic quartzofeldspathic types but including some quartz-rich sands, such as those of the Kallala Quartzite in the southwest, were deposited during the period of volcanism. The calcareous and evaporitic sediments of the Corella Formation in the Duchess Belt of the central area may be of similar age.

Intrusive activity. The emplacement of felsic and mafic dykes, and perhaps some granite comagmatic with the volcanics, accompanied the volcanism.

Palaeogeography. During the igneous activity most of the region was probably a land area, but marine conditions may have prevailed locally, especially in the Duchess Belt of the central area.

Remarks. Some of the older basement rock units may be Early Proterozoic—similar in age to the Yaringa Metamorphics (west of Mount Isa), which are probably between about 2000 and 2100 m.y. old (Page & others, 1982). Others, including parts of the Sulieman Gneiss, undivided Tewinga Group, and Plum Mountain Gneiss, may be similar in age to lithologically similar upper Archaean rocks of the Gawler Craton, South Australia (e.g., Parker, 1980).

About 1900 m.y.?

Tectonism. During a major tectonic event some time before 1880 m.y., perhaps at about 1900 m.y., the older basement was tightly folded and regionally metamorphosed to amphibolite facies gneissic, schistose, and granulitic rocks.

Intrusive activity. Some granitic intrusions, such as the One Tree Granite of the Kalkadoon Batholith, may have been emplaced during or shortly after the folding and metamorphism.

Palaeogeography. During the tectonism the region was uplifted to form part of a mountainous land area that may have extended well beyond the present confines of the Mount Isa Inlier.

About 1880–1810 m.y.

Volcanism. Extensive felsic and minor mafic volcanic activity, represented by the Leichhardt Volcanics, took place in the central area. The abundance of ignimbritic deposits and paucity of associated volcaniclastic and other sedimentary rocks indicate subaerial eruptions. The volcanism probably commenced about 1875 m.y. ago or a little earlier, and may have lasted for 10 m.y. or more. The volcanism represented by the Saint Ronans Metamorphics of the western area is possibly of a similar age.

Intrusive activity. Granites of the Kalkadoon Batholith, comagmatic with the felsic volcanics, were emplaced in the central area before, during, and after the Leichhardt volcanism. Some mafic dykes were emplaced at about the same time, and these formed small net-veined complexes where they intersected partly molten granite. Younger mafic dykes, formed of non-magnetic dolerite, intruded the Kalkadoon–Leichhardt Block after 1850 m.y. but before 1780 m.y.

Deformation and metamorphism. Minor contact metamorphism and local folding and faulting accompanied granite emplacement and volcanism. However, there does not appear to have been a major deformational and regional metamorphic event at this time (Blake, 1981b). From about 1850 m.y., when felsic igneous activity probably ceased, to about 1810 m.y. the region seems to have been tectonically stable.

Palaeogeography. Throughout the period the region probably remained a land area subjected to erosional processes. By 1810 m.y. parts of the Kalkadoon Batholith had been unroofed and large areas of metamorphosed basement rocks were exposed.

About 1810–1750 m.y.

The older cover sequences were laid down during this period.

Sedimentation. At about 1810 m.y., subsidence in the Dajarra Belt of the central area and probably in the western area resulted in sedimentation commencing in a linear depression corresponding to the Leichhardt River Fault Trough (Zone) of Glikson & others (1976), Plumb & others (1980, 1981), and Derrick (1982). The first sediments laid down, those of the Bottletree Formation and the Yappo Member of the Mount Guide Quartzite, were immature fluvial and shallow-marine deposits derived from contemporaneous volcanics and from older rocks mainly to the east. They were succeeded by the more mature, probably shallow-marine sediments of the upper part of the Mount Guide Quartzite. Shallow-water sedimentation continued in the depression during the accumulation of the Eastern Creek Volcanics, Jayah Creek Metabasalt, Oroopo Metabasalt, and Judenan beds. To the east, penecontemporaneous fluvial sediments present within the Magna Lynn Metabasalt and Argylla Formation were laid down on the Kalkadoon–Leichhardt Block of the central area, which was part of an extensive landmass at this time. Subsequent subsidence farther east—after the deposition of the Haslingden Group to the west—resulted in thick accumulations of mainly shallow-water clastic and other sediments in the eastern area—those of the upper part of the Argylla Formation, and the Marraba Volcanics, Mitakoodi Quartzite, Overhang Jaspilite, Answer Slate, Kuridala Formation, and Soldiers Cap Group. During this subsidence the Kalkadoon–Leichhardt Block also became a depositional area, accumulating shallow-marine clastic and carbonate sediments represented by the Ballara Quartzite, Corella Formation?, and possibly the Stanbroke Sandstone, Makbat Sandstone, and part or all of the Surprise Creek Formation?; these were laid down conformably to locally unconformably on volcanics of the Argylla Formation and unconformably on older rocks.

