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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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Geology of the Drummond Basin Queensland

BY

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SUMMARY

The Upper Devonian to Lower Carboniferous Drummond Basin sequence crops out over an area of approximately 25 000 km^2, mainly west but also east of the Anakie Inlier in east-central Queensland. The Drummond Basin is a structural remnant of a large intermontane depositional basin that developed in the Tasman Geosynclinal zone after the Tabberabberan Orogeny. It received up to 12 000 m of predominantly fluviatile sediments which were transported into the basin by a northerly flowing river system. There may have been some marine incursions. Basement to the basin consists of early Palaeozoic slightly metamorphosed sediments and granite. Sedimentation in the Drummond Basin ceased at the onset of the Kanimblan orogenic event, during which the sequence was folded and uplifted to form a structural high shedding detrital material into the Bowen and Galilee Basins.

INTRODUCTION

The Upper Devonian to Lower Carboniferous Drummond Basin sequence crops out over an area of about 25 000 km^2 in east-central Queensland, including the central highlands and surrounding tablelands, plains, and lowlands.

The southern part of the basin was mapped by combined parties of the Bureau of Mineral Resources and Geological Survey of Queensland in 1960-63, as part of the regional mapping of the Bowen Basin; in 1966-67 the northern part of the basin was mapped and the southern region re-examined.

The largest town in the area is Clermont, with a population of about 2 000. Alpha, Blair Athol, Anakie, Bogantungan, Sapphire, and Rubyvale are the only other settlements. The central railway, from Rockhampton on the coast to Longreach in central Queensland, passes through the southern part of the area and there is a branch line from Emerald to Clermont and Blair Athol. Clermont has a regular air service. The area is served by a network of unsealed main and subsidiary roads. The Gregory Developmental Road connects Clermont with Charters Towers to the north and Emerald to the east. The central highway follows the central railway, and other main roads connect Alpha and Clermont and extend eastward from Clermont to Sarina on the coast, and from the Gregory Developmental Road south of Mount Douglas homestead to Collinsville via Mount Coolon. Numerous station tracks provide good access throughout the region. Most of the roads and tracks are impassable after heavy rain.

Complete photographic cover at 1:50 000 and 1:85 000 scales is available. Planimetric maps at 1 inch to 4 miles published by the Army, and at 1:250 000 published by the Division of National Mapping, and cadastral maps at scales of 1 inch to 2 miles and 1 inch to 4 miles, published by the Department of Lands, Brisbane, are also available for the entire area.

The climate is subtropical to tropical, subhumid to semi-arid, with an annual rainfall decreasing from about 680 mm in the east to about 500 mm in the west. The rainfall is highly variable, particularly in the west. About three-quarters of the rain falls between November and April; February is the wettest month, with an average of at least 90 mm at most stations. The driest months are August and September. Mean maximum temperatures range from approximately 21°C in July to 35°C in January, and the mean minimum temperatures range from about 7°C in July to about 21°C in January. Frosts occur in winter, especially in the south. The mean annual evaporation is about 1·8 m.

Eucalypts dominate the open woodland that covers most of the area. Dense scrub is common in the eastern part of the Buchanan Sheet area and the northern parts of the Galilee and Clermont Sheet areas, and grassland is widespread east and northeast of Clermont on the Peak Downs. Pedley (*in* CSIRO, 1967) gives a detailed description of the vegetation of the whole region.

Beef-cattle raising is by far the most important industry; a few sheep are run. Large areas of scrub have been cleared in recent years for pasture improvement, and cultivation for grain crops, mainly sorghum, wheat, and oats is becoming increasingly important on the basalt country in the Clermont district. Coal is the only mineral being mined commercially. About 76 000 tons per year are taken from an open cut at Blair Athol, mainly for the railways.

Previous Investigations

The earliest geological reports cover isolated parts of the Drummond Basin. The first regional survey was carried out by Shell (Qld) Development Pty Ltd (1952) in the Springsure region. Since 1960 combined Bureau of Mineral Resources and Geological Survey of Queensland parties have mapped the whole of central Queensland (Exon, Galloway, Casey, & Kirkegaard, 1970; Malone, Corbett, & Jensen, 1964; Malone, Jensen, & Gregory, 1966; Mollan, 1967; Mollan, Dickins, Exon, & Kirkegaard, 1969; Olgers, Doutch, & Eftekharnezhad, 1967; Olgers, 1969a, b, 1970; Veevers, Randal, Mollan, & Paten, 1964a; Veevers, Mollan, Olgers, & Kirkegaard, 1964b; Vine, Jauncey, Casey, & Galloway, 1965; Wyatt, Paine, Clarke, & Harding, 1970; Wyatt, Paine, Clarke, Gregory, & Harding, 1971). A complete evaluation of the basin was made by de Bretizel (1966).

A BMR helicopter gravity survey (Gibb, 1966) covers the whole basin, and an aeromagnetic survey conducted by Adastra Hunting Geophysics Pty Ltd (Adastra, 1962) covers the northern part (Fig. 1). Seismic surveys have been made only farther west, where the Galilee and Eromanga Basin sequences crop out (Fig. 1).

No petroleum exploration wells have been sited in the Drummond Basin outcrop belt, but of the many wells to the west and south, Jericho 1, Warrang 1, Penjobe 1, Purbrook 1, and possibly Lake Galilee 1 penetrated the Drummond Basin sequence at depth (Fig. 5). Shows of gas were encountered in the Lake Galilee 1 well and a drill stem test of the interval from 8 679 to 8 752 feet (2 645·3-2 667·6 m) recovered 3 m of 43° gravity oil with a small flow of petroliferous gas from the Upper Carboniferous or Lower Permian rocks.

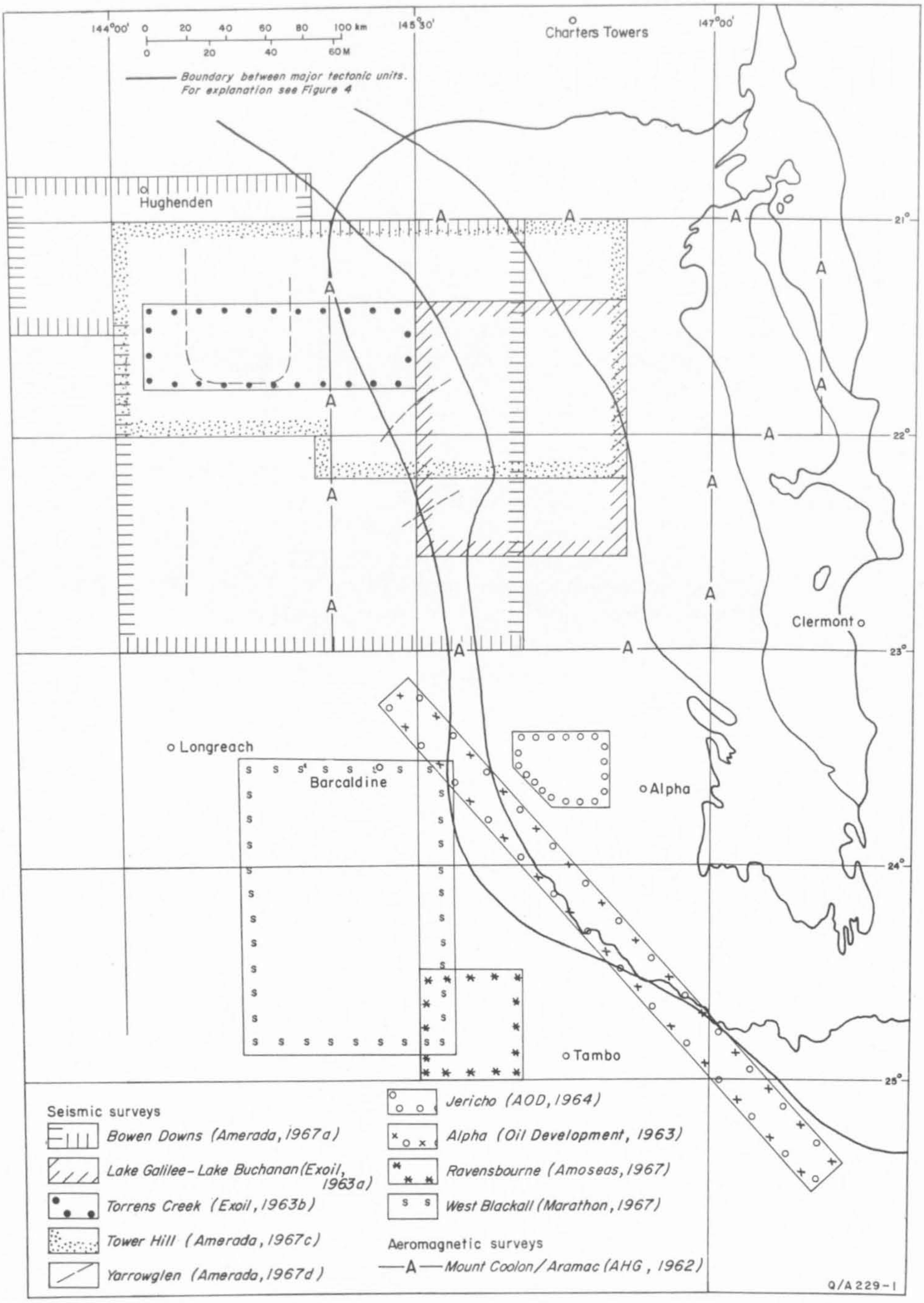

Figure 1. Geophysical surveys.

GEOMORPHOLOGY

The geomorphology of most of the area has been described in detail by Galloway (*in* CSIRO, 1967, pp. 97-100), and the following account is largely taken from his work.

Physical Regions

Eight physical regions have been distinguished on the basis of topography and geology (Fig. 2). Each is complex and only the major features are described.

The *western plains and tablelands*, in the northwestern and western parts of the basin, consist mainly of plains and gently undulating low tablelands covered by Tertiary detrital rocks and laterite. Where the Cainozoic cover rocks have been removed by erosion the harder formations in the underlying Permian, Triassic, and Jurassic sequences form low ranges up to about 100 m high. They usually have gentle slopes but are locally deeply dissected. The ranges are surrounded by extensive confluent low-gradient fans several kilometres across with shallow inactive anastomosing channels. The small exposures of deeply weathered clay and shale are covered by heavy soil and dense scrub. The larger streams in this region tend to have fairly wide alluvial flats with clearly developed levees.

In the *northern hills* the topography reflects the complex geology and the extent of Cainozoic sedimentation, erosion, and weathering. In the west there are a series of steep parallel ridges 6 to 60 m high, running roughly north-south; they are separated by strike valleys up to a kilometre wide. The ridges have been exposed by removal of the Tertiary cover rocks. The Bulliwallah and Natal Formations in the west are also dissected into a group of hills. The central belt of lower undulating country is underlain by only slightly weathered granite and more deeply weathered metamorphics with occasional hills of more resistant rocks. To the east, the Bulgonunna Volcanics are dissected into low rocky hills from 15 to 90 m high. The fringes of the Bulgonunna Volcanics are covered by remnants of Tertiary sandstone, particularly in the Rottenstone Range in the northwest. In the extreme east the undulating weathered basalt is overlain by small remnants of Tertiary sandstone.

The *north-central clay plain* extends from the latitude of Clermont to the northern hills. Much of the clay is associated with deep weathering profiles on Tertiary claystone and older rocks, and tends to be acid at depth. More alkaline clay, derived from weathered basalt, has been laid down in extensive fans near Diamond Downs homestead. Extensive sheets of clay of uncertain origin, generally alkaline, occur near Moray Downs homestead. The larger rivers have broad alluvial flats up to 16 km wide, and flood extensively.

The *basalt lowland* extends along the eastern margin of the area. Isolated mesas of Tertiary basalt and volcanic plugs rise 30 to 450 m above the lowlands. Most of the streams are bordered by fine-textured alluvium.

The *central highlands* range from low hills to low mountains with a relief of 30 to 450 m. They extend southwards from near Cairo homestead to south of Mount Portwine. The height and form of the highlands is strongly influenced by the underlying geology. In the north, they consist of undulations and low hills in the Anakie Inlier and on the Tertiary cover rocks. In the centre, the rocks in the Anakie Inlier are less weathered and much more closely dissected, with local relief up to 150 m west of Clermont. In the south, the highlands are mainly formed by resistant elements in the Drummond Basin sequence. The highest point of the central highlands, Mount Tabletop (810 m), lies in this southern sector. The remnants of the

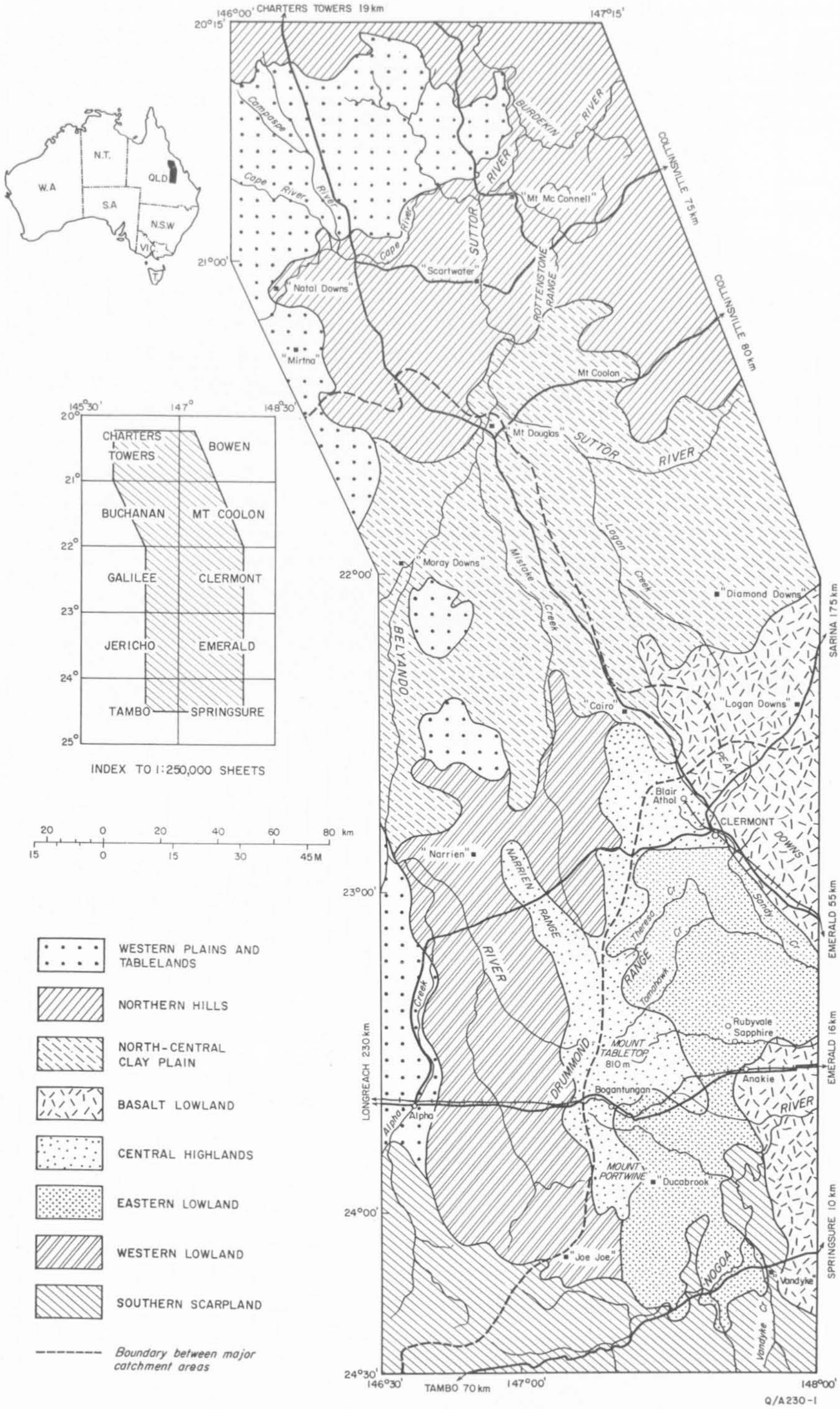

Figure 2. Physical regions and drainage.

Tertiary deep weathering profile decrease from north to south and are barely discernible in the south. For much of their length the central highlands coincide with the Drummond Range, which forms the divide between the Nogoa and the Belyando Rivers.

The *eastern lowland* belt, to the east of the central highlands, extends southwards from Clermont to the Nogoa River. The lowland includes rolling country on granite and basalt, and undulating to low hilly country on Permian quartzose sediments. Extensive remnants of Tertiary deep weathering profiles and Tertiary sediments survive around Anakie. On the moderately dipping Ducabrook rocks, low ill defined scarps have been developed. Small areas of much steeper country lie west of Springsure. Fairly wide alluvial flats extend along the larger streams.

The *western lowland* belt extends southwards from Narrien homestead to Joe Joe homestead, where it coalesces with the southern end of the eastern lowland. It generally has a low relief with weakly developed scarps and strike ridges on the moderately dipping sedimentary rocks of the Drummond Basin. A number of anticlines are defined by rugged ranges consisting of steep strike ridges and cuestas with a relief of up to 360 m. The central part of the lowland northeast of Alpha is covered by gravelly clay. A considerable part of the lowland consists of gently undulating surfaces on Cainozoic sediments. Some of the larger rivers are fringed with wide alluvial flats, but others are incised into narrow flats.

The *southern scarpland* loops in an arc around the southern end of the area. Most of the Tertiary sediments and deep weathering profile have been removed by erosion, and the topography is controlled largely by the lithology of the underlying rocks. Broken dissected hills of resistant sandstone alternate with undulating lowlands on the shaly formations. Moderately extensive alluvial flats are present on the softer rocks, but the streams on the harder rocks flow in defiles.

Drainage

The Nogoa River draining the southeastern part of the area flows from southwest to northeast; its main tributaries are Sandy Creek, draining most of the Clermont district, and Vandyke Creek, which flows north from the high Buckland Tableland in the far south. The Nogoa River is part of the Fitzroy River drainage system, which enters the sea at Rockhampton. The Suttor River drains the northeastern part of the area; it is formed by the Belyando River, which drains the western part, at Mount Douglas homestead, and by the Cape River, from the northwest, at Lornesleigh homestead. The Suttor joins the Burdekin River, which flows to the northeast and reaches the sea at Ayr. The Great Dividing Range, separating the streams draining into the Pacific Ocean from the Lake Eyre internal drainage basin, lies just west of the area described.

GEOLOGY

The Drummond Basin is one of a number of downwarps which developed in the Tasman Geosynclinal zone after the Tabberabberan Orogeny. A great thickness of continental and some marine sediments was laid down in the basin in the Upper Devonian and Lower Carboniferous. Marine sedimentation took place mainly farther north and east along the present eastern Australian coast (Fig. 3).

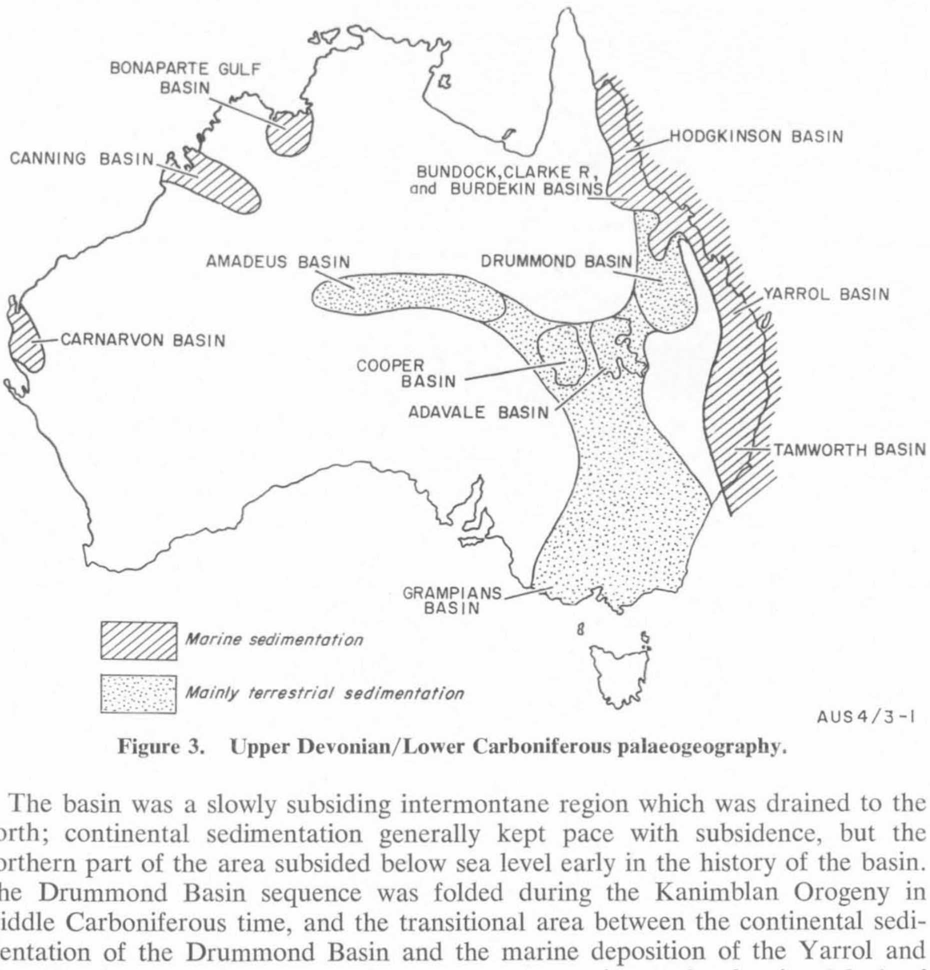

Figure 3. Upper Devonian/Lower Carboniferous palaeogeography.