Volcanism. Mafic and felsic volcanism, some of which may have been subaqueous, accompanied the earliest sedimentation in the Dajarra Belt—that of the Bottletree Formation. After a period of quiescence, mafic volcanism recommenced in the west with voluminous outpourings of basaltic lavas—those of the Eastern Creek Volcanics, which were laid down conformably on sands (Mount Guide Quartzite) in the central part of the depression and overlapped eastwards onto basement rocks. Basaltic lavas of probably similar age, those of the Jayah Creek Metabasalt and Oroopo Metabasalt in the southwest, were laid down unconformably on basement rocks. At this time, on the Kalkadoon–Leichhardt Block to the east, the basaltic lavas of the Magna Lynn Metabasalt were erupted, and were accompanied and succeeded by the eruption of the mainly felsic volcanics, especially pyroclastic flows, of the Argylla Formation. North of the Duchess–Urandangi region some Argylla-type felsic volcanism continued on the Kalkadoon–Leichhardt Block into Ballara Quartzite time (Blake, 1981b).

In the eastern area an early phase of felsic volcanism, represented by the Argylla Formation, was followed by eruption of the basaltic lavas of the Marraba Volcanics. Abundant interlayered sedimentary rocks indicate that both the felsic and mafic volcanism here may have been largely subaqueous. Similar felsic and mafic volcanism persisted on a smaller scale during the deposition of the overlying Mitakoodi Quartzite. Farther east, contemporaneous or younger basaltic and rhyolitic lavas and pyroclastics were erupted, probably under water, during the deposition of the Kuridala Formation and Soldiers Cap Group sediments. These two units include exhalative-type banded iron formation formed by chemical sedimentation during one or more of the volcanic episodes.

Intrusive activity. Many mafic and some felsic dykes were emplaced during this period, and some probably vented to the surface, forming feeders for extrusive flows.

Palaeogeography. The depression in the west was probably bounded initially by a large hilly or mountainous landmass to the east—the main source of at least the early detritus—and a lower land area to the west. Subsidence in the depression more or less kept pace with sedimentation, the depositional area was gradually enlarged, especially to the west, and the land areas were eroded down to form broad plains with some residual hills. Volcanic eruptions on the land areas—especially on the Kalkadoon–Leichhardt Block, which was part of the eastern landmass—resulted in extensive sheets of basaltic lavas and felsic pyroclastic flows filling topographic depressions, rather than the formation of prominent volcanic edifices. A relative rise in sea level and regional subsidence in the east towards the end of Argylla Formation time caused much of the region to become a mainly shallow depositional area—perhaps part of a broad shelf. By about 1750 m.y., sediments derived from land areas nearby had reached thicknesses of at least 10 000 m in parts of the western and eastern subsidence areas.

Remarks. In this interpretation the Magna Lynn Metabasalt and Argylla Formation postdate the Mount Guide Quartzite; that is, they are not part of the basement underlying the Haslingden Group, as proposed by Derrick and his co-workers (e.g., Derrick & Wilson, 1981b); also, the basaltic lavas of the Eastern Creek Volcanics are regarded as similar in age to those of the Magna Lynn Metabasalt and older than those of the Marraba Volcanics.

About 1750–1700 m.y.

Sedimentation. No sediments of this age are preserved in the western and central areas. In the eastern area, shallow to moderately deep-water sedimentation (Doherty Formation and perhaps the upper parts of the Overhang Jaspilite, Answer Slate, Kuridala Formation, and Soldiers Cap Group) may have continued without major interruption until at least 1720 m.y.

Volcanism. In the eastern area, minor mafic and felsic volcanism accompanied the deposition of the predominantly sedimentary Kuridala Formation, Soldiers Cap Group, and Doherty Formation. Rhyolite lavas in the Doherty Formation were erupted 1720 ± 7 m.y. ago (Page, 1983a).