The basin was a slowly subsiding intermontane region which was drained to the north; continental sedimentation generally kept pace with subsidence, but the northern part of the area subsided below sea level early in the history of the basin. The Drummond Basin sequence was folded during the Kanimblan Orogeny in middle Carboniferous time, and the transitional area between the continental sedimentation of the Drummond Basin and the marine deposition of the Yarrol and Hodgkinson Basins is now occupied by younger granites and volcanics. Much of the Drummond Basin sequence, both east and west of the Anakie Inlier, is obscured by younger sediments, and the Drummond Basin outcrop belt is only a small structural remnant of the original basin of sedimentation.

Formerly all the Devonian and Carboniferous rocks in the area were included in the Drummond Basin sequence, but as the Middle and Upper Devonian and the Lower and Upper Carboniferous successions each contain an angular unconformity on and near the Anakie Inlier, only the Upper Devonian and Lower Carboniferous rocks are here included in the Drummond Basin sequence. The Middle Devonian

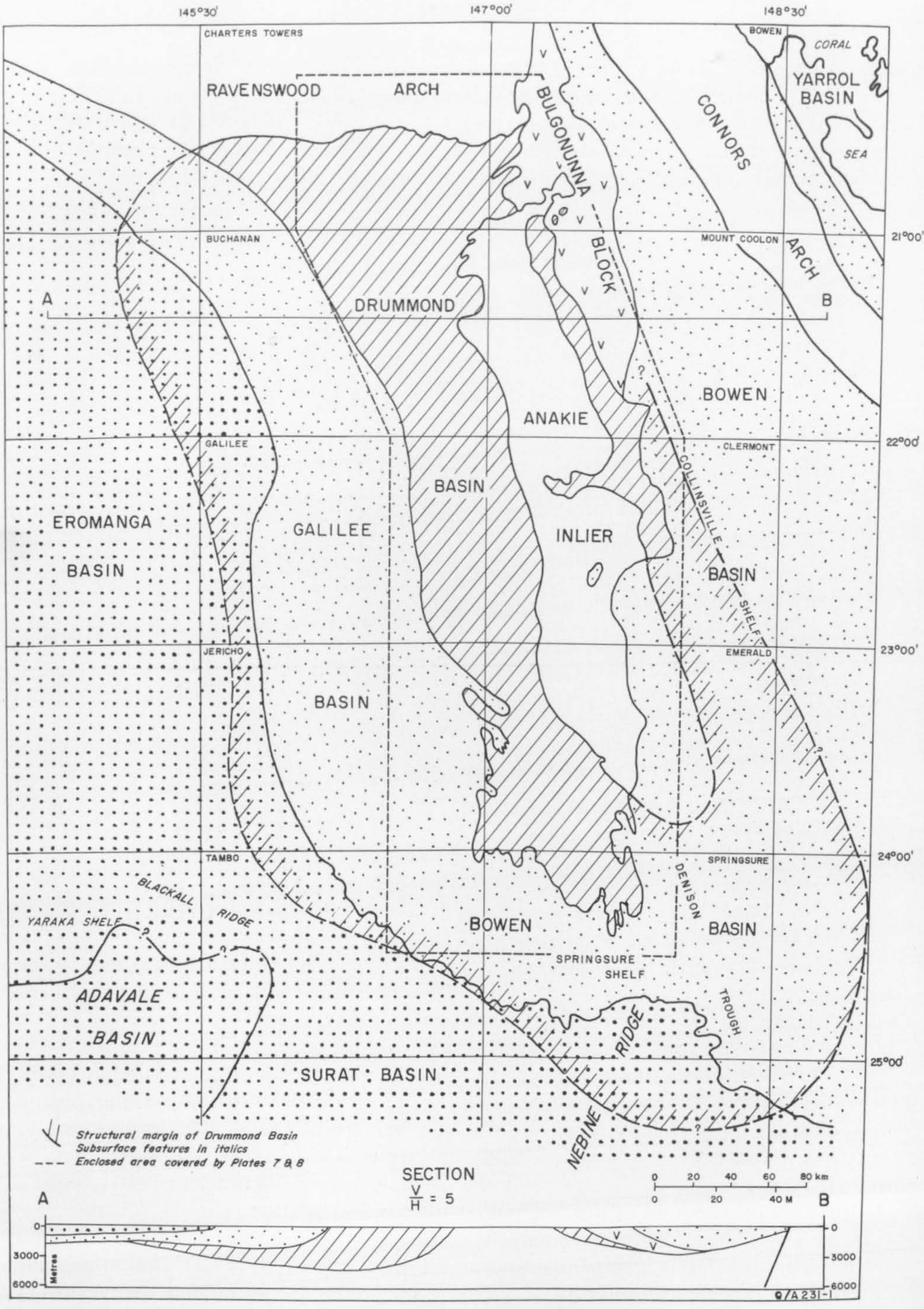

Figure 4. Tectonic setting.

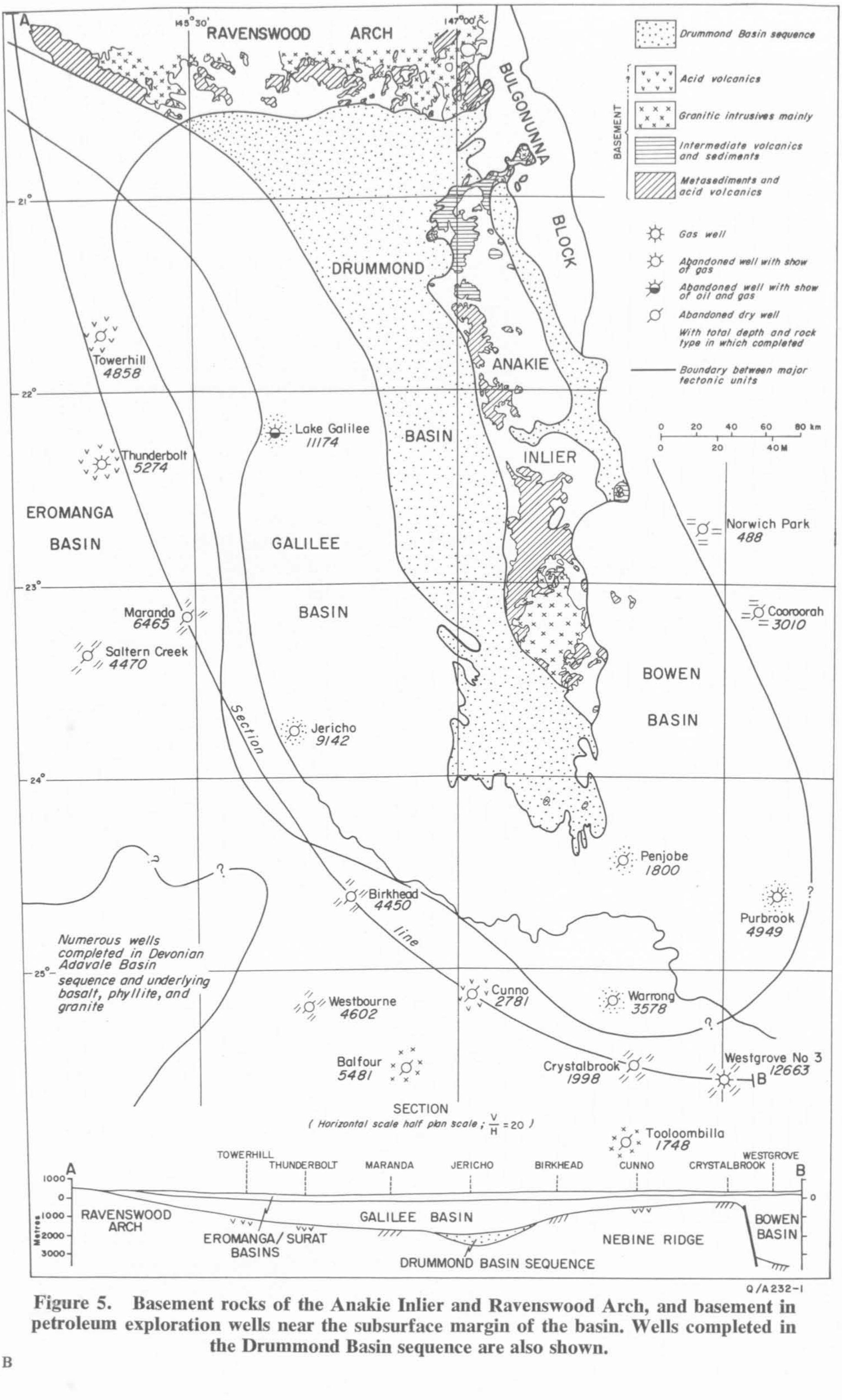

Figure 5. Basement rocks of the Anakie Inlier and Ravenswood Arch, and basement in petroleum exploration wells near the subsurface margin of the basin. Wells completed in the Drummond Basin sequence are also shown.

sequence is part of the basement and the Upper Carboniferous strata are included in the Galilee Basin sequence (Fig. 8).

The subsurface Adavale Basin to the southwest (Fig. 4) contains Lower, Middle, and Upper Devonian rocks. The Upper Devonian (Buckabie Formation) consists of up to 3 000 m of red-beds. The sequence may extend into the Lower Carboniferous and overlies marine Middle Devonian rocks (the Etonvale Formation) with apparent conformity. The Buckabie Formation is the only part of the Adavale Basin sequence that can be correlated with part of the Drummond Basin sequence (Fig. 6). The red-beds and pyroclastic rocks encountered in the Jericho 1 well 95 km west of the Drummond Basin outcrop belt may be equivalent to the Buckabie Formation.

The Drummond Basin succession has also been encountered in the petroleum exploration wells, Lake Galilee 1, Warrong 1, Penjobe 1, and Purbrook 1 (Table 3).

The rock units shown on the accompanying geological map (Pl. 7) are described in three main groups: basement, Drummond Basin sequence, and post-Drummond volcanics, sediments, and intrusives. The basement and post-Drummond rocks are only briefly described.

BASEMENT

Basement rocks crop out in the Anakie Inlier and Ravenswood Arch, and have been recorded from numerous petroleum exploration wells west and south of the Drummond Basin outcrop belt (Fig. 5). Basement consists mainly of low-grade metasediments of early Palaeozoic age, small isolated areas of Middle Devonian sediments and volcanics, and Middle Ordovician to Upper Devonian granites.

The relationships between the basement rocks are shown diagrammatically in Figure 6.

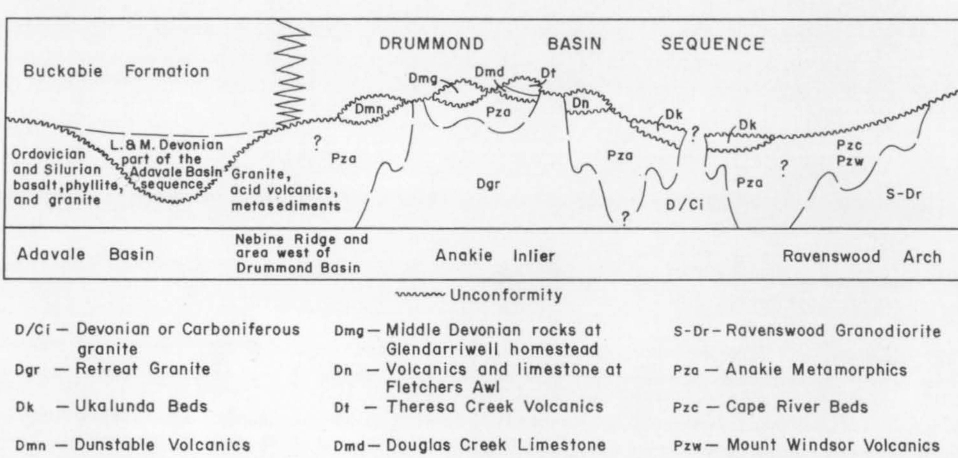

Figure 6. Basement rock relationships.

Anakie Inlier

The Anakie Inlier, which was called the Anakie Structural High or Anakie Complex by Hill & Denmead (1960) and was renamed Anakie Inlier by Veevers et al. (1965b), is a north-northwesterly trending basement ridge composed of the pre-Devonian Anakie Metamorphics, Middle Devonian volcanics and sediments, and

Upper Devonian intrusive granite. It extends from Ukalunda in the north to Anakie in the south, and continues to the south-southwest under the Bowen and Surat Basins as the Nebine Ridge (Fig. 4).

The inlier is composed mainly of Anakie Metamorphics, which are unconformably overlain by the Ukalunda Beds in the north, the Theresa Creek Volcanics and Douglas Creek Limestone near Clermont, the Dunstable Volcanics west of Springsure, and volcanics and limestone near Fletchers Awl northeast of Clermont and Glendarriwell homestead southeast of Anakie. All the overlying formations, with the exception of the Ukalunda Beds, consist of small outcrops of intermediate volcanics and minor sediments, including coralline limestone, which are remnants of an extensive Middle Devonian volcanic and marine sedimentary province. The Anakie Metamorphics and Middle Devonian rocks were intruded by granite in the Upper Devonian.

The history of the Anakie Inlier is summarized in Figure 20. During the Tabberabberan Orogeny in the Middle Devonian a geanticline was developed between the Drummond Basin to the west and the Yarrol Basin to the east. Sedimentation in the Drummond Basin progressively transgressed the western part of the geanticline, and the area was again uplifted in the Kanimblan Orogeny in middle Carboniferous time to form the Anakie Inlier and Nebine Ridge. The Anakie-Nebine axis was largely exposed during sedimentation in the Galilee and Bowen Basins, and only a thin sequence of sediments was deposited on the Springsure Shelf over the axis.

Anakie Metamorphics

Jensen (1921) used the term Anakie Series for the granite, porphyry, schist, and slate near Anakie, and later, the name Anakie Metamorphics was used on the Geological Map of Queensland (Hill, 1953) for all the Lower Palaeozoic rocks from Anakie to southwest of Collinsville.

The Anakie Metamorphics consist of a tightly folded sequence of quartz-mica schist, knotted schist, phyllite, quartzite, slate, lithic sandstone, and some unfossiliferous limestone and volcanics. Some broad structures can be discerned on the air-photographs west of Anakie, but the sequence has a uniform dendritic air-photo pattern. The age of the metamorphics is not known, but isotopic dating of a mica schist from west of Clermont indicates a Middle Ordovician age for the metamorphism (A. W. Webb, pers. comm.). The Anakie Metamorphics may be correlated with the early Palaeozoic Cape River Beds of the Ravenswood Arch (Fig. 6).

Ukalunda Beds

Jack (1889) was the first to describe the rocks around Ukalunda, an abandoned mining centre west of Mount Wyatt. Malone et al. (1966), who first used the name Ukalunda Beds, recognized two lithological units within the Ukalunda Beds, one consisting mainly of siltstone and sandstone and the other predominantly of sandstone and limestone. These units were not mapped. The limestones contain a rich fauna of corals, brachiopods, gastropods, pelecypods, bryozoans, stromatoporoids, and fish bones of Middle Devonian age (Hill *in* Malone et al., 1966). The Ukalunda Beds, which form the northern part of the Anakie Inlier, are in places tightly folded and have been mildly regionally metamorphosed. In some areas the rocks have a pronounced schistosity, but in others cleavage is poorly developed. Some of the rocks mapped as Ukalunda Beds may belong to the underlying Anakie Metamorphics with which they are probably infolded.

Douglas Creek Limestone (Hill, 1939)

Limestone (the Douglas Creek Limestone) and acid and intermediate volcanic rocks crop out in a small outlier southwest of Clermont. The limestone near the eastern margin of the outlier contains a rich lower Middle Devonian fauna of corals, stromatoporoids, brachiopods, molluscs, and crinoids (Hill, 1939; Jones, 1941). The limestone is overlain by a thin sequence of Middle Devonian micaceous siltstone that was mapped as an unnamed unit by Veevers et al. (1964a), but was later included in the Douglas Creek Limestone (Olgers et al., 1967).

Theresa Creek Volcanics (Veevers et al., 1964a)

The Douglas Creek Limestone is overlain apparently conformably by the Theresa Creek Volcanics. All the intermediate and acid volcanic rocks were originally included in the Theresa Creek Volcanics, but Olgers et al. (1967) have subdivided them into a lower unit (Theresa Creek Volcanics) consisting mainly of andesite and trachyandesite intruded by granite, and an upper unit (correlated with the Silver Hills Volcanics) composed of spherulitic rhyolite, welded tuff, and rhyolite breccia, which rests nonconformably on the granite.

Dunstable Volcanics (Hill, 1957)

The name Dunstable Formation, as used by Hill (1957) in place of Shell's Dunstable Series (SQD, 1952), applied to the whole sequence exposed below the Telemon Formation in the core of the Nogoa Anticline in the northern part of the Springsure Sheet area. Mollan et al. (1969) subdivided Hill's Dunstable Formation into a lower volcanic unit (Dunstable Volcanics) composed of tough andesitic lavas and pyroclastics with lenses of coralline limestone, which is unconformably overlain by a sequence of predominantly acid volcanics and minor sediments (Silver Hills Volcanics). The Dunstable Volcanics form a faulted northeasterly trending inlier in the core of the Nogoa Anticline. The limestone contains a rich lower Middle Devonian fauna of corals, stromatoporoids, and bryozoans (Hill, 1957; Hill, appendix *in* Veevers et al., 1964b).

Middle Devonian Rocks at Glendarriwell Homestead

A small inlier of Middle Devonian rocks was mapped by Veevers et al. (1964b) in the Permian sequence. They comprise rhyolite, shale, siltstone, tuff, pebbly sandstone, and limestone. The limestone contains a rich Middle Devonian fauna (Hill, appendix *in* Veevers et al., 1964b). The rhyolite may belong to the Silver Hills Volcanics.

Middle Devonian Rocks at Fletchers Awl

Pyroxene andesite and andesitic basalt, with interbeds of olive-green micaceous shale and siltstone and dark grey recrystallized limestone, crop out in a small inlier in Permian sandstone and Tertiary basalt northeast of Clermont. The sequence overlies the Anakie Metamorphics and is unconformably overlain by the Silver Hills Volcanics. The limestone contains some poorly preserved fossils and the sequence is correlated with the Middle Devonian Theresa Creek Volcanics.

Retreat Granite (Veevers et al., 1964b)

Most of the Anakie Inlier in the Emerald Sheet area is composed of the Retreat Granite. The granitic rocks range from granodiorite to adamellite, but small outcrops of gabbro, diorite, quartz diorite, and andesite have been observed. The isotopic ages of nine samples from the main body range from 345 to 372 m.y. (Upper Devonian) (Webb, Cooper, & Richards, 1963). The Retreat Granite intrudes the Anakie Metamorphics and Theresa Creek Volcanics and is nonconformably overlain by the Silver Hills Volcanics. The small outcrops of granite in the core of the Nogoa Anticline and near Fletchers Awl have tentatively been mapped as Retreat Granite because they are also nonconformably overlain by the Silver Hills Volcanics.

Devonian-Carboniferous Granite (D/Ci)

The northern part of the Anakie Inlier is intruded by five large granitic bodies which crop out in a line trending roughly northeast; they are generally irregular in shape owing to the presence of large roof pendants and embayments, and consist mainly of adamellite and granodiorite. The southerly intrusions are regarded as Upper Carboniferous (Cui on Pl. 7; see Table 2) as they intrude the Middle Devonian Ukalunda Beds, Upper Devonian Mount Wyatt Beds, and Upper Devonian to Lower Carboniferous St Anns Formation. The granite northeast of Mount Wyatt is mapped as Devonian-Carboniferous as it intrudes the Ukalunda Beds and is thought to be unconformably overlain by the Upper Carboniferous Bulgonunna Volcanics (Malone et al., 1966).

Ravenswood Arch

The Ravenswood Arch, an easterly trending basement ridge to the north of the Drummond Basin, is composed mainly of early Palaeozoic low-grade metasediments and intrusive granite. It probably formed an effective barrier between the Drummond Basin and the Burdekin Basin to the north during most of the Devonian and Carboniferous, but the current directions in the Raymond Formation just south of the arch suggest that the Drummond Basin drainage system at times flowed across the eastern part of the arch into the marine Burdekin Basin.

Ravenswood Granodiorite Complex (Wyatt et al., 1970)

The Ravenswood Granodiorite Complex, which forms the bulk of the Ravenswood Arch, consists mainly of granodiorite and subordinate granite, adamellite, diorite, and gabbro. Recent isotopic dating by the Rb/Sr whole rock method has shown that most of the complex is Middle Ordovician (454 $\pm$ 30 m.y.); some of the specimens yielded an isochron of 394 $\pm$ 30 m.y. (Upper Silurian or Lower Devonian), the age of the Lolworth Igneous Complex (Clarke & Paine, 1970), to the west.

Cape River Beds (Paine et al., in press)

The Cape River Beds extend eastwards from the type area in the Hughenden Sheet area into the Charters Towers Sheet area. They crop out in a large number of irregular inliers within the Ravenswood Granodiorite Complex. The general stratigraphic relationships have not been established because of the variation in metamorphic grade and discontinuity of outcrop, but several belts of acid volcanics (Mount Windsor Volcanics) have been mapped separately. The Cape River

Beds consist mainly of schist, quartzite, and phyllite, and the metamorphism appears to have been caused by the intrusion of the Ravenswood Granodiorite Complex (Wyatt et al., 1971). Preliminary isotopic age determinations on samples from the Mount Windsor Volcanics suggest an Upper Cambrian age, and the Cape River Beds are regarded broadly as Cambrian to Ordovician (Clarke & Paine, 1970). The presence of the Middle or Upper Devonian plant *Calamophyton* near Palamana homestead indicates the presence of younger rocks. The older rocks in the Cape River Beds can probably be correlated with the Anakie Metamorphics, and the younger are probably equivalent to the Ukalunda Beds.

Subsurface Basement

A large number of petroleum exploration wells have been drilled in the Galilee, Eromanga, and Bowen Basins, but only those near the Drummond Basin outcrop belt are considered here (Fig. 5). Most of the wells penetrate Mesozoic and Upper Palaeozoic rocks and terminate in basement (Table 1). The basement consists of granite (Balfour 1 and Tooloombilla 1), acid volcanic rocks (Towerhill 1, Thunderbolt 1, and Cunno 1), and low-grade metasediments and sediments (Saltern Creek 1, Maranda 1, Birkhead 1, Westbourne 1, and Crystalbrook 1). Five wells (Table 3) terminated in the Drummond Basin sequence (Lake Galilee 1?, Jericho 1, Warrong 1, Penjobe 1, and Purbrook 1), and two (Cooroorah 1 and Norwich Park Scout) to the east of the Anakie Inlier in andesitic volcanics and interbedded sediments (Table 1).

The subsurface Adavale Basin southwest of the Drummond Basin has also been extensively drilled. To the east, south, and west it is largely bounded by areas of post-Devonian uplift and erosion. Onlapping limits of deposition have been recognized to the north and northwest. The basin contains a thick sequence of mainly Devonian sediments over Ordovician and Silurian basalt, phyllite, and granite. The Upper Devonian to Lower Carboniferous(?) Buckabie Formation of the Adavale Basin is equivalent to part of the Drummond Basin sequence; the Middle Devonian part of the sequence is equivalent to the Middle Devonian rocks of the Anakie Inlier (Fig. 6), but unlike the Anakie rocks they are relatively undisturbed and are overlain apparently conformably by the Buckabie Formation.

The volcanics in the basement are described as grey quartz-feldspar porphyries. Cobbles and pebbles of these porphyries occur in the Mount Hall Formation at Mount Donnybrook, in the Narrien Range, and in the Telemon Anticline. The porphyries may be related to the Silver Hills Volcanics, but could be older and equivalent to the acid volcanics of the Mount Windsor Volcanics.

The age of the widely distributed low-grade metamorphic rocks in the basement is uncertain, but they are probably mainly equivalent to the Lower Palaeozoic Anakie Metamorphics and the Cape River Beds. Equivalents of the Ukalunda Beds may also be present.

The granite in Balfour 1 was dated at 420 ± 20 m.y. and was correlated with the granite underlying the Devonian rocks of the Adavale Basin.

The wells east of the Anakie Inlier terminated in andesitic volcanics and interbedded sediments which are probably equivalent to the small patches of Middle Devonian rocks in the Anakie Inlier (Dunstable Volcanics, Theresa Creek Volcanics etc.). Their presence close to the eastern margin of the Anakie Inlier indicates that the Drummond Basin sequence does not extend far to the east below the Bowen Basin sequence (Fig. 4).

The section in Figure 5 shows that the basement west of the Drummond Basin

TABLE 1—SUBSURFACE BASEMENT IN PETROLEUM EXPLORATION WELLS
(See Fig. 5 for location)

Well	*Basement Rock*	*Hydrocarbon Shows*	*Remarks*
Amoco *Towerhill No. 1* (Hayworth, 1968)	Ignimbrite: tough, massive, pink and grey mottled; feldspar (40%) and quartz (20%) in devitrified ashy matrix	None	Volcanics in Towerhill and Thunderbolt wells can possibly be correlated with Silver Hills Volc. Volcanics in Cunno are similar. May be older and equivalent to Windsor Volc. (see p. 16)
Amerada *Thunderbolt No. 1* (Amerada, 1967b)	Wash of weathered angular pebbles of metamorphic and igneous rocks, overlying fractured and partly weathered dacite	Shows in several Permo-Carboniferous sands below 1 350 m, but no recovery from drill stem tests	
Oil Development *Maranda No. 1* (Le Blanc, 1963)	Mudstone: steeply dipping, contorted and brecciated, green, slightly calcareous, slightly pyritic, recrystallized, sheared	None	
Longreach *Saltern Creek No. 1* (Mott & Assoc., 1964)	Mainly quartzite: grey to green, fine-grained, silicified, sugary; interbedded with green, grey, white, and purple tuff. Some schistosity in quartzite	None	Sediments may be equivalent to Adavale Basin sequence
South Pacific *Birkhead No. 1* (South Pacific Ltd, 1957)	Shale: hard, brittle, veined with calcite, some pyrite, light grey limestone	None	May be equivalent to Adavale Basin sequence, or older.
Amoseas *Westbourne No. 1* (Gerrard, 1964)	Banded shale: indurated, black and steel grey, steeply dipping (40°), brittle, splintery, fractured across bedding; incipient slaty cleavage	None	Similar to basement rocks in Birkhead 1
Amoseas *Cunno No. 1* (Gerrard, 1966b)	Dacite: pale grey, quartz and feldspar phenocrysts in dominantly feldspathic ground mass. Volcanic shards	None	K/Ar age: 187±20 m. y. (Triassic). Volcanics overlain by Permian sediments; apparent age due to later tectonic event
Amoseas *Balfour No. 1* (Gerrard, 1966a)	Feldspar porphyry: partly recrystallized, grey, mottled pink, orange, and minor dark green, holocrystalline; phenocrysts mainly plagioclase, orthoclase, quartz	Faint fluorescence in Clematis Sst	Age 420±20 m. y. (Silurian)
Planet *Crystalbrook No. 1* (Meyers, 1964a)	Quartzite: grey and greenish grey, fine-grained. Some phyllite with slight slaty cleavage. Quartz-filled fractures	None	Probably older than Timbury Hills Fm because of cleavage
AAO *Westgrove No. 3* (Minad, 1963a)	Extremely hard rocks; possibly metamorphics or granite	Gas well. Production from thick Permian sequence	Drilled just E of Nebine Ridge in Denison Trough. Permian on unidentified basement
AFO *Cooroorah No. 1* (Derrington, 1960)	Andesite, andesite tuff, quartzite, sandstone, siltstone	None	Probably equivalent to M. Devonian volcanics farther west in Anakie Inlier (Theresa Ck Volc, Dunstable Volc, etc.)
AFO *Norwich Park Scout*	Andesitic volcanics, sediments	None	
Planet *Tooloombilla No. 1* (Meyers, 1964c)	Granite porphyry	None	Triassic rocks directly overlie granite

slopes gently to the south from about 600 m above sea level in the Ravenswood Arch to about 1 700 m below sea level at Maranda. The gravity minimum in the northern area (Pl. 8) was interpreted as a basement depression (Gibb, 1966), but is now believed to be due to the presence of widespread low-density acid volcanics, granite, and other rocks. South of Maranda, basement deepens to more than 2 400 m below sea level; if the Drummond and Adavale Basins were continuous in the Upper Devonian and Lower Carboniferous, then the connexion was in this area (see Fig. 21). To the southeast the basement gradually rises to 900 m below sea level at Birkhead, 1 246 m at Cunno 1, and 104 m at Crystalbrook 1. This rise (the Nebine Ridge) is the southerly extension of the Anakie Inlier. The Nebine Ridge has a steep easterly slope, and basement is at least 3 300 m below sea level at West-

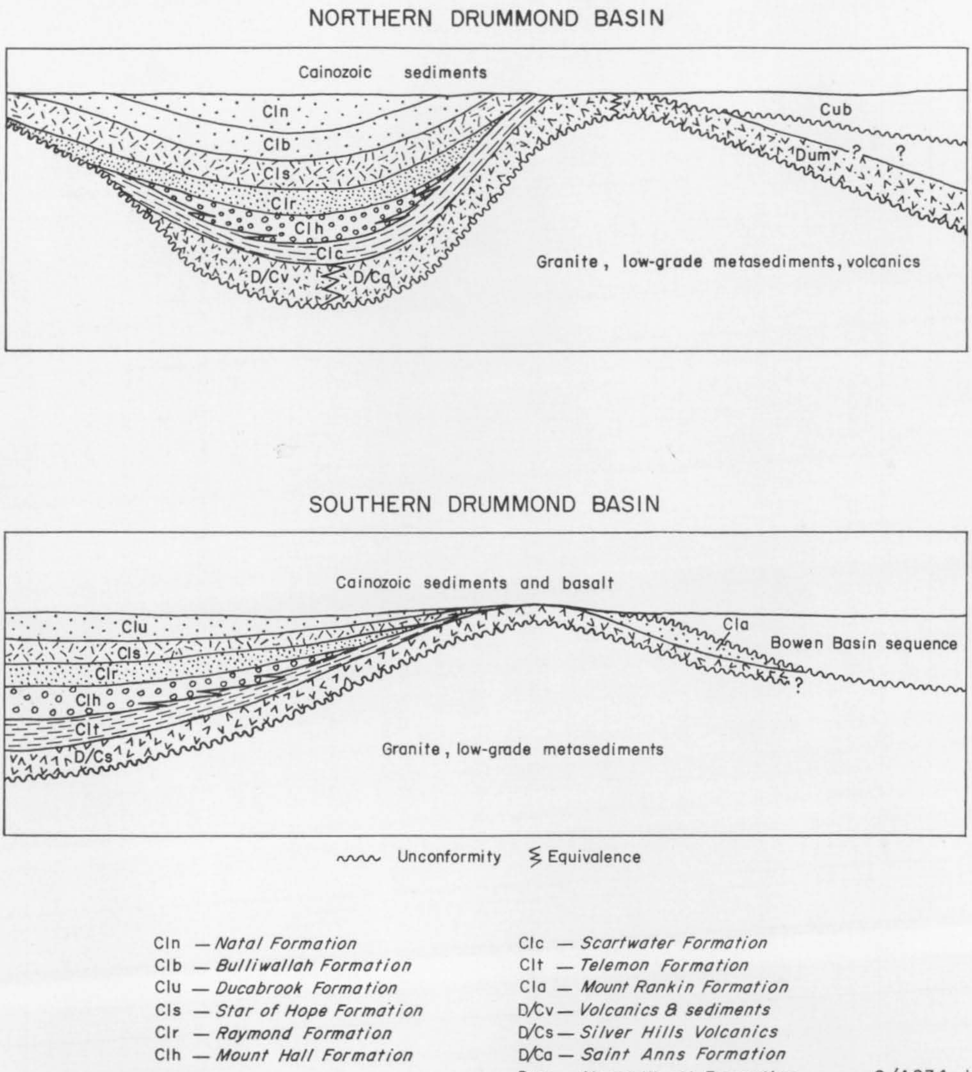

Figure 7. Relationships in the Drummond Basin sequence.

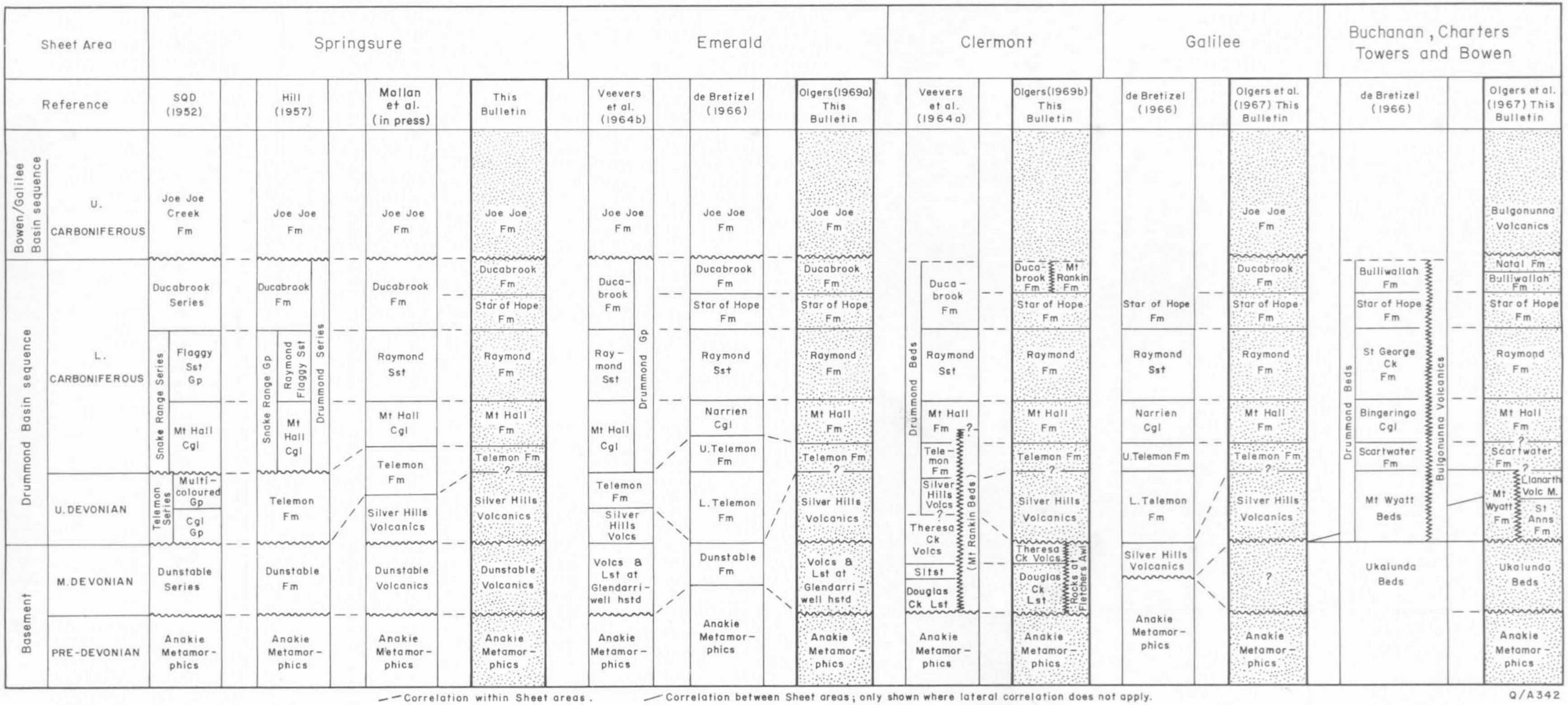

Figure 8. Evolution of Drummond Basin stratigraphic nomenclature.

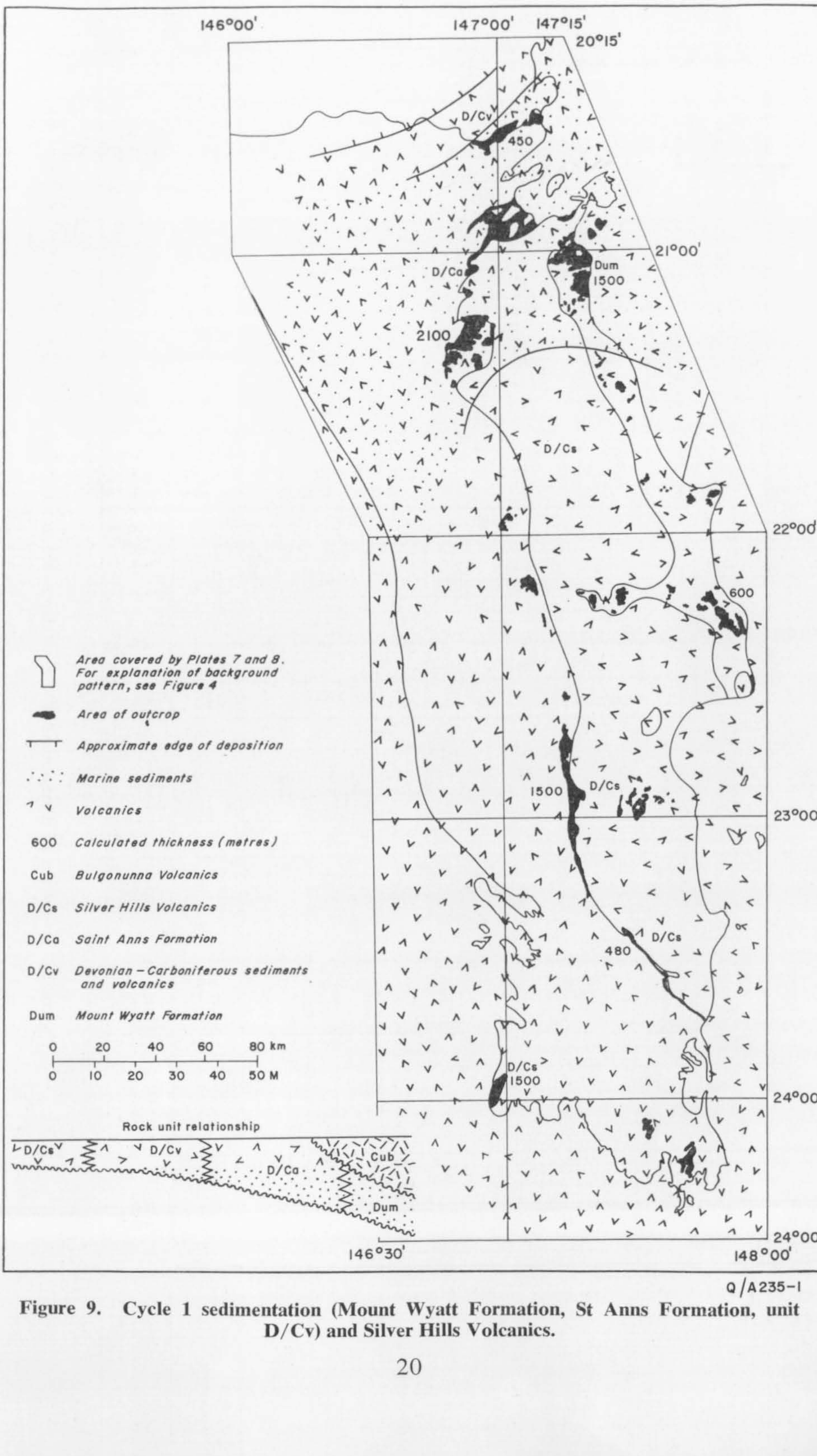

Figure 9. Cycle 1 sedimentation (Mount Wyatt Formation, St Anns Formation, unit D/Cv) and Silver Hills Volcanics.