Intrusive activity. Isotopic dating of granites north of the region (Page, 1980, 1983b) indicates that most of the Wonga Batholith plutons in the eastern part of the central area were probably emplaced between 1740 and 1720 m.y. ago. The mafic component of the Mount Erle Igneous Complex and Myubee Igneous Complex was emplaced either at this time or sometime later. Some mafic and felsic dykes, comagmatic with contemporaneous volcanics, probably intruded the eastern area.

Tectonism. Granite emplacement in the central area was probably accompanied by local folding and faulting, as well as by contact metamorphism, but no tight folding and regional metamorphism of region-wide extent are thought to have taken place during this period (Blake, 1981b).

Palaeogeography. The eastern area was part of a depositional basin for all or most of the period. The remainder of the region—except perhaps the eastern part of the central area, the loci for granite plutons and a likely zone of uplift—may also have been below sea level for much of the time.

About 1700–1650 m.y.

Volcanism and sedimentation. Minor felsic volcanism (Carters Bore Rhyolite) followed by deposition of shallow-water sediments (Mount Isa Group, McNamara Group, and possibly part or all of the Surprise Creek Formation?) took place in the western part of the region between about 1680 and 1670 m.y. ago (Page 1978, 1981b, 1983a). The sediments of the Staveley Formation, Agate Downs Siltstone, Marimo Slate, and Roxmere Quartzite? in the eastern area may have been deposited at this time or during a later period.

Intrusive activity. Most of the granitic plutons making up the Sybella Batholith, and some spatially associated mafic dykes, were probably emplaced about 1670 m.y. ago (Page, 1981a), presumably shortly after the deposition of the Mount Isa Group. The Garden Creek Porphyry intrusion in the western part of the central area may be of a similar age.

Tectonism. A widespread deformational event causing tight to isoclinal folding and regional metamorphism to the greenschist and amphibolite facies may have taken place during this period, more or less coincident with the emplacement of the Sybella Batholith. However, the main folding and metamorphic event evident in the region is thought to have taken place between about 1610 and 1550 m.y.

Palaeogeography. Between 1700 m.y. and about 1680 m.y. the western part of the region was probably emergent, and rocks overlying the Eastern Creek Volcanics and Judenan beds and their correlatives had been removed by erosion by the time the Carters Bore Rhyolite was erupted. Between about 1680 and 1670 m.y. a depositional basin developed once again in the west while the remainder of the region may have been a low-lying land area. With the onset of granite emplacement, region-wide uplift took place; the greatest amount of uplift was possibly in the west.

About 1650–1350 m.y.

Sedimentation and volcanism. The shallow-water sediments of the Staveley Belt—Staveley Formation, Agate Downs Siltstone, Marimo Slate, and Roxmere Quartzite?—may have been deposited between about 1650 and 1600 m.y. ago. Minor basaltic volcanism accompanied the deposition of the Staveley Formation.

Plutonism and tectonism. Some time after the deposition of the Staveley Belt sediments, between about 1610 and 1550 m.y. ago, major metamorphic and deformational events affected the entire region. During these events the Staveley Belt sediments and older rocks were tightly folded about mainly northerly trending axes and regionally metamorphosed to the greenschist and amphibolite facies, and some possible nappe structures were formed; units folded before 1880 m.y. were refolded. The foliated granites of the Williams Batholith, and sills and other intrusions of dolerite in the eastern area, including those near Kuridala, may have been emplaced at about this time. The tectonism was closely followed by the intrusion of the main plutons of the Williams Batholith in the eastern area and perhaps by the formation of the Mount Philp Breccia bodies in the east of the central area. The granite emplacement may have been accompanied and/or followed by mild low-grade regional metamorphism, which resulted in a redistribution of rubidium and strontium isotopes (see Page, 1978) and relatively young (1450–1350 m.y. old) K–Ar biotite ages (Richards & others, 1963).

Palaeogeography. Between about 1650 and 1600 m.y. part of the eastern area may have been submerged, forming a depositional basin. Subsequent major deformation and granite emplacement resulted in widespread uplift, and a period of erosion commenced which probably continued to the end of the Precambrian.

Remarks. Many of the ore deposits in the region may have formed during the tectonism of this period, when metals present in trace amounts in the rocks were mobilised, concentrated, and deposited in favourable sites.

About 1350–1100 m.y.

Sedimentation and volcanism. None have been recorded.

Intrusive activity. A series of dolerite dykes cutting across regional trends was emplaced between about 1200 and 1100 m.y. ago.