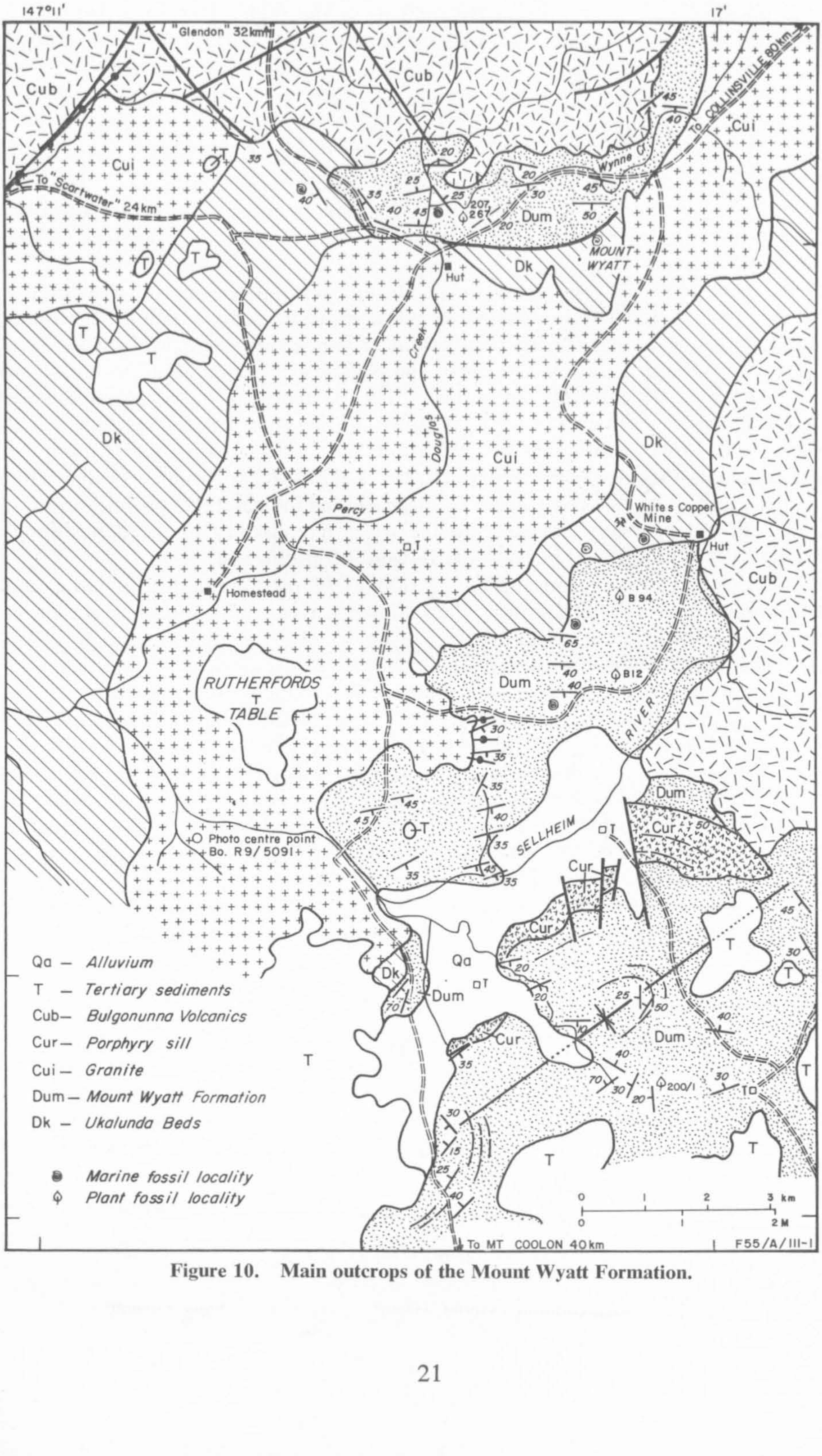

Figure 10. Main outcrops of the Mount Wyatt Formation.

grove 3, in the Denison Trough just to the east of the ridge. The ridge consists of granite, acid volcanics, and low-grade metamorphic rocks, and it probably supplied much of the sediment laid down in the Drummond and Adavale Basins in the Upper Devonian and Lower Carboniferous.

DRUMMOND BASIN SEQUENCE

Sedimentation in the Drummond Basin began in Upper Devonian time with the deposition of marine sediments in the north. The sea extended into this region from the Yarrol and Hodgkinson Basins to the north and east, the sites of widespread marine sedimentation (Fig. 3).

Uplift accompanied by widespread volcanism occurred toward the end of the Devonian. The sea regressed to the north and continental sedimentation began in a large intermontane basin. The original extent of the basin is not precisely known. The present southern margin is formed by the Nebine Ridge and adjacent basement rocks to the west beneath the Surat Basin. The Adavale Basin to the southwest, where continental sediments were laid down during the Upper Devonian and perhaps in the Lower Carboniferous, was probably connected with the Drummond Basin, although they are now separated by a subsurface basement ridge (the Blackall Ridge). The western margin of the basin, as indicated by seismic surveys, is truncated, but probably lies close to the western boundary of the depositional basin; the eastern margin lies beneath the Bowen Basin (Fig. 4).

In the Lower Carboniferous up to 12 000 m of predominantly fluviatile and lacustrine sediments were laid down. The sediments were transported into the basin by a northerly flowing river system.

The depositional environment was stable over long periods, and even after minor epeirogenic events that caused abrupt changes in sedimentation, the same conditions were re-established. Sedimentation in the Drummond Basin can be subdivided into three cycles separated by minor epeirogenic events; each started with the deposition of torrential sediments and ended with that of mature sediments. The marine and continental sediments of the first cycle were laid down in the Upper Devonian in the north and west, while the eastern part of the area was probably being eroded. The end of the first cycle was marked by widespread volcanism in the north and east in the late Devonian or early Carboniferous (Fig. 21A). The volcanic episode was followed by the deposition of a thick sequence of continental sediments in a narrow basin west of the Anakie Inlier (cycle 2, Fig. 21B, C, D). Sedimentation kept pace with subsidence. The third and last cycle began after renewed uplift and volcanism along the borders of the basin, and it was during this period that the Drummond Basin was developed to its fullest extent.

The stratigraphic units are described under the sedimentary cycles during which they were laid down. The volcanics, which were extruded between cycles 1 and 2, are described with cycle 1 because in the north and southwest they are intimately related to the sediments of cycle 1.

The evolution of the stratigraphic nomenclature is set out in Figure 8, which also provides a basinwide correlation of stratigraphic units; the relationships of the formations are shown in Figure 7.

Cycle 1: Mount Wyatt Formation, Unit D/Cv, St Anns Formation, (Silver Hills Volcanics)

The distribution of the units and their relationships are shown in Figure 9.

Mount Wyatt Formation

The Mount Wyatt Beds (Daintree, 1870; Malone et al., 1966) are here renamed Mount Wyatt Formation. The type area is in the Sellheim River area southeast of Rutherfords Table, where the formation is exposed in the northern limb of a large syncline (Fig. 10). The formation crops out on the northern margin of the Anakie Inlier north of Mount Wyatt, along its eastern margin between the type area and Mount Coolon, and in two inliers in the Bulgonunna Volcanics east of the type area. Malone et al. (1966) mapped the upper part of the sequence south of the Sellheim River as an unnamed Devonian-Carboniferous volcanic unit; but here it is included in the Mount Wyatt Formation, from which it is lithologically indistinguishable. Most of the volcanics reported by Malone et al. (1966), on which the volcanic unit was presumably based, are quartz-feldspar porphyry and rhyolite sills intruded into the sediments, and outliers of the younger Bulgonunna Volcanics.

The Mount Wyatt Formation consists mainly of sediments, but volcanics are present, particularly near the top of the sequence in the Rosetta Creek area (5 km south of the southern boundary of Fig. 10 along the Mount Coolon road).

North of Mount Wyatt, the formation consists mainly of thinly bedded olive-green siltstone, shale, and tuffaceous feldspatholithic sandstone. Conglomerate, containing pebbles of granite, chert, and volcanic and sedimentary rocks, crops out in Percy Douglas Creek and in Wynne Creek (Fig. 10) near the confluence with Percy Douglas Creek. The conglomerate in Wynne Creek contains abundant marine fossils, mainly *Cyrtospirifer*. Fossil plants, including *Leptophloeum australe,* are present in the finer sediments directly above the conglomerate (Appendix).

In the type area, and farther south, the lower part of the formation consists mainly of green, khaki, and grey shale, siltstone, and lithic sandstone, containing marine fossils and plants. The sequence contains some thin interbeds of conglomerate, containing pebbles of granite and quartz. This basal sequence, which is lithologically similar to the beds at Mount Wyatt, is overlain by well bedded chert, poorly sorted lithofeldspathic sandstone, shale, siltstone (containing plant debris), thin beds of conglomerate, some tuff, and at the Sellheim River, thick-bedded feldspatholithic sandstone containing pieces of flaggy siltstone up to 10 cm across. The sandstone and many of the finer-grained rocks are cross-bedded and ripple-marked. South of the Sellheim River, the beds are poorly exposed and consist mainly of greenish and grey feldspatholithic sandstone, olive-green mudstone, and conglomerate containing numerous pebbles of volcanic rocks. Some beds of tuff and crystal tuff occur in the upper part of the sequence.

Farther south, where the Mount Coolon/Ukalunda road crosses Rosetta Creek, the formation consists of khaki-brown tuffaceous lithic sandstone, siltstone, conglomerate, and some tuffs and thin flows. The sequence at Rosetta Creek crops out in the centre of a syncline and is probably the youngest part of the Mount Wyatt Formation exposed.

The Mount Wyatt Formation is the only unit in the Drummond Basin sequence that contains marine fossils. Most of them belong to a species closely allied to *Cyrtospirifer* cf. *reidi* (Maxwell). They were found at several localities in the type area and in one locality northwest of Mount Wyatt, all in the lower part of the formation. Plants, including *Leptophloeum australe*, are abundant (Appendix). The fossils indicate that the lower part of the formation is late Upper Devonian (Famennian).

The thickness of the Mount Wyatt Formation is not known because the top is not preserved and the base is probably faulted in the type area, but at least 1 500 m is exposed in the type area.

The Mount Wyatt Formation rests unconformably on the Ukalunda Beds and is unconformably overlain by the Bulgonunna Volcanics. The lower unconformity is only exposed in a small tributary of Percy Douglas Creek, 3 km west-northwest of Mount Wyatt (Fig. 10), where conglomerate unconformably overlies sheared siltstone and bryozoal limestone of the Ukalunda Beds. All other contacts are faulted, brecciated, or intrusive. At Mount Wyatt, the formation dips to the south under the Ukalunda Beds which form the summit of the mountain; however, the boundary is faulted and partly intruded by a trachyte dyke. In the type area, where the contact with the Ukalunda Beds is poorly exposed, the rocks are extensively brecciated, probably owing to faulting.

The formation is intruded by granite at Mount Wyatt and east and south of Rutherfords Table. At several localities, notably west of Mount Wyatt just west of Percy Douglas Creek, a thin zone of highly sheared and brecciated Ukalunda Beds separates the granite from Mount Wyatt Formation.

The Mount Wyatt Formation can be correlated with the sediments at the base of unit D/Cv along the southern margin of the Ravenswood Arch, and with the lower part of the St Anns Formation along the northern and western margins of the Anakie Inlier (Fig. 9). The youngest rocks of the Mount Wyatt Formation in Rosetta Creek are probably equivalent to the middle part of the St Anns Formation. The Mount Wyatt Formation can possibly be correlated in part with the sequence encountered in the Lake Galilee 1 well between 9 320 and 11 175 feet (2 840·7-3 385·6 m) (see Table 3). This sequence is mainly early Upper Devonian in age, but probably extends into the late Upper Devonian. The lower exposed part of the Mount Wyatt Formation is late Upper Devonian.

The beds were laid down in a near-shore shallow marine and paralic environment. The sediment was brought in by streams draining neighbouring areas of low-grade metasediments, granite, and volcanic rocks. The presence of well preserved shells and the absence of fragmental shell material in the conglomerate indicate that there was little reworking. Volcanism was common, particularly towards the end of this period of deposition.

St Anns Formation (Olgers, 1970)

The St Anns Formation is the sequence that unconformably overlies the Ukalunda Beds and is conformably overlain by the Scartwater Formation. The formation was laid down in the northern part of the basin and crops out along the northwest margin of the Anakie Inlier. The best exposures are in the type area near St Anns homestead.

In the type area, the formation is about 2 100 m thick and can be subdivided into three parts: a sedimentary sequence about 660 m thick at the base, which grades into a predominantly volcanic sequence with interbedded limestone in the middle (330 m), and a volcanic unit 1 100 m thick at the top. Near St Anns homestead the upper volcanic sequence has a distinctive air-photo pattern and it was mapped as the Llanarth Volcanics by Olgers et al. (1967). Subsequently it was found that because of changes in facies, complex structure, and poor exposures the volcanics cannot be recognized as a separate unit to the north of the type area, and consequently they have been renamed the Llanarth Volcanic Member.

To the west of the Anakie Inlier the basal sedimentary sequence crops out in an almost continuous belt from Mount Douglas homestead in the south to Pyramid homestead in the northeast. It consists mainly of conglomerate, sandstone, mudstone, and limestone, but there are rapid changes in lithology, both laterally and vertically. The beds are generally poorly exposed, but are mainly thin-bedded, fine to coarse-grained, and commonly partly calcareous. Conglomerate and conglomeratic sandstone, containing pebbles and fragments of granite, acid volcanic rocks, and schistose rocks, are common at the base of the sequence. The conglomerate is overlain by lithic sandstone, thin-bedded chert, olive-green mudstone, and oolitic and algal limestone. The sandstone contains fragments of schist, black and green chert, and varying proportions of quartz and feldspar; the limestone also contains fragments of quartz, feldspar, and schist. Many of the limestone beds are partly silicified, and in places contain numerous worm tubes. They are most common around St Anns homestead. Occasional beds of volcanic agglomerate and tuff occur in the lower part of the formation, and two beds of phosphatic sandstone, containing up to 15 percent P_2O_5, crop out at the top of the sedimentary sequence, southwest of St Anns homestead. The phosphatic beds are separated by fine-grained acid tuffs. The sedimentary beds near St Anns homestead grade up into a sequence composed mainly of fine-grained acid tuff, crystal lithic tuff containing fragments of schist and acid volcanic rocks, and lapilli tuff, with interbeds of algal limestone and fine sediments. Three kilometres south of St Anns homestead, the top of the middle sequence is defined by a massive conglomerate containing abundant material derived from the underlying sediments, including large slabs of limestone and fragments of schistose rocks from the Anakie Inlier. The remainder of the formation above the conglomerate consists of fine-grained acid tuffs of the Llanarth Volcanic Member.

The basal part of the predominantly sedimentary sequence north of the type area is overlain by a sequence of interbedded volcanics and sediments with a marked increase in the proportion of volcanics toward the top. The sediments are mainly lithic and tuffaceous sandstone with interbeds of conglomerate, calcareous and ferruginous siltstone, mudstone, and some limestone containing worm tubes. The volcanics are mainly tuff, lithic tuff, agglomerate, and flows of rhyolite and porphyritic dacite.

The St Anns Formation rests unconformably on the Ukalunda Beds. The unconformity is well exposed northeast of Scartwater homestead, where the Ukalunda beds dip steeply to the east and the St Anns Formation gently to the west. At the contact are thick lenses of boulder conglomerate. The conglomerate near the base of the St Anns Formation, west of Pyramid homestead, contains pebbles of fossiliferous limestone derived from the Ukalunda Beds.

The lower sedimentary part of the formation was laid down in a near-shore shallow marine or paralic environment and can be correlated with the Mount Wyatt Formation and the lower part of the Upper Devonian to Lower Carboniferous volcanics and sediments (D/Cv). The volcanic sequence at the top of the formation, which was laid down partly on land and partly in water, is equivalent to the upper part of the Devono-Carboniferous volcanics and sediments (D/Cv) and the Silver Hills Volcanics (Fig. 9).

The St Anns Formation contains a rich flora (Appendix). The exact age of the formation is uncertain; it is probably mainly Upper Devonian, but possibly extends into the Lower Carboniferous.

Upper Devonian to Lower Carboniferous Volcanics and Sediments (D/Cv)

A sequence of purple acid volcanics, including flow-banded rhyolite, quartz-feldspar porphyry, volcanic breccia, agglomerate, crystal tuff, and tuff, with a few interbeds of volcanolithic and lithic sandstone, is exposed along the northern margin of the Drummond Basin. The full extent of the sequence is not known because of overlap by the Bulgonunna Volcanics in the east and the Scartwater Formation in the west. About 450 m of volcanic rocks crop out north of Cranbourne homestead.

North of the confluence of the Suttor and Burdekin Rivers, and eastward along the margin of the Drummond Basin, the typical purple volcanic sequence is underlain by khaki, brown, and greenish volcanolithic conglomerate and sandstone, crystal and crystal lithic tuff, and siltstone. This sequence is extensively faulted and intruded by porphyry dykes, and is absent north of Cranbourne homestead. It is probably equivalent to the Mount Wyatt Formation and lower part of the St Anns Formation. The volcanics are equivalent to the upper part of the St Anns Formation and the Silver Hills Volcanics (Fig. 9).

Silver Hills Volcanics (Veevers et al., 1964b)

The formation is named after Silver Hills homestead, 21 km west-northwest of Anakie in the Emerald Sheet area. The type area is 1½ km west of the homestead.

The Silver Hills Volcanics were originally mapped west of the Anakie Inlier in the Emerald and Clermont Sheet areas, but they have since been recognized on and east of the inlier and in the core of the Nogoa Anticline west of Springsure. The formation was laid down over a large area in the southern and central part of the Drummond Basin, and is best exposed in the core of the Mount Beaufort Anticline and along the western margin of the Anakie Inlier, where it forms a prominent range.

The formation consists mainly of spherulitic and flow-banded rhyolite, and acid welded tuff, with subordinate andesite, agglomerate, tuff, lithic sandstone, and mudstone.

In the type area the formation consists mainly of spherulitic rhyolite and trachyte with minor siltstone. In the Mount Beaufort Anticline, Veevers et al. (1964b) mapped only the rhyolite at Mount Beaufort as Silver Hills Volcanics; they included the overlying volcanic rocks and interbedded sediments, which contain red-beds and *Leptophloeum australe*, in the Telemon Formation. As there are no volcanic rocks in the Telemon Formation in the type area, the overlying volcanic rocks and interbedded sediments in the Mount Beaufort Anticline are now included in the Silver Hills Volcanics. Mount Beaufort consists largely of spherulitic and flow-banded rhyolite and is probably a volcanic dome. The vertically flow-banded rhyolites in the northeastern part of the Clermont Sheet area are probably also vents.

The Silver Hills Volcanics consist mainly of a sequence of terrestrial volcanics which are widely distributed in the south. They were extruded on a terrain of folded Anakie Metamorphics, Retreat Granite, and small isolated areas of lower Middle Devonian volcanics and limestone. The unconformity is well exposed southwest of Clermont, where there is a thin sequence composed mainly of granitic and metamorphic debris between the basement rocks and the volcanic sequence, and near Fletchers Awl, where the unconformity is marked by a conglomerate containing pebbles of intermediate volcanics, granite, and metamorphics. South of

Red Mountain (in Eastern Creek) the basal beds of the Silver Hills Volcanics contain boulders of the Anakie Metamorphics.

The Silver Hills Volcanics can be correlated with a similar volcanic sequence that was extruded along the northern margin of the basin (the upper part of unit D/Cv), and with the upper part of the St Anns Formation (Fig. 9). The sequence between 5 507 and 9 142 feet (1 678·5-2 786·5 m) in the Jericho 1 well, 95 km west of the Mount Beaufort Anticline, which includes red-beds and tuffs, has been correlated with the Buckabie Formation in the Adavale Basin (red-beds), and is probably equivalent to the Silver Hills Volcanics in the core of the Mount Beaufort Anticline (lava flows, tuffs, and red-beds).

The Silver Hills Volcanics are probably late Upper Devonian to Lower Carboniferous because they overlie the Upper Devonian Retreat Granite and contain *Leptophloeum australe* (Appendix).

The maximum thickness recorded is 1 500 m along the western margin of the Anakie Inlier west of Clermont, and a similar thickness may be present in the Mount Beaufort Anticline. The formation thins to the north, and only a thin veneer remains in places on the Anakie Inlier. At least 600 m is present east of the inlier.

Cycle 2: Telemon, Scartwater, Mount Hall, and Raymond Formations

The relationships between the Telemon, Scartwater, Mount Hall, and Raymond Formations are shown in Figure 7. The succession consists mainly of fluviatile sediments. The Mount Hall Formation, the best marker in the basin, consists of grey quartz sandstone, pebbly quartz sandstone, and conglomerate. It consists of a belt of pointbar and channel log deposits laid down by a meandering system of northerly flowing rivers in the central part of the basin to the west of the Anakie Inlier. The pointbar and channel log deposits are underlain by, interfinger with, and grade laterally into floodplain deposits derived mainly from the south, and piedmont alluvial plain deposits derived from the sides of the basin. These fluviatile sediments have been mapped as the Telemon Formation in the south and as the Scartwater Formation in the north (Fig. 22). The Mount Hall, Telemon, and Scartwater Formations are overlain by the fine fluviatile sandstone and mudstone of the Raymond Formation.

Telemon Formation

The Telemon Formation (SQD, 1952; Hill, 1957) crops out in the cores of the Telemon, Nogoa, and Mount Beaufort Anticlines in the south, along the eastern margin of the basin west of Anakie, and in the cores of the Narrien and Beresford Anticlines in the central part of the basin. An equivalent sequence of the Scartwater Formation crops out in the north (Fig. 11).

In the Nogoa Anticline, the formation rests unconformably on the Silver Hills Volcanics, and in the Telemon Anticline unconformably overlies the Silver Hills Volcanics, Anakie Metamorphics, and Retreat Granite. The Telemon Formation and Silver Hills Volcanics are also exposed in the Mount Beaufort Anticline and along part of the eastern margin of the basin. The presence of conglomerate at the contact suggests that it is probably disconformable. The base of the Telemon Formation is not exposed in the Narrien and Beresford Anticlines. The Telemon Formation interfingers with the overlying Mount Hall Formation, and is overlain by the Raymond Formation where the Mount Hall Formation is absent. The relationship between the Telemon and Mount Hall Formations is discussed on page

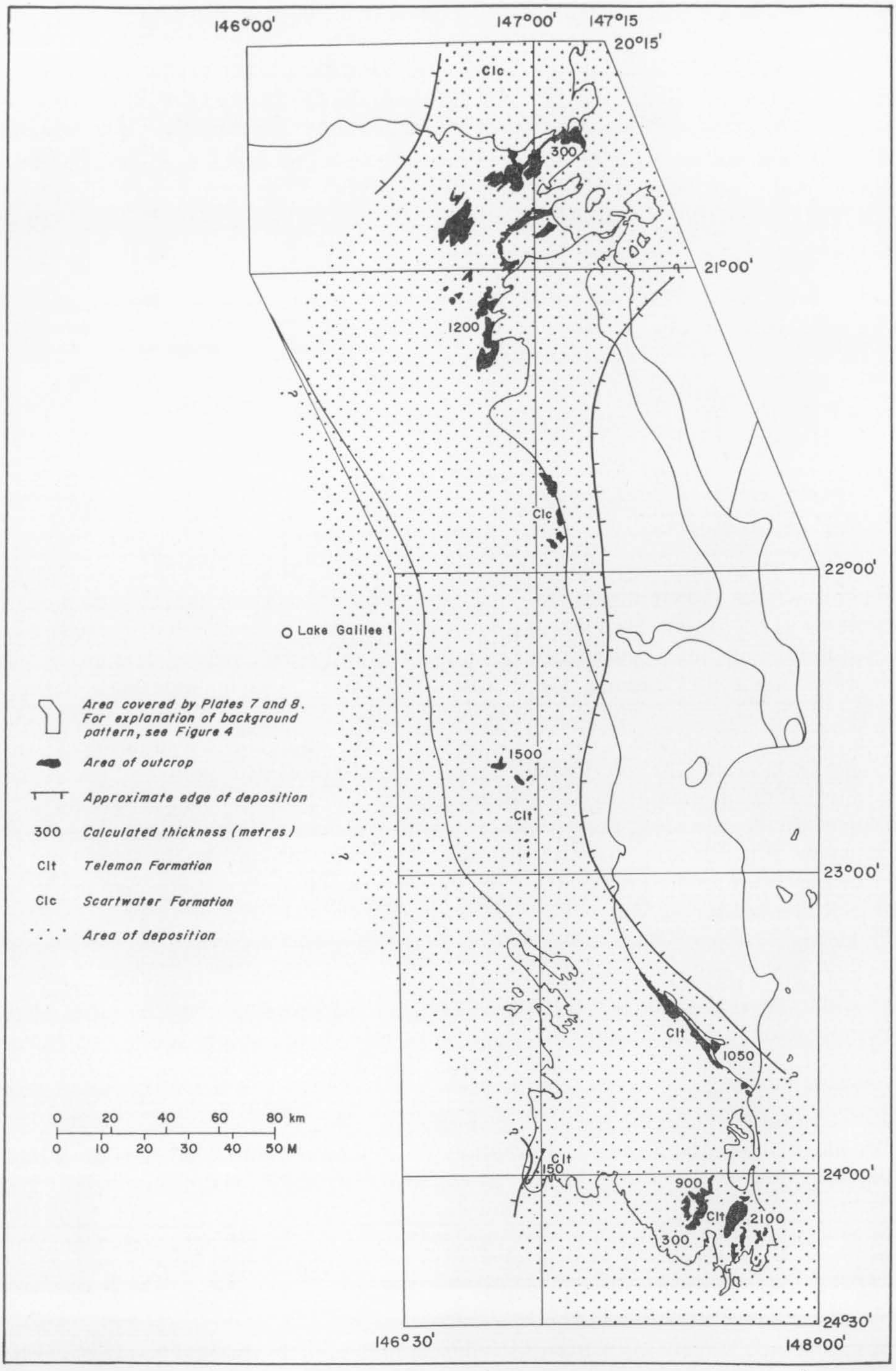

Figure 11. Palaeogeography of the Telemon and Scartwater Formations.

34. West of Clermont, the Telemon Formation is overlapped by the Raymond Formation.

In the Nogoa and Telemon Anticlines, the formation can be subdivided into a basal sequence of conglomerate and conglomeratic sandstone and an upper sequence of fine-grained sediments and limestone. The conglomerate is commonly cross-bedded and consists of well rounded pebbles and cobbles of milky quartz, quartzite, schist, feldspar porphyry, and various other igneous rocks set in a poorly sorted coarse matrix of rock fragments, quartz, and feldspar. Most of the pebbles and cobbles in the basal conglomerate in the Telemon Anticline consist of volcanics similar to those in the underlying Silver Hills Volcanics. The conglomerates are interbedded with reddish brown flaggy lithic sandstone, chert, shale, mudstone, and tuffaceous sandstone.

The finer upper part of the formation consists mainly of olive-green, brown, and red quartz sandstone, arkose, and lithic sandstone, interbedded with vari-coloured mudstone and hard red siltstone. The thin bands of concretionary and algal limestone throughout the upper part of the formation are usually interbedded with the mudstone. The individual algal colonies are commonly spheroidal, dome-shaped, and cylindrical. The sediments are generally cross-bedded, and faint graded bedding, sole marks, and current striations can be seen in some of the sandstones.

West of Anakie, the Telemon Formation is generally finer in grain than in the south, and cannot be subdivided. It consists mainly of olive-green mudstone and shale with thick interbeds of sandstone and some conglomerate. The conglomerate forms only a small part of the formation, and occurs at the base and in the upper part of the sequence (Fig. 12). The sandstones are green and grey, fine to coarse, poorly sorted, and generally well bedded. They consist mainly of quartz (65-75%), with varying proportions of feldspar and rock fragments, and very little matrix. The rock fragments are mainly chert, quartzite, mica schist, sedimentary rocks, and some grains of granite. Some of the sandstones contain pebbles or cobbles of quartz, and subordinate purple acid volcanics, low-grade metamorphics, and chert. Thin interbeds and concretions of limestone are present.

The formation crops out in a narrow belt in the east limb of the Mount Beaufort Anticline. Most of the sequence in the anticline was previously included in the Telemon Formation (Veevers et al., 1964b), but they are now mapped as Silver Hills Volcanics (see p. 26). At the base of the Telemon Formation there is a boulder conglomerate containing boulders of flow-banded and spherulitic rhyolite up to 50 cm in diameter set in a matrix of pebbly lithic sandstone. The conglomerate contains thin interbeds of lithic sandstone, and is overlain by purple siltstone, thin beds of agglomerate and tuff, and olive-green mudstone containing cushions of algal limestone and thin interbeds of lithic sandstone.

In the Narrien Anticline, feldspathic quartz sandstone, green mudstone, and a little fine and coarse acid tuff crop out in two small areas. In the Beresford Anticline, the Telemon Formation consists of a thick sequence of olive-green and brown mudstone with some limestone, overlain by 600 m of interbedded quartz sandstone and mudstone, which can be regarded as a transitional sequence between the Telemon and Mount Hall Formations.

The thickness of the Telemon Formation ranges from 2 100 m in the Nogoa Anticline to 150 m in the Mount Beaufort Anticline (Fig. 11). The lower conglomeratic sequence thins rapidly to the west and north from 600 m in the Nogoa

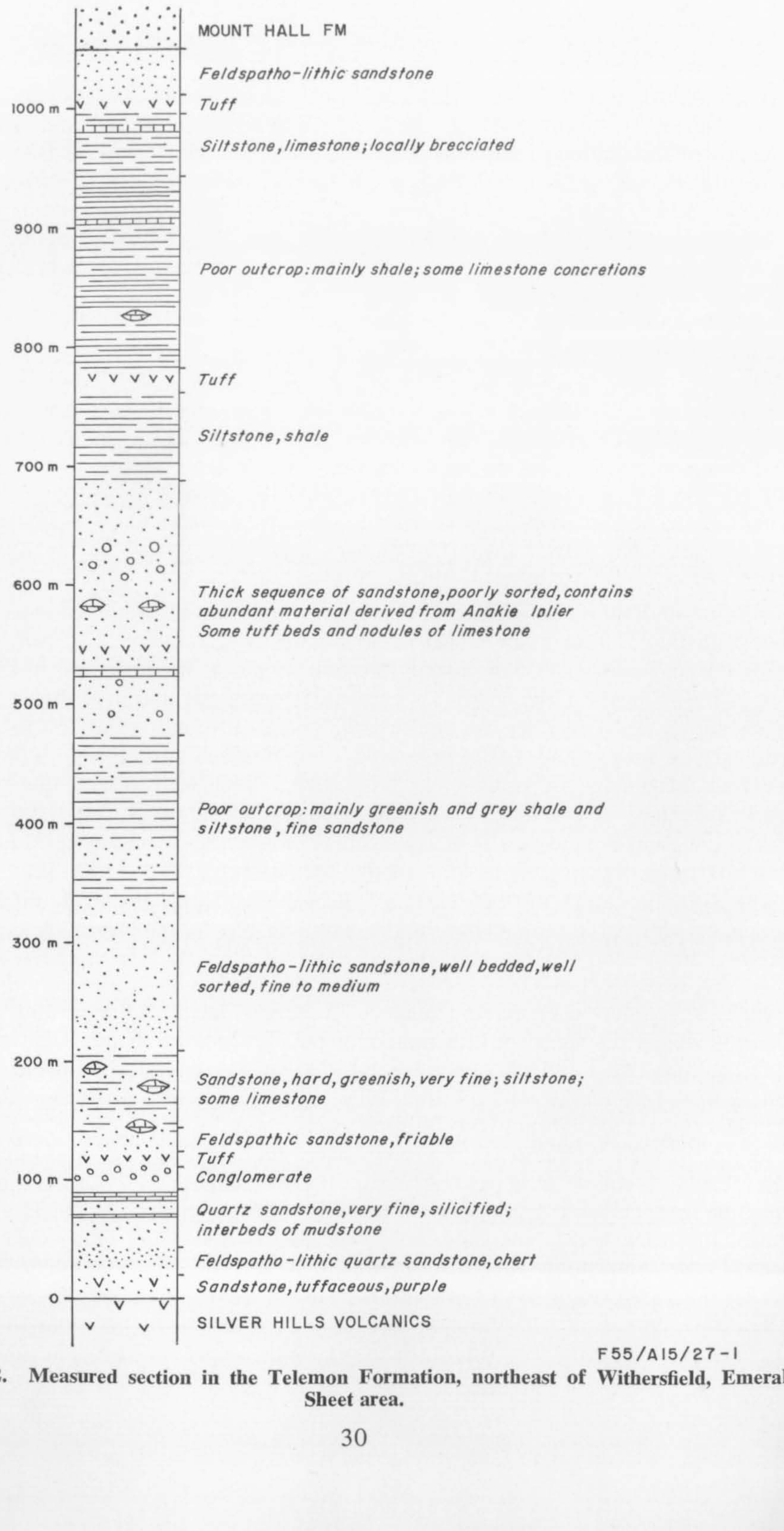

Figure 12. Measured section in the Telemon Formation, northeast of Withersfield, Emerald Sheet area.

Anticline to about 15 m in the Telemon and Mount Beaufort Anticlines and along the eastern margin of the basin west of Anakie.

The only fossils found are plants, algae, fish scales, and the branchiopod *Leaia* (SQD, 1952). None of the fossils is diagnostic, but the formation is considered to be Lower Carboniferous (Appendix).

Scartwater Formation

The name Scartwater Formation was introduced by de Bretizel (1966) for the sequence between the St Anns and Mount Hall Formations. The name is derived from Scartwater homestead in the northeastern part of the Buchanan Sheet area (Olgers, 1970). The type area is 16 km south of the homestead.

The formation crops out in a long narrow belt along the northeastern margin of the basin, in isolated areas west of Scartwater homestead, and in a northeasterly belt extending from Dandenong Park homestead to Glenroy homestead.

The Scartwater formation consists mainly of quartz sandstone interbedded with mudstone and subordinate thin beds of limestone conglomerate, tuff, and lithic sandstone. The sandstone is brown, grey, and greenish grey and is commonly

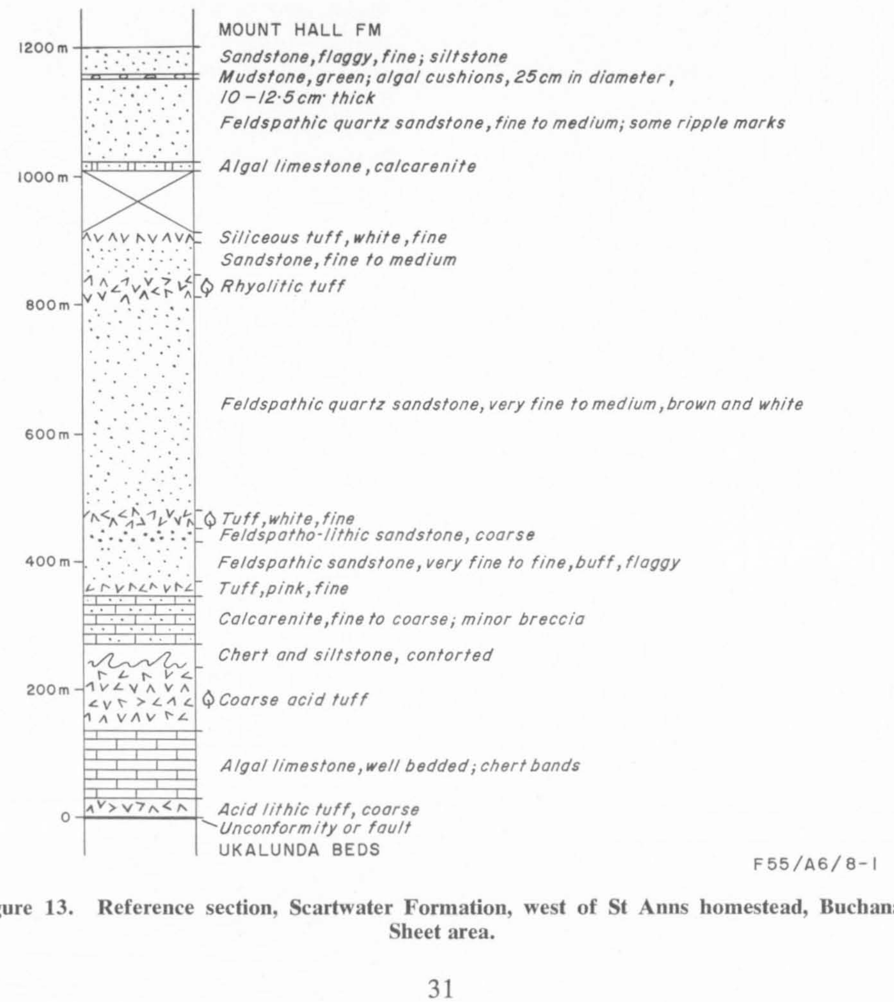

Figure 13. Reference section, Scartwater Formation, west of St Anns homestead, Buchanan Sheet area.

composed of quartz with a little feldspar, rock fragments, and clay matrix. It is generally well sorted and well bedded, and ranges from very fine to coarse. Small-scale cross-bedding and ripple marks have been observed. The mudstone is olive-green and commonly contains calcareous concretions up to 30 cm in diameter and 5 to 7½ cm thick.

In the type area (Fig. 13) the formation consists mainly of sandstone with a thick sequence of algal limestone near the base; several beds of tuff are also present. The proportion of mudstone increases to the north of the type area; south of Cranbourne homestead sandstone and mudstone are present in about equal proportions, and along the northern margin of the basin, north of the Burdekin River, mudstone predominates.

The lower part of the formation is well exposed northwest of Cranbourne homestead, where it disconformably overlies acid volcanics of unit D/Cv. The sequence consists of conglomerate, containing pebbles of volcanic rock up to 12½ cm in diameter, overlain by olive-green mudstone with thin interbeds of fine sandstone, followed by a bed of nodular limestone containing fish scales, some lithic sandstone, and a massive conglomerate containing cobbles of porphyritic acid volcanic rocks up to 20 cm in diameter. The conglomerate is overlain by green mudstone interbedded with fine sandstone. About 450 m above the base of the formation there is a thin sequence of plant-bearing tuff and crystal lithic tuff interbedded with mudstone and sandstone. The upper part of the sequence southwest of Cranbourne homestead consists mainly of fine to medium-grained sandstone and mudstone. The sandstone is thin to thick-bedded and well bedded.

The formation is about 1 200 m thick in the type area, but it thins to about 300 m in the Burdekin River area.

The Scartwater Formation contains a rich Lower Carboniferous flora. It disconformably overlies the St Anns Formation and unit D/Cv, and is overlain by and interfingers with the Mount Hall Formation. In the southern part of the basin it is correlated with the Telemon Formation.

Mount Hall Formation

The Mount Hall Formation was originally named Mount Hall Conglomerate (SQD, 1952; Hill, 1957) after the type locality at Mount Hall in the Telemon Anticline. The formation crops out in the cores of a large number of anticlines and along the eastern margin of the basin west of Anakie and southeast of Mount Douglas homestead; it was probably encountered in the Warrong 1 well south of the Drummond Basin outcrop belt (Fig. 5; Table 3).

Figure 14 shows the distribution of the formation, isopachs, prevailing current directions, and probable limits of the depositional basin. The basin can be subdivided into a central belt of fluviatile deposits laid down by a meandering system of rivers flanked by floodplain deposits.

The Mount Hall Formation consists mainly of grey quartz sandstone, pebbly quartz sandstone, and conglomerate which form a useful marker throughout the basin. The sandstones consist mainly of angular grains of quartz with a little kaolinitic cement. Some are well sorted and fine-grained, but most are poorly sorted, coarse-grained, and pebbly. The sandstones are thin to thick-bedded and generally cross-stratified. Low-angle planar and trough cross-beds, in units up to 3 m thick, are common. Slumping is also common. Some of the pebbles in the pebbly sandstone are scattered throughout the rock, but most of them are concentrated in pockets and thin bands parallel to the bedding, or on the foreset beds.