Palaeogeography. The region probably remained a land area throughout the period, and was gradually worn down to a peneplain.

About 1100 m.y. to present

Sedimentation and palaeogeography. After prolonged erosion, tillite was deposited near Duchess during one of the glacial epochs which affected northern Australia in the Late Proterozoic. Shallow-marine sedimentation recommenced early in the Cambrian and continued, with several breaks marked by disconformities, into the Ordovician. The Cambrian and Ordovician sediments, which included calcareous and phosphatic types, may have blanketed the entire region, but are now largely confined to the Burke River Structural Belt in the centre of the region and to the main part of the Georgina Basin in the far west. After relative uplift and resulting erosion, during which much of the lower Palaeozoic sedimentary blanket was removed, the region was partly or entirely covered by fluvial and shallow-marine sediments of the Jurassic to Cretaceous Eromanga and Carpentaria Basins. Since the Mesozoic the region has been part of a continental landmass. Planation and lateritisation of this landmass took place during the Tertiary. The present, largely dissected landscape can be attributed to late Tertiary and Quaternary changes in climate and relative sea level.

Tectonism. Some faulting took place during the Palaeozoic, mainly along reactivated Precambrian structures, and in places within the Pilgrim Fault Zone the Cambrian strata were steeply tilted. In general, though, the Cambrian and younger strata are flat-lying, indicating that the region has remained essentially stable tectonically throughout the Phanerozoic.