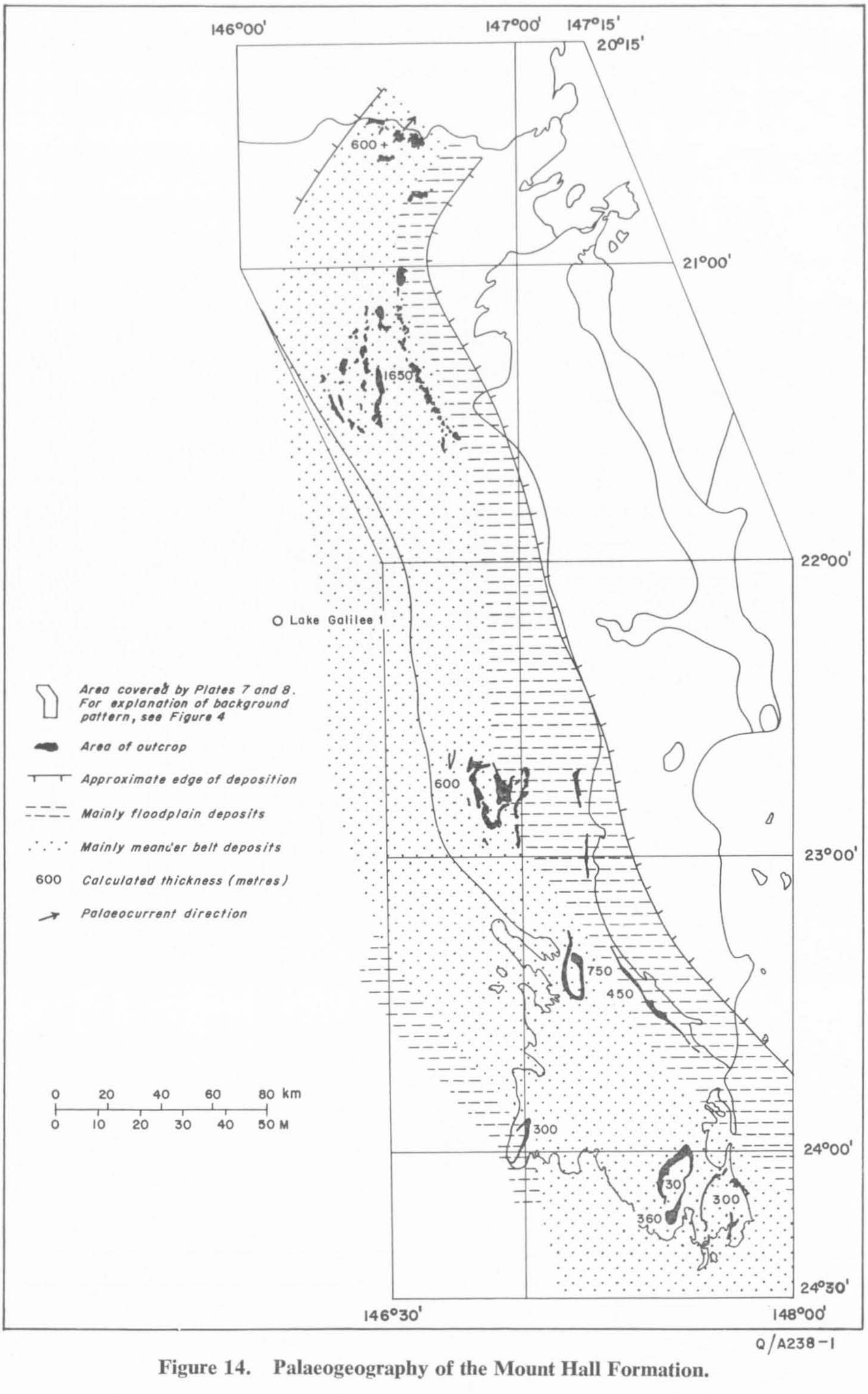

Figure 14. Palaeogeography of the Mount Hall Formation.

The conglomerate consists mainly of pebbles of milky quartz set in a matrix of poorly sorted quartz sandstone, but pebbles of black and green chert, quartzite, and porphyritic volcanic rock are also present. The coarsest conglomerates contain rounded cobbles of volcanic rocks up to 30 cm in diameter, but quartz pebbles ranging from 2½ to 5 cm predominate. The conglomerates are also cross-stratified on a large scale, and cut and fill structures are common.

The thick sequence along the central axis of the basin (Fig. 14) consists mainly of conglomerate and pebbly quartz sandstone (Pl. 3) with some thin beds of fine sandstone and mudstone. Coarse conglomerates, containing boulders up to 30 cm in diameter, are common, particularly in the south; the most northerly occurrence is in the Mount Gregory area. Some of the larger cobbles consist of grey quartz-feldspar porphyry which are probably equivalent to the acid volcanic rocks encountered at the bottom of the Thunderbolt and Towerhill wells to the west. Farther north in the Bingeringo Anticline and east of the Bulliwallah Syncline, the Mount Hall Formation is mainly composed of pebbly quartz sandstone, containing pebbles up to 5 cm in diameter, and quartz sandstone.

Along the eastern margin of the basin southeast of Mount Douglas homestead and west of Anakie, and in the Vandyke Creek area, the typical grey quartz sandstone and pebbly quartz sandstone occur in a number of well defined beds separated by thick beds of olive-green mudstone and lithic and feldspathic quartz sandstone similar to those in the Telemon Formation. West of Anakie, the quartz sandstone beds can be traced for many kilometres on the air-photographs (Pl. 2). The beds range from 9 to 30 m thick, and individual beds commonly maintain a uniform thickness over a considerable distance. In the Nogoa Anticline, however, the formation is represented by a number of isolated lenses up to 3 km wide and 30 m thick. Where the typical Mount Hall Formation sandstone is interbedded with sediments similar to those in the Telemon and Scartwater Formations, the whole sequence has been mapped as Mount Hall Formation because it is impracticable to separate them. The interfingering of the two units east of Withersfield is illustrated in Figure 15. The Mount Hall sandstone pinches out against a ridge in the basement. Farther southeast, the sandstone reappears, interbedded with sediments of the Telemon Formation.

In the north, southwest of Cranbourne homestead, a thick sequence of grey quartz sandstone and pebbly sandstone of the Mount Hall Formation interfingers with and grades northeastwards into a sequence of greenish quartz sandstone and olive-green mudstone of the Scartwater Formation. East of the Suttor River, in this same region, the Mount Hall Formation consists of two almost continuous beds of cross-bedded and slumped grey quartz sandstone, up to 15 m thick, which merge near Mount McConnel; this same bed can be traced northward to the Burdekin River where it lenses out. The two sandstone beds south of Mount McConnel are separated by a sequence of sandstone and mudstone, which has been mapped as Scartwater Formation. At Mount McConnel homestead the formation is 24 m thick; to the northeast it grades into sandstone of the Scartwater Formation.

The thickest part of the Mount Hall Formation was laid down in a narrow northerly trending belt directly west of the Anakie Inlier. It attains a thickness of about 3 000 m in the north, but thins rapidly towards the margins of the basin (Fig. 14).

Large-scale cross-stratification is common. In the central part of the basin the cross-beds are commonly about 1 m thick, but range up to 3 m; smaller-scale cross-

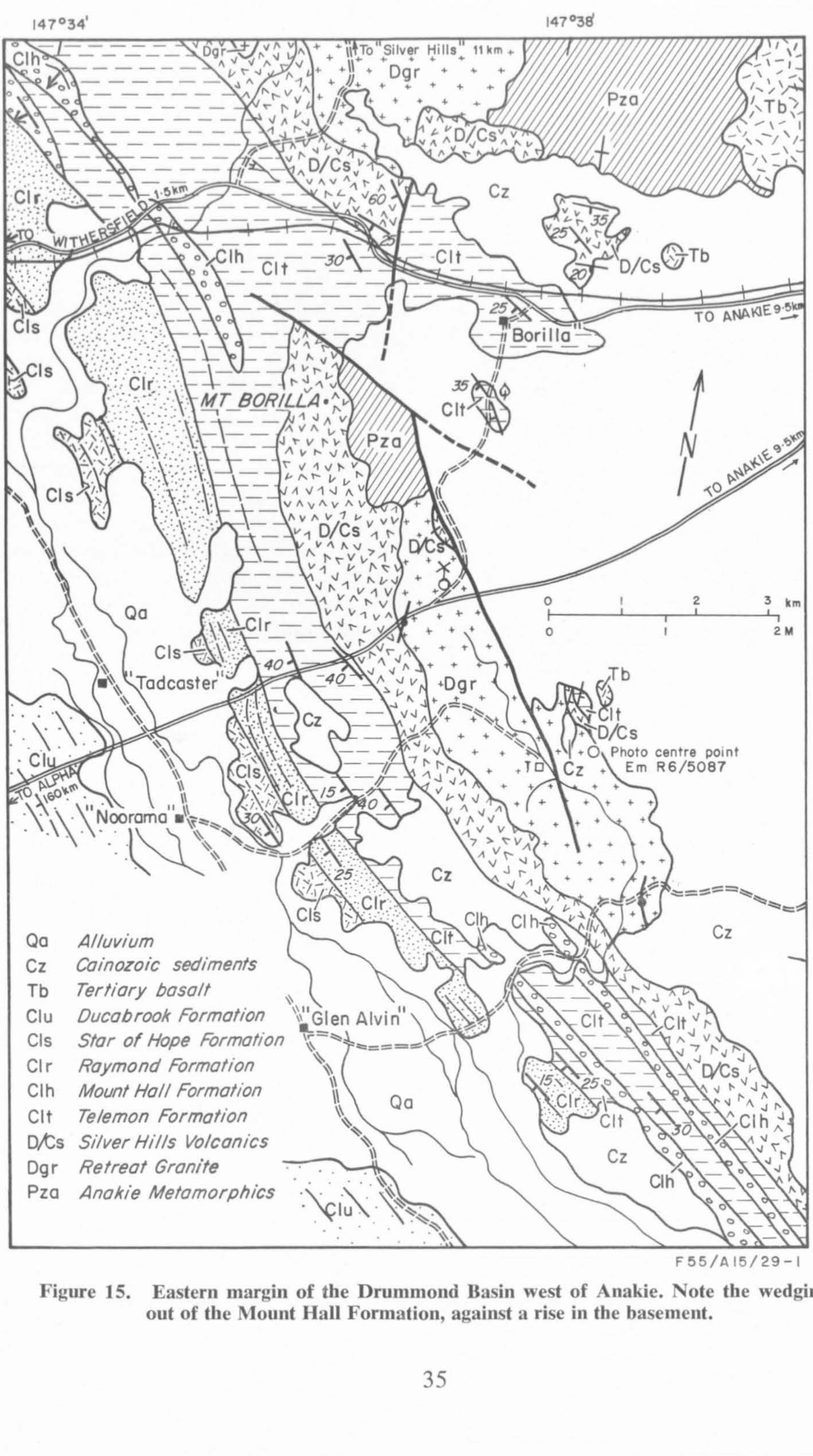

Figure 15. Eastern margin of the Drummond Basin west of Anakie. Note the wedging out of the Mount Hall Formation, against a rise in the basement.

bedding is more common near the margins. The cross-bedding is predominantly of the planar and trough types, with the foreset dips ranging from 15° to 30°.

About 300 cross-bed measurements were made at 28 localities, some of which are shown in Figure 14. All readings were stereographically corrected for tilt. The number of measurements at each locality ranges from 2 in some of the thin sands to 23 in the central part of the basin. The study was hampered by the rubbly nature of many of the outcrops and by poor access in some areas. Also, the Mount Hall Formation crops out in a number of widely spaced anticlines along the axis of the basin and along the eastern margin west of Anakie, so that measurements could not be made systematically. The measurements were made at suitable locations regardless of their position within the sequence, and over as much of the section as possible in each place. The consistency of the results shows that they are adequate to indicate the direction of transport within the basin during the deposition of the Mount Hall Formation. The same direction of transport can probably also be inferred in the closely related sediments above and below.

The current directions between Springsure in the south to southwest of Scartwater homestead in the north range from north to northwest. North and northwest of Scartwater homestead, the trend is southwest to south. Just west of Scartwater homestead the southerly and northerly directions swing abruptly to the east. The easterly currents near Scartwater homestead are at right angles to the closely spaced isopachs, which suggests that the area was close to the eastern margin of the basin. If the downwarp in which the formation was deposited extended eastward, the isopachs would have been parallel to the direction of the cross-bedding.

The Mount Hall Formation was laid down in a basin at least 500 km long and 65 to 80 km wide. The limits of deposition are known southwest of Cranbourne homestead, south of Peak Vale homestead, east of Withersfield, and in the Nogoa Anticline, where the formation lenses out; the limits of deposition are approximately known in the east limbs of the Mount Beaufort Anticline and Mistake Creek Syncline, where the formation is overlapped by the Raymond Formation. The easterly and northerly limits of sedimentation can be deduced reasonably well from these observations. The limit to the west is known, even approximately, only in the Mount Beaufort area, and to the south it extended beyond the Warrong 1 well.

Raymond Formation

The Flaggy Sandstone Group of Shell (SQD, 1952) was renamed Raymond Flaggy Sandstone by Hill (1957) and Raymond Sandstone by Veevers et al. (1964b). The name is here amended to Raymond Formation. The type area is in the southern part of the Telemon Anticline near Raymond Creek in the Springsure Sheet area.

In the south, the formation crops out in a large number of anticlines, in the Star of Hope Syncline, and along the eastern margin of the basin west of Anakie and Clermont; in the north, it occurs in the Bingeringo and Hopkins Anticlines, and in a narrow sinuous northerly belt from the Belyando River to Palamana homestead (Fig. 16). The formation was probably encountered in the Warrong 1 well (Table 3).

The Raymond Formation consists mainly of well bedded fine to medium-grained quartz sandstone and olive-green mudstone. In the type area the sequence consists predominantly of flaggy medium-bedded fine to medium-grained quartz sandstone. The sandstone is commonly buff, greenish brown, and creamy white;

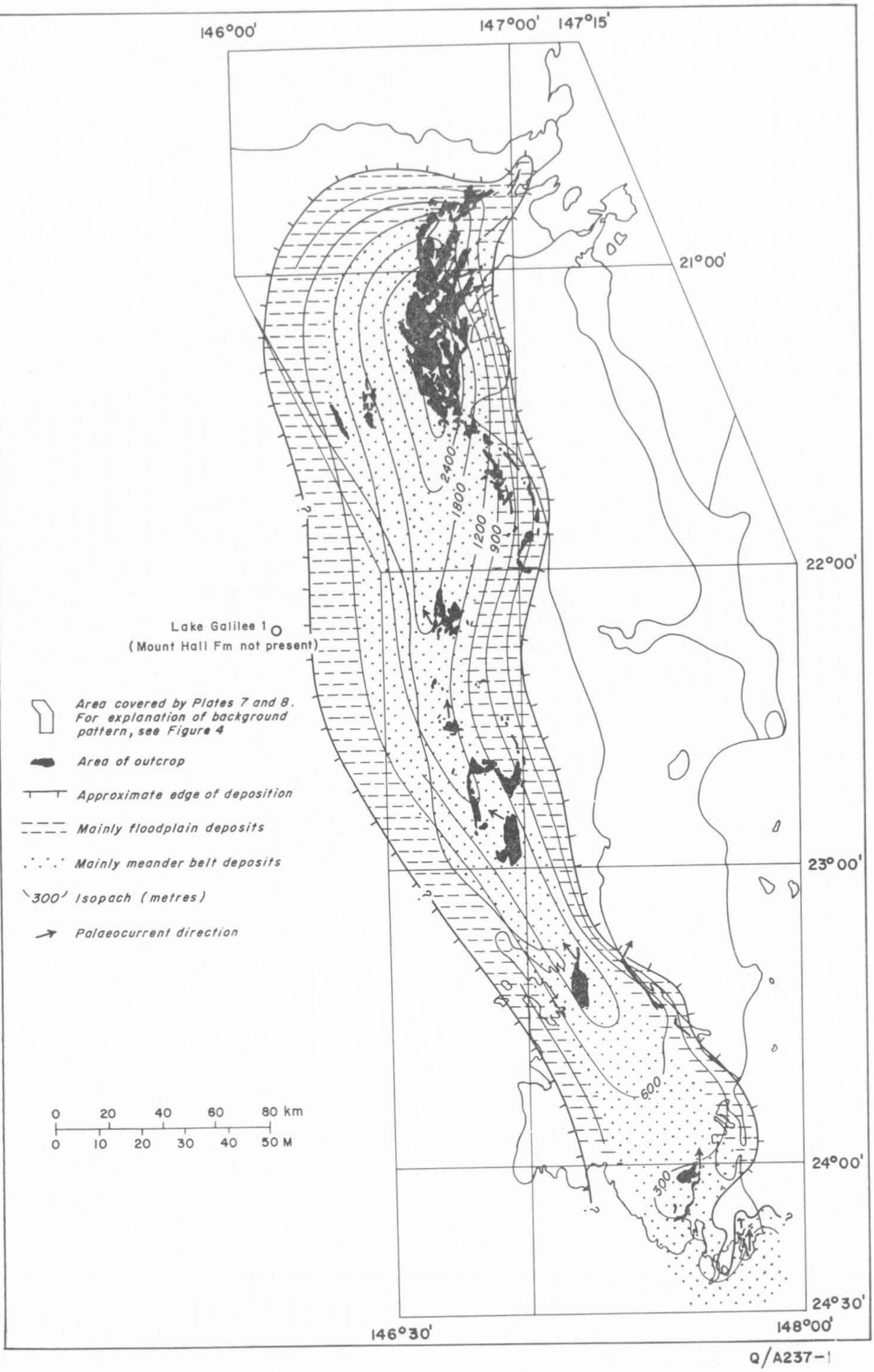

Figure 16. Palaeogeography of the Raymond Formation.

carbonaceous fragments and flakes of mica are common on the bedding planes. The sandstone is well sorted. Most of the quartz grains, which form about 80 percent of the rock are angular; fragments of chert, schist, and feldspar are also present. The sandstone is very well bedded, and individual beds can be traced for several kilometres on the air-photographs. Cross-bedding units, 30 to 60 cm thick, and ripple marks are common. Thin beds of mudstone are interbedded with the sandstone. West of Anakie, the formation consists mainly of mudstone and shale with interbeds of grey and greenish grey flaggy fine quartz sandstone (Pl. 2). The mudstone contains thin lenticular beds of limestone and bands of concretions.

In the Narrien Anticline/Mistake Creek Syncline area, the formation consists of about equal proportions of sandstone and mudstone. The mudstone contains calcareous concretions, and near the base of the sequence there is a 3-m bed of limestone which has a bituminous smell when fractured.

In the north, the formation consists mainly of sandstone similar to that in the type area. It is well sorted and contains up to 75 percent of angular grains of quartz, together with feldspar and rock fragments, and a little matrix. South of Mount Elsie and Harvest Home homesteads the formation consists mainly of mudstone with interbeds of sandstone.

Cross-bedding and ripple marks are common in the sandstone. Large-scale festoon cross-beds up to 30 cm thick occur in the north. Measurements were difficult to obtain, but 12 readings in the Palamana homestead area indicate a northeasterly current direction (Fig. 16), although scattered readings throughout the basin indicate that the currents were generally northerly. Ripple marks, ripple laminations, and small-scale festoon cross-bedding, in units about 1 cm thick, were observed throughout the basin.

The absence of marine fossils, the presence of plant debris, the close relationship with the fluviatile Mount Hall Formation, and the abundance of small-scale festoon cross-bedding and ripple laminations indicate that the Raymond Formation was laid down in a fluviatile environment. The coarser sands were deposited in a long narrow belt along the axis of the basin, and fine sands and interbedded muds were laid down on the adjacent flood-plains (Fig. 16).

The lateral change from sandstone to mudstone can be observed only in the east limb of the Mount Beaufort Anticline, where the formation in the north consists of very well bedded finely cross-bedded sandstone (Pl. 4, fig. 1) with mudstone becoming progressively more common towards the south.

The Raymond Formation is transgressive; it conformably overlies the Mount Hall Formation, and where this formation is absent it rests disconformably on older sediments. In the Nogoa and Mount Beaufort Anticlines, the Raymond Formation rests on the Telemon Formation, in the Palamana homestead area on the Scartwater Formation and Cape River Beds, and in the Red Mountain area west of Clermont on the Silver Hills Volcanics. The formation is overlain by the Star of Hope Formation, except in the southeast, where the Ducabrook Formation overlaps the Star of Hope Formation and rests directly on the Raymond Formation (Pl. 8).

The formation is intruded by an Upper Carboniferous granite stock northwest of Withersfield; basalt sills, probably of Tertiary age, occur in the same area.

Cycle 3: Star of Hope, Ducabrook, Mount Rankin, Bulliwallah, and Natal Formations

Subsidence and widespread volcanism resulted in an abrupt change in sedimentation, particularly in the north. The change from grey quartz sandstone and olive-green mudstone to red volcanolithic sandstone and tuff and conglomerate can be traced throughout the basin. During cycle 3 there was a gradual change from torrential to more mature fluviatile and lacustrine sedimentation, but intermittent volcanic activity continued throughout the cycle. Sedimentation came to an end with the onset of the Kanimblan Orogeny.

Star of Hope Formation

The name Star of Hope Formation was introduced by de Bretizel (1966) for the sequence between the Raymond and Ducabrook Formations in the Narrien Anticline and environs. The formation was briefly described by Olgers (1970). De Bretizel mapped the lower part of Hill's (1957) Ducabrook Formation as Star of Hope Formation, and retained the name Ducabrook Formation for the upper part of the sequence. This subdivision is now used throughout the southern part of the basin. In the north, the formation also overlies the Raymond Formation and overlaps it onto older rocks, and is overlain by the Bulliwallah Formation.

The Star of Hope Formation is a useful marker throughout the basin because it contains varicoloured sediments and volcanics which can be easily distinguished, particularly in the south, from the grey and greenish quartz sandstone, feldspathic quartz sandstone, and green mudstone of the overlying and underlying formations.

The lithology ranges from quartz-pebble conglomerate in the type area to volcanolithic sandstone and tuff in the south, interbedded quartz-pebble conglomerate and tuff in the northwest, and a variety of sedimentary rocks and volcanics in the northeast in the Mount McConnel Syncline. These sediments were all mapped as Star of Hope Formation because of their stratigraphic position and lithogenetic similarity.

In the type area in the Star of Hope Syncline, the formation consists mainly of cross-bedded slightly feldspathic pebbly quartz sandstone and pebble conglomerate similar to those in the Mount Hall Formation. The pebbles in the sandstone and conglomerate consist predominantly of quartz, with subordinate jasper, black chert, fine sandstone, and siltstone. The sequence contains some interbeds of green mudstone, fine feldspatholithic quartz sandstone, and fine tuff.

Along the southern margin of the basin, and in the Pebbly Creek, Zamia, Mount Beaufort, Medway, and Telemon Anticlines the sequence consists mainly of purplish red sediments and fine-grained volcanics. Volcanolithic sandstones predominate. They are fine to coarse, generally poorly sorted, and contain abundant angular and rounded fragments of volcanic rocks and angular grains of feldspar. Fragments of low-grade metamorphic and sedimentary rocks are also present. The purple volcanic grains, which closely resemble the Silver Hills Volcanics, impart the characteristic purplish red colour to the rocks. Poorly sorted pebbly sandstone and conglomerate are interbedded with the sandstone. The conglomerate contains angular and rounded pebbles of volcanic rocks and sediments, up to 5 cm in diameter, and some rounded quartz pebbles. Lenses of pebbly quartz sandstone, similar to those in the type area, were observed along the eastern margin of the basin. The poorly sorted coarse clastic rocks are interbedded with purple and green mudstone, fine tuff, and crystal lithic tuff. The tuffs are generally associated with the finer-grained sediments.

In the flanks of the Blowhard and Bulliwallah Synclines and Bingeringo Anticline the formation consists of acid tuff and tuffaceous and volcanolithic sandstones. At or near the base of the volcanic sequence, there is a thin interval of pebbly quartz sandstone which in places is associated with a bed of green coarse volcanolithic sandstone and fossil wood.

Between the Bulliwallah Syncline and the Cape River, the Star of Hope Formation is tightly folded and consists of a sequence of interbedded pebbly quartz sandstone and thin-bedded acid tuff. Pebbly sandstone predominates in the west, and acid volcanics in the east.

Still farther north, between the Cape River and the basement rocks of the Ravenswood Arch, the formation is deeply weathered and crops out poorly; it consists mainly of fine-grained clastic rocks, including volcanolithic sandstone, mudstone, tuff, and crystal lithic tuff. Conglomerates are common in the Burdekin River area. One of them, containing cobbles and boulders of volcanic rocks, is well exposed in the Fitzroy River 3 km downstream of the confluence with the Suttor River.

The abrupt change from fine quartz sandstone and mudstone of the Raymond Formation to the volcanolithic sandstone, quartz-pebble conglomerate, and tuff of the Star of Hope Formation signifies renewed uplift and volcanism in the provenance areas, probably mainly in the less stable regions to the east and south. The cross-bedding measurements at two localities in the Star of Hope Syncline indicate northwesterly and west-southwesterly current directions (Fig. 17). By far the greatest thickness of sediment accumulated in the northern part of the basin.

In places the Star of Hope Formation contains a rich flora, notably 6½ km east of Lornesleigh homestead (Appendix). Several fossil tree trunks in their original position occur 3 km east of Mount McConnel homestead in the north bank of the Sellheim River.

In the north, the Star of Hope Formation is transgressive. It overlies the Raymond Formation and basement rocks in the northwest, and the Mount Hall and Scartwater Formations in the northeast. In the south, it conformably overlies the Raymond Formation and lenses out in the southern nose of the Telemon Anticline. The formation is conformably overlain by the Ducabrook Formation in the south and grades up conformably into the Bulliwallah Formation in the north.

Ducabrook Formation

The Ducabrook Formation (Hill, 1957) was originally named the Ducabrook Series by Shell (SQD, 1952) after Ducabrook Pastoral Holding in the Emerald Sheet area. De Bretizel (1966) mapped the lower part of the formation in the Narrien Anticline as Star of Hope Formation, and retained the name Ducabrook Formation for the upper part of the sequence. The Ducabrook Formation is the youngest unit in the Drummond Basin sequence, and occurs only in the southern part of the basin (Fig. 18). It can be correlated with the Bulliwallah and Natal Formations in the northern part of the basin and with the Mount Rankin Formation east of the Anakie Inlier. The formation crops out extensively in the south. The topography ranges from fairly flat and gently hilly terrain to rugged ranges with a distinctive air-photo pattern.

The formation is up to 2 100 m thick, and consists essentially of a very well bedded sequence of interbedded sandstone and mudstone with some beds of tuff, reworked tuff, conglomerate, and limestone. Pallister (*in* Schneeberger, 1942), who mapped the Bogantungan-Zamia area west of Anakie in some detail, reports: 'For local correlation, subdivisions were made of the Ducabrook Series. . . . This subdivision is based on the variable predominance of certain lithological types, and no distinct boundary horizons can be traced. Therefore the groups are not

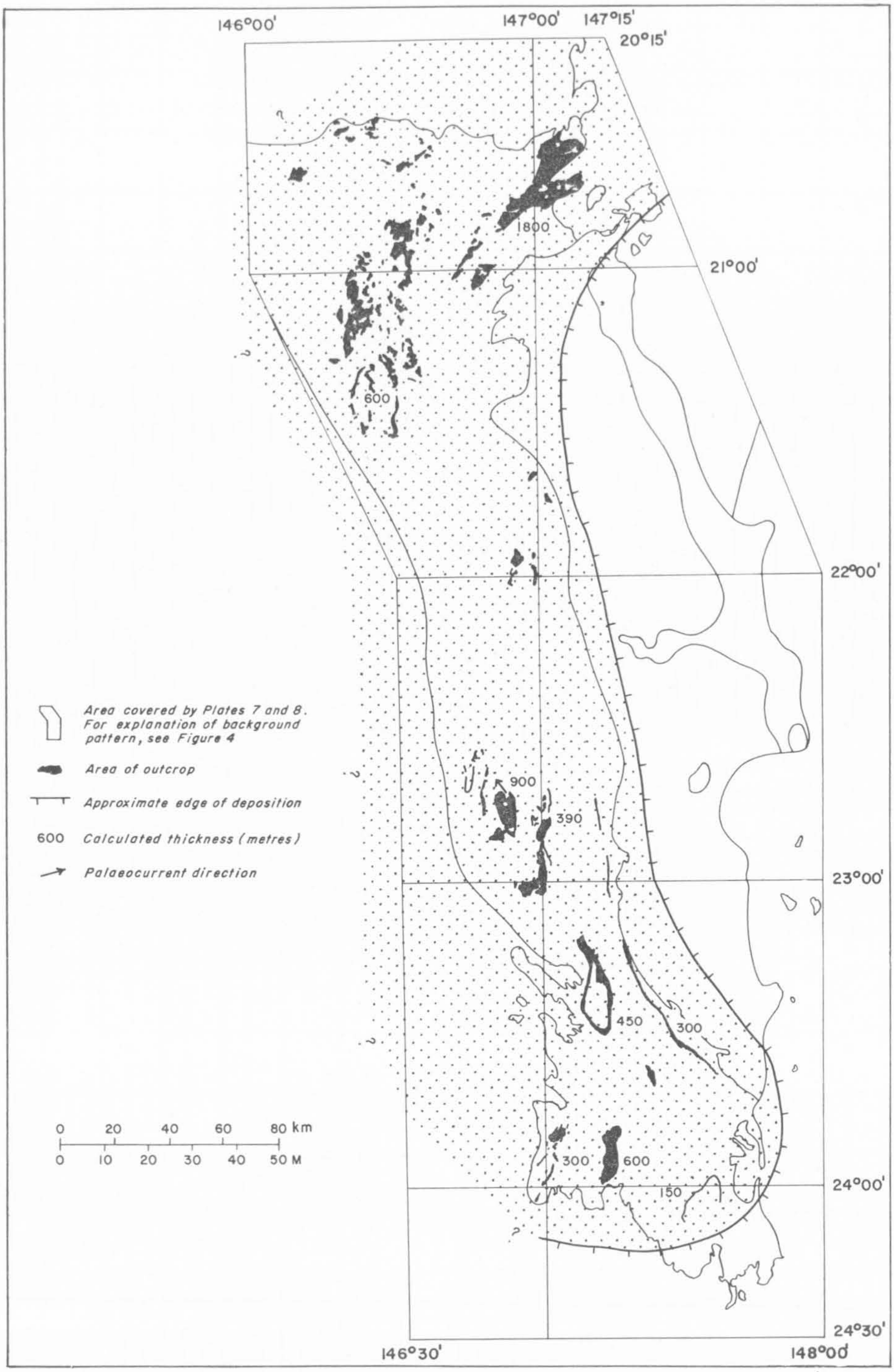

Figure 17. Palaeogeography of the Star of Hope Formation.

expected to be of wide application nor are their separate thicknesses closely comparable even within the limits of the area.' These local abrupt vertical and lateral lithological changes are common throughout the whole area.

The sandstone is green and khaki-brown, thin to thick-bedded, and in places flaggy; it consists mainly of quartz grains with varying proportions of feldspar and lithic fragments, predominantly schist. The proportion of matrix is small in most of the sandstones, and some of them are calcareous. Sorting is generally good but the grains are angular, particularly the quartz and feldspar. The sandstone is commonly cross-bedded, with current striations on the bedding planes. Current ripple marks are also common. Mud clasts and flakes are common near the base of some of the sandstone beds. The sandstone is interbedded with purplish, khaki, and olive-green mudstone, which is generally massive and rarely shaly. Lenses and irregular aggregates of algal limestone are common in the mudstone, and calcareous nodules and cone-in-cone limestone were observed in a few places.

The sequence contains beds of silty limestone, with layers of ooliths and oolitic limestone, which in places contain abundant fish scales. The ooliths are generally less than 3 mm in diameter. Beds of pink rhyolitic vitric tuff up to 3 m thick are interbedded with the sediments, particularly in the upper part of the formation. The lithology in certain areas has been discussed in detail by Schneeberger (1942) and Veevers et al. (1964b).

The Ducabrook Formation rests conformably on the Star of Hope Formation. The contact is exposed along the eastern margin of the basin west of Anakie, and in the core of the Zamia Anticline east of Bogantungan. The formation is unconformably overlain by the Joe Joe Formation, or by the Colinlea Sandstone where the Joe Joe Formation is absent (Pl. 6, fig. 2). About 2 100 m of sediment are preserved in the south-central part of the basin; considerable thinning takes place to the east and north. The formation is intruded by five olivine dolerite and gabbro plugs of the Hoy Basalt, and by numerous related dolerite sills.

The Ducabrook Formation contains fish scales, a spine of the estuarine or freshwater acanthoidian fish *Gyracanthides murrayi* Smith Woodward, palaeoniscid fish remains, the branchiopod *Leaia*, and plants (Appendix), which indicate a Lower Carboniferous age.

The environment of deposition is not fully understood, but is thought to be shallow water fluviatile and lacustrine.

Mount Rankin Formation

The Mount Rankin Beds of Malone (1966) consist of a sequence of volcanic and sedimentary rocks which crop out along the eastern margin of the Anakie Inlier. The sequence disconformably overlies the Silver Hills Volcanics and is unconformably overlain by the Bulgonunna Volcanics in the north and the Bowen Basin sequence in the south. The beds in the northeastern part of the Clermont Sheet area were later subdivided into a lower volcanic unit correlated with the Silver Hills Volcanics, and an upper sedimentary sequence for which the name Mount Rankin Beds was preserved (Olgers, 1970). The name is here amended to Mount Rankin Formation. Malone's (1964) Mount Rankin Beds north of Mount Coolon, which consist mainly of sedimentary rocks, are now included in the Mount Wyatt Formation, and the predominantly acid volcanic sequence between Mount Coolon and Mount Rankin is mapped as Silver Hills Volcanics.

The Mount Rankin Formation crops out in a small syncline and anticline east of

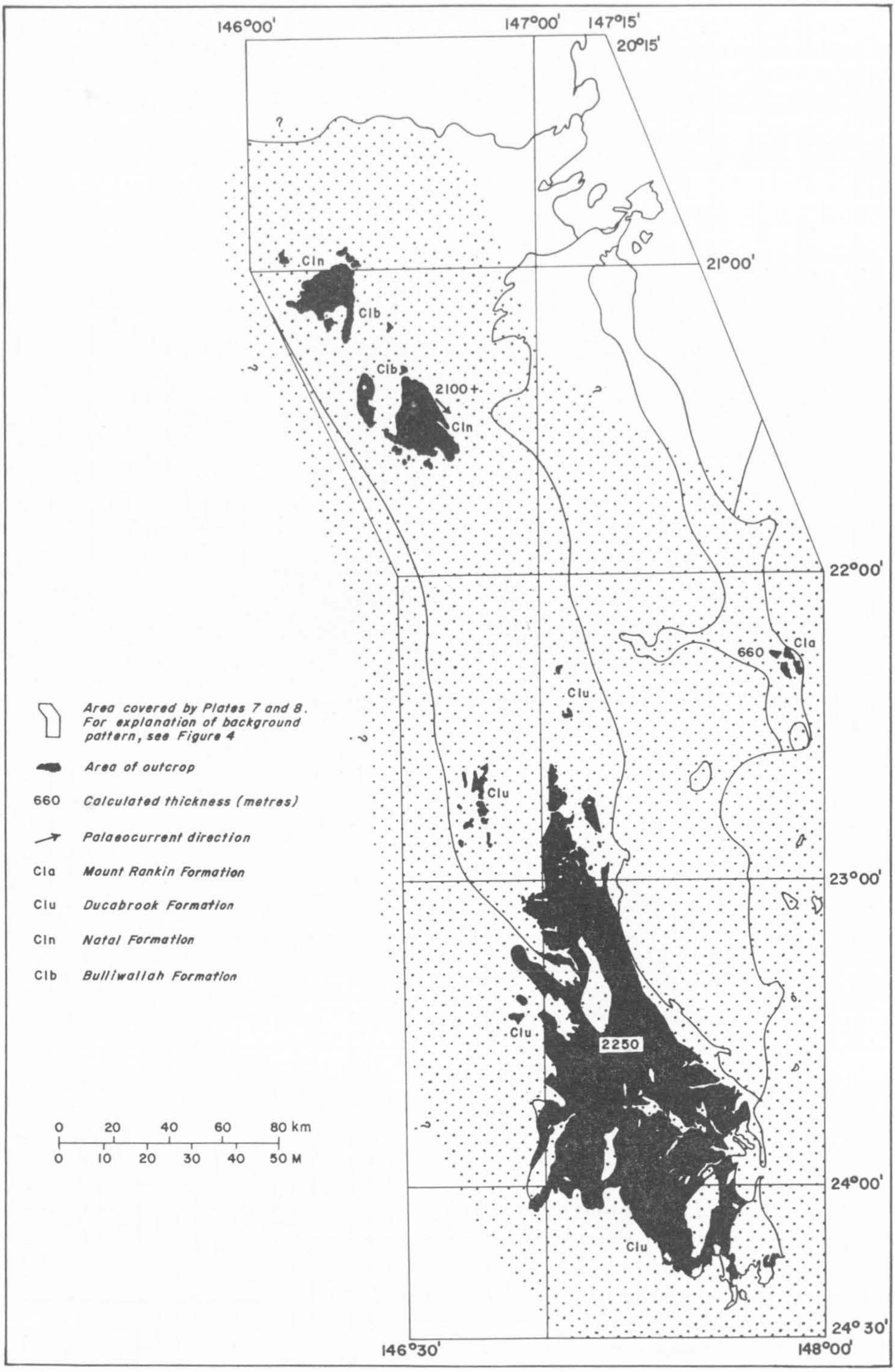

Figure 18. Palaeogeography of the Mount Rankin, Ducabrook, Bulliwallah, and Natal Formations.

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Mount Rankin. The upper part of the formation is overlapped by the Bowen Basin sequence, and only the lower 660 m is exposed.

The Mount Rankin Formation consists of (from the base upward): well bedded feldspathic and lithic quartz sandstone and lithic sandstone interbedded with green and grey mudstone and chert; intraformational conglomerate containing abundant debris derived from the underlying sediments and Silver Hills Volcanics; well bedded grey chert; some tuff; greenish poorly sorted sandstone, containing up to 70 percent quartz and varying amounts of feldspar and lithic fragments including chert and mica schist, interbedded with green mudstone, feldspathic sandstone, and some beds of conglomerate containing abundant pieces of green sedimentary rock. The formation rests disconformably on the Silver Hills Volcanics and contains a rich Lower Carboniferous flora (Appendix).

Bulliwallah Formation

The name Bulliwallah Formation was introduced by de Bretizel (1966) for the sequence resting conformably on the Raymond Formation in the Bulliwallah Syncline in the eastern part of the Buchanan Sheet area. De Bretizel's Bulliwallah Formation has been subdivided into two units: the name Bulliwallah Formation has been retained for the lower part of the sequence, which comprises about 1 800 m of sedimentary rocks, and the upper unit has been named the Natal Formation. It comprises 300 m of sediments in the centre of the Bulliwallah Syncline and more than 1 200 m northeast of Natal Downs homestead (Olgers, 1970). The Bulliwallah Formation derives its name from the Bulliwallah Range in the eastern part of the Buchanan Sheet area, which is the type area. It occurs only in the northern part of the Drummond Basin and crops out in the Bulliwallah and Blowhard Synclines, in an isolated area south of Natal Downs homestead, and in a northerly trending belt between Natal Downs homestead and the Gregory Developmental Road; it can be correlated with part of the Ducabrook Formation in the southern part of the basin.

The formation consists essentially of well bedded quartz sandstone, interbedded with lithic sandstone, feldspathic sandstone, and thin beds of olive-green mudstone. Interbeds of tuff and volcanolithic sandstone occur in the sandstone near the base of the formation (Fig. 19). The quartz sandstone is greenish grey and fine-grained, and is composed mainly of poorly rounded grains of quartz with some grains of feldspar, chert, volcanic rocks, and metasediments. Some of the thick beds of lithic sandstone and feldspathic sandstone are pebbly. Small-scale cross-bedding and current ripple marks are common, and larger cross-beds, up to 120 cm thick, occur in some of the coarser sandstones.

The poorly preserved plant remains, including *Stigmaria ficoides* Bgt, indicate a Lower Carboniferous age (Appendix).

The abundance of plant debris and small-scale festoon cross-bedding, and the presence of mud cracks, ripple marks, and some large-scale festoon cross-bedding (up to 1 m thick) suggest that the sediments were laid down in a shallow fluviatile or lacustrine environment. Volcanism was common, particularly during the deposition of the lower part of the formation. Current-bedding measurements in the east limb of the Bulliwallah Syncline indicate a southeasterly current direction (Fig. 18).