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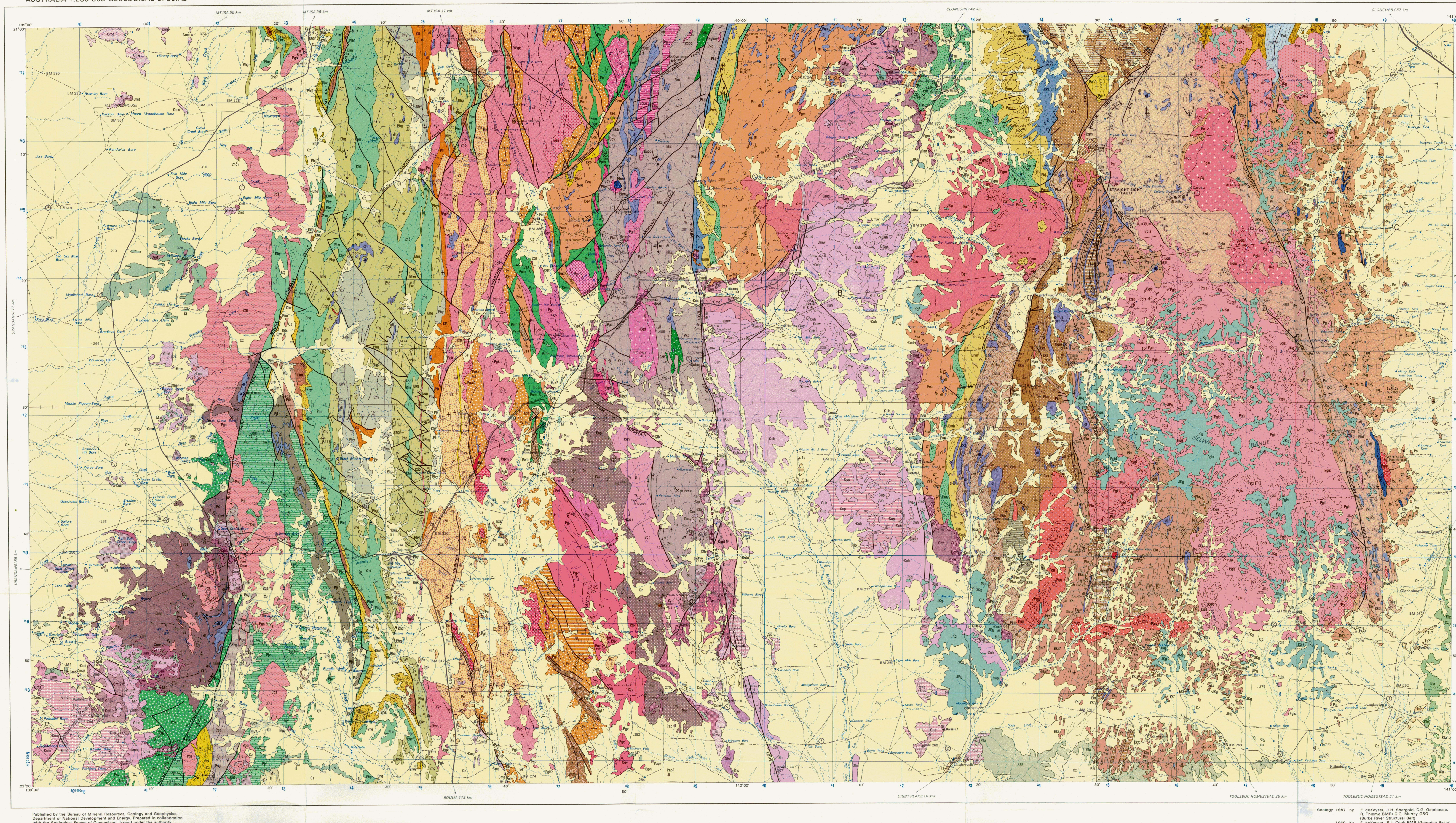
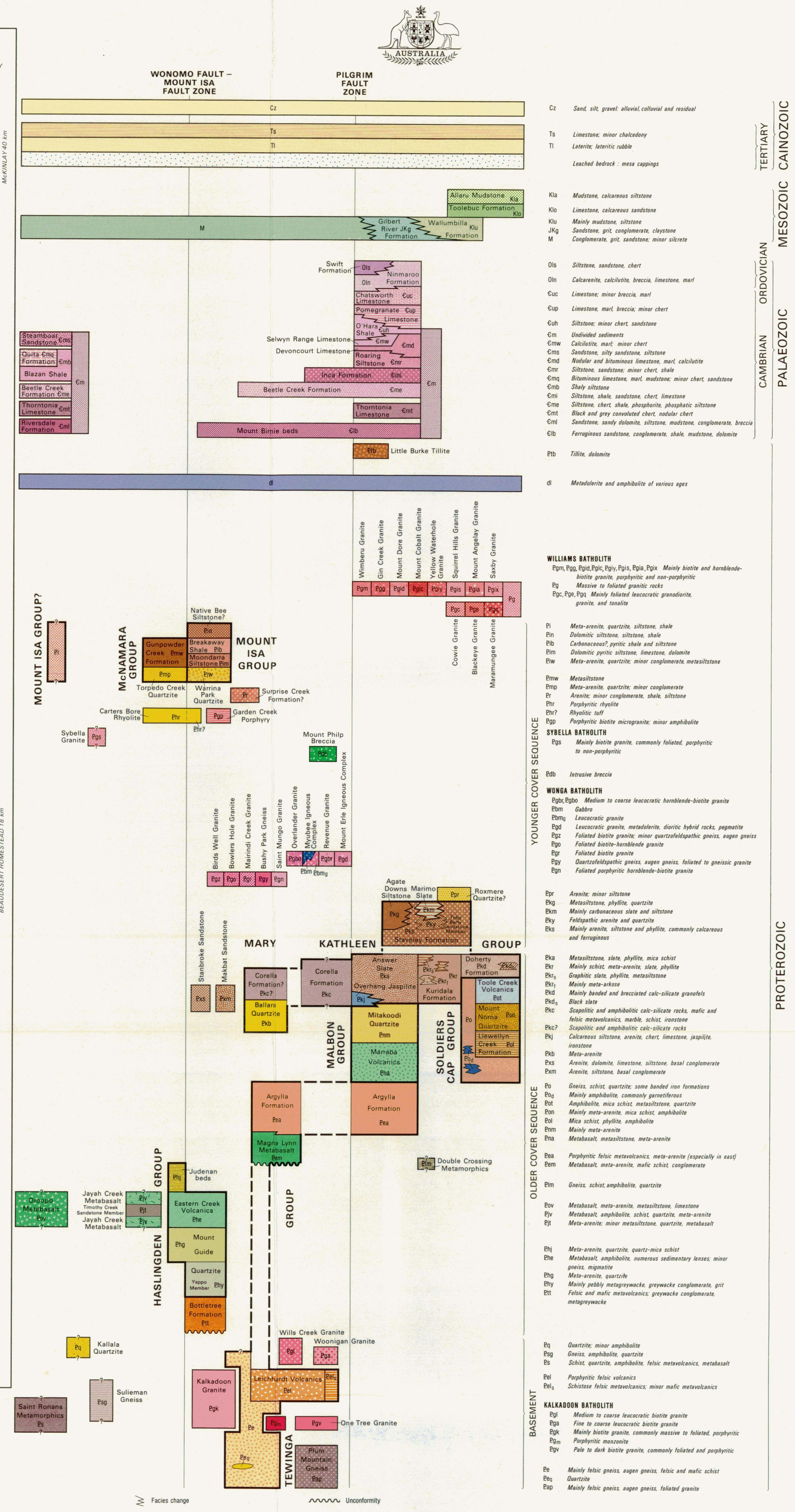
AUSTRALIA 1:250 000 GEOLOGICAL SPECIAL