Natal Formation

The Natal Formation (Olgers, 1969b) rests conformably on the Bulliwallah Formation. The name is derived from Natal Downs homestead in the northern part

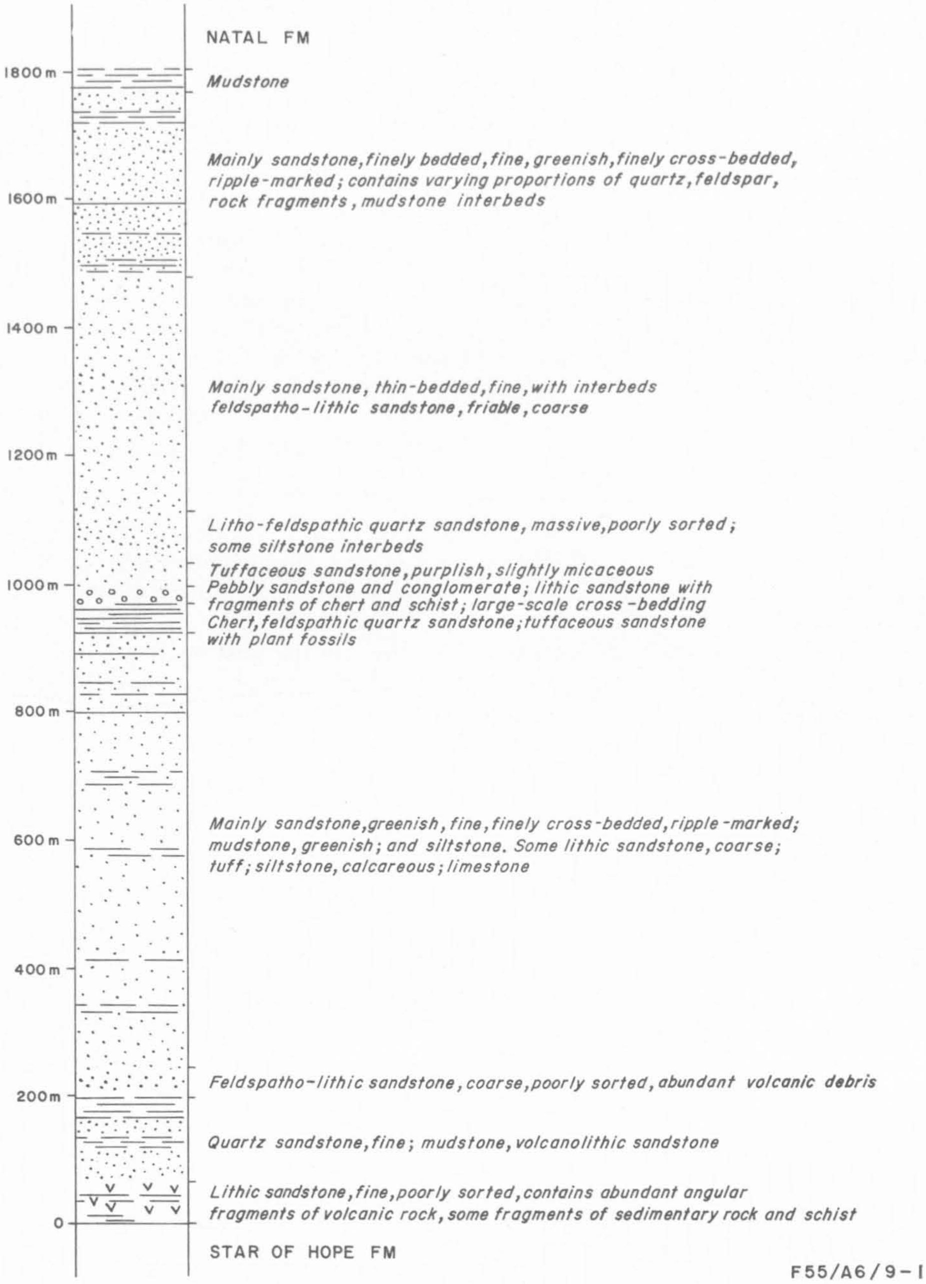


Figure 19. Generalized section, Bulliwallah Formation, east limb of the Bulliwallah Syncline.

of the Buchanan Sheet area. The reference area is northeast of the homestead along the track to Peggurrimma yard.

The formation crops out in the trough of the Bulliwallah Syncline and northeast of Natal Downs homestead. It consists of a monotonous sequence of thin well bedded fine-grained feldspathic quartz sandstone with interbeds of olive-green siltstone and mudstone. The sandstone is greenish grey and khaki and is generally well sorted. It is commonly ripple-marked and finely cross-bedded. The sandstone can be distinguished from the underlying sandstone of the Bulliwallah Formation by the uniform thin-bedding, fine grainsize, and good sorting.

About 300 m of the Natal Formation is preserved in the trough of the Bulliwallah Syncline, where the upper part has been removed by erosion. A considerable thickness, in the order of 1 200 m, crops out northeast of Natal Downs homestead, where the top is concealed by superficial Cainozoic deposits.

The Natal Formation contains some poorly preserved plant remains. It is Lower Carboniferous in age and can be correlated with part of the Ducabrook Formation in the southern part of the basin. It was probably laid down in a fluviatile or lacustrine environment.

Geological History

The development and depositional history of the Drummond Basin is closely linked with the history of the Tasman Geosyncline. The history of the central Queensland part of the geosyncline can be traced back as far as the Lower Devonian. Miogeosynclinal sediments were laid down in the west in Lower and lower Middle Devonian times (lower Adavale Basin sequence and Ukalunda Beds); the eugeosyncline was farther to the east (Dunstable and Theresa Creek Volcanics, Douglas Creek Limestone, and volcanics and sediments at Fletchers Awl and Glendarriwell homestead) (Fig. 20). Most of these rocks were deformed during the late Middle Devonian Tabberabberan Orogeny; the miogeosynclinal Adavale Basin was not affected by the orogeny and sedimentation continued, without a break, into the Upper Devonian, although the marine deposition (Etonvale Formation) gave way to continental redbed sedimentation (Buckabie Formation). During the orogeny, a geanticline rose in the orthogeosynclinal belt and the intermontane Drummond Basin was formed to the west of the geanticline obliquely across the craton margin; most of the sediments in the basin were derived from the geanticline (Fig. 20). Eugeosynclinal sedimentation continued in the east in the Yarrol Basin.

The Drummond Basin can be termed an exogeosyncline—'One in which thick detrital sediments within the craton were derived from uplift beyond the margin of the craton' (Kay, 1951)—or a transverse basin—'one which extends into the craton margin as a prong from the orthogeosynclinal zone' (Krumbein & Sloss, 1951). Transverse basin is preferable, to avoid the use of the term geosyncline for marginal and intracratonic basins.

The oldest sediments in the Drummond Basin were laid down in a shallow sea bordered to the northwest by the Ravenswood Arch and to the southeast by the geanticline (Fig. 21). To the northeast, the basin merged with the marine and paralic environment prevailing in the northern part of the Yarrol Basin (Campwyn Beds; Clarke, Paine, & Jensen, in prep.); the southerly extent of the sea west of the geanticline is not known. There is no evidence that the Upper Devonian sediments encountered in the Lake Galilee 1 well were deposited in the sea; they are possibly transitional (deltaic?) between the marine sediments to the northeast and the continental redbed sequence (Buckabie Formation) to the southwest, which was

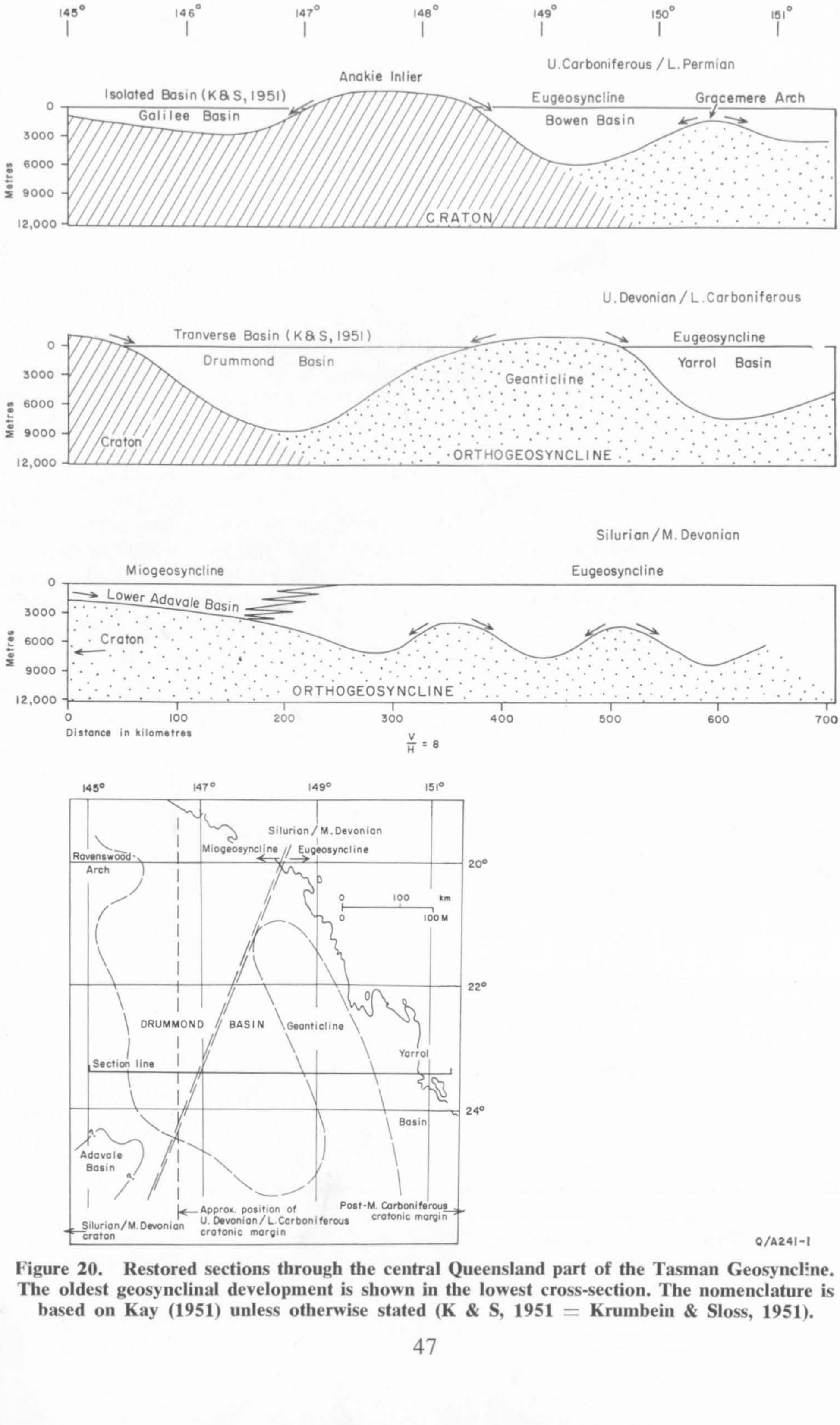


Figure 20. Restored sections through the central Queensland part of the Tasman Geosyncline. The oldest geosynclinal development is shown in the lowest cross-section. The nomenclature is based on Kay (1951) unless otherwise stated (K & S, 1951 = Krumbein & Sloss, 1951).

encountered in the Jericho 1 well and in numerous wells in the Adavale Basin (Fig. 21A).

Only a small part of this extensive Upper Devonian area of deposition, the strait or embayment between the two basement blocks, is now exposed in the north. The area to the northeast, between this embayment and the Yarrol Basin, is now occupied by younger intrusive and extrusive rocks, and its westerly and southerly extent is obscured by younger sediments.

In the north, sediment was brought into the sea by streams draining the neighbouring land areas. Gravel, pebbly sand, and cross-bedded poorly sorted sand, containing abundant coarse terrigenous material and some plant debris, were deposited near the margins, and the finer sediment was laid down in a shallow sea in the central part of the basin. The presence of well preserved shells and the absence of fragmental shell material in some of the gravels indicate that there was little reworking of the littoral deposits. Beds and lenses of limestone, containing algae and worm casts and abundant angular fragments of terrigenous material in places, accumulated near the shore; thin beds of phosphorite were laid down locally in the quiet waters along the margin of the basin.

Sedimentation was interrupted by volcanism toward the end of the Upper Devonian and acid flows and pyroclastics were laid down on land and in water over most of the area (Fig. 21A). The volcanic activity was concentrated in the north and east, where the basement was exposed; tuff and interbedded sediments were laid down in the intervening shallow sea, and towards the end of the cycle some of the tuff was possibly deposited subaerially. In most areas, volcanism ceased abruptly in the late Upper Devonian or early Lower Carboniferous, when widespread subsidence occurred along the entire western flank of the geanticline from the Ravenswood Arch in the north to at least southwest of Springsure. Sedimentation then started again in this long narrow intermontane basin (Fig. 21B). The geanticline was being eroded, and torrential streams transported coarse and fine detritus into the basin. Gravel and intercalated sand were deposited in large piedmont alluvial fans along the margins of the basin, and fine-grained sediments were laid down farther out on the alluvial plains (Fig. 22). Algal and oolitic lime muds, some containing fish scales, accumulated in intermittent lakes. The presence of the minute branchiopod *Leaia* indicates a shallow freshwater environment. Fluviatile and lacustrine sedimentation probably prevailed initially in most of the basin, but shallow epi-continental marine incursions may have occurred, particularly in the north, where thick lime muds accumulated locally, although there is no supporting fossil evidence.

A change in this pattern of sedimentation was brought about either by an increase in the rate of uplift of the margins of the basin, particularly in the south, or by a change of climatic conditions such as increased rainfall. Gravel, pebbly quartz sand, and quartz sand were distributed through the basin mainly by a northerly flowing river system (Figs 21A, 22). The main provenance area was to the south, but the presence of very coarse conglomerate along the axis of the basin as far north as Mount Gregory, and of locally derived lithic sandstone along the margin indicate that all the margins of the basin were being actively eroded. The coarse cross-bedded gravel and pebbly sand were laid down as pointbar deposits interbedded with finer sand and mud. Fine floodplain deposits accumulated nearer the margins of the basin. The river system swept intermittently across the marginal areas and deposited coarser sands and pebbly sands over the floodplain deposits. However, for most of the time the river was confined to the central part of the

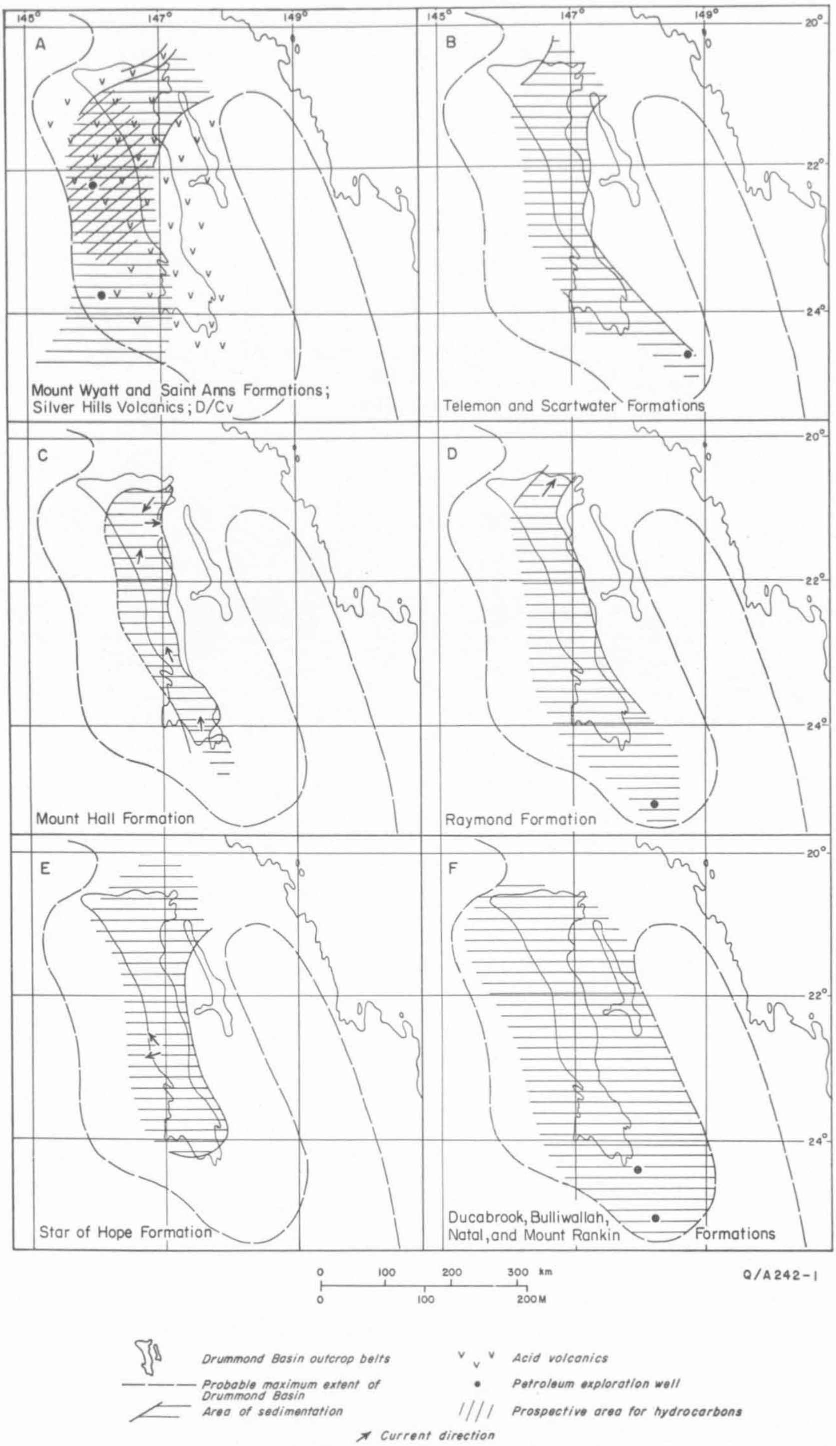


Figure 21. Upper Devonian/Lower Carboniferous palaeogeography of the Drummond Basin.

basin where subsidence was greatest and a great thickness of coarse sediment accumulated. The consistent direction of the current bedding indicates that the palaeoslope was moderately steep and that the stream channel was relatively straight. The river system, after depositing its load in the basin west of the geanticline and south of the Ravenswood Arch, flowed eastwards across the northern part of the geanticline into the sea.

The torrential stream deposition in the central part of the basin gradually diminished as the provenance areas were eroded. The margins of the basin were eroded back and fine quartz sand and mud overlapped most of the older deposits (Fig. 21D). Sand was laid down in the axial part of the basin and interbedded sand and mud along the margins. In the north, the river system changed course from east to northeast (Fig. 21C, D) and now flowed out to sea across the eastern part of the Ravenswood Arch.

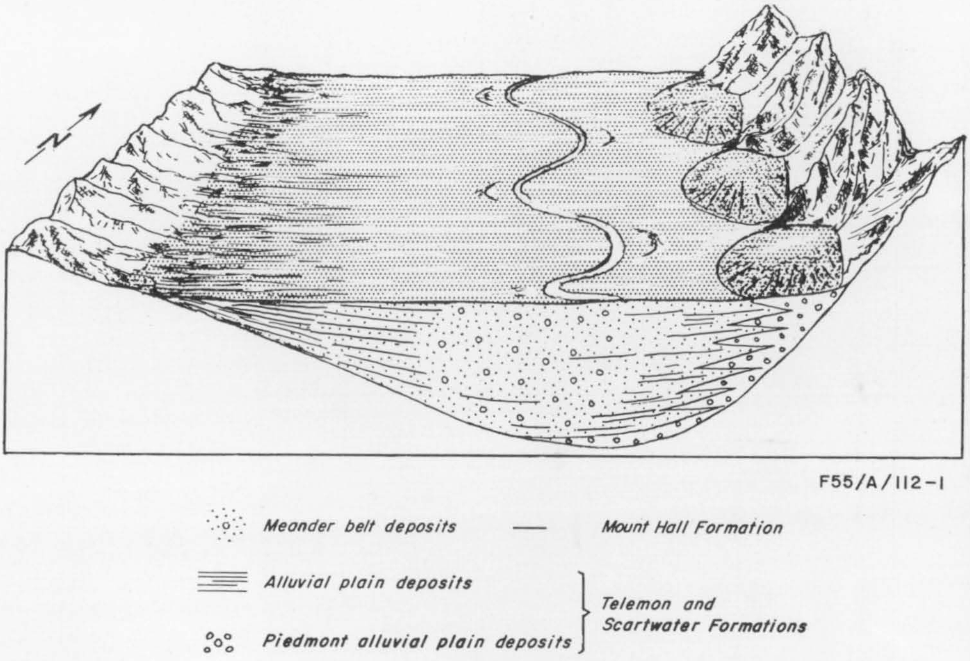


Figure 22. Model illustrating the relationships between the alluvial facies of the Mount Hall, Telemon, and Scartwater Formations.

This mature fluviatile deposition came abruptly to an end when uplift and volcanism were renewed along the borders of the basin. Ashfall tuff and volcanolithic sand and gravel were laid down throughout the basin (Fig. 21E). As the provenance areas were eroded the torrential