GEOLOGY OF THE DUCHESS-URANDANGI REGION

QUEENSLAND





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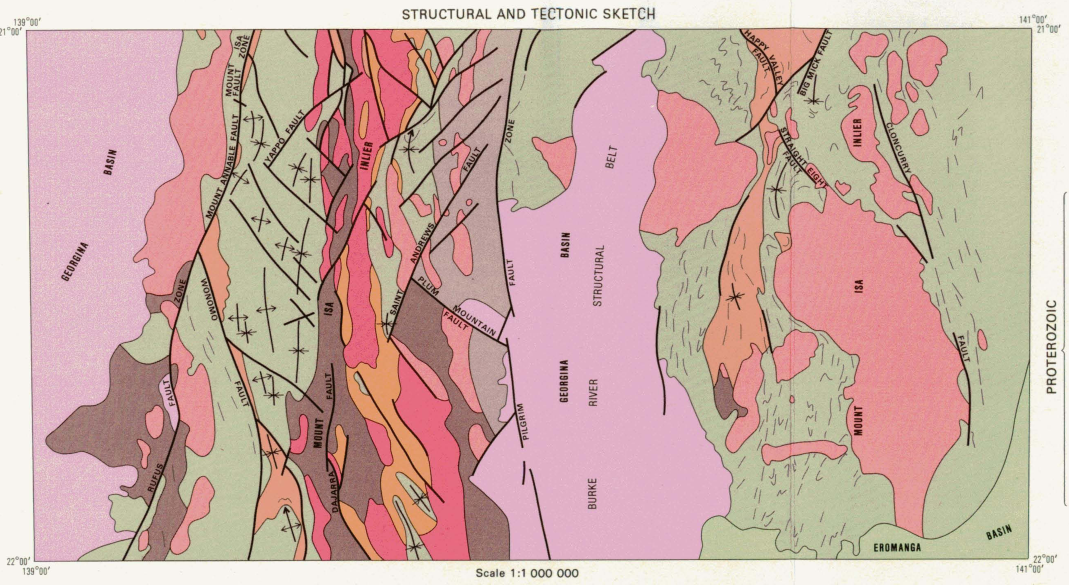

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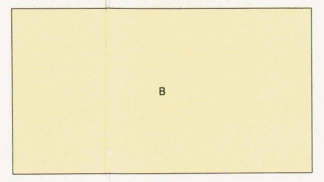
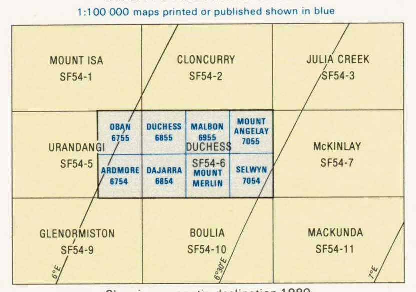
TRANSVERSE MERCATOR PROJECTION

RELIABILITY DIAGRAM



Geology B Detailed reconnaissance and airphoto interpretation

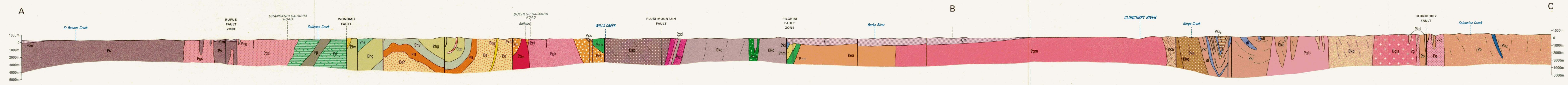
INDEX TO ADJOINING SHEETS



Showing magnetic declination 1980

SCHEMATIC SECTION

Mesozoic and Cainozoic sediments omitted



GEOLOGY OF THE DUCHESS-URANDANGI REGION

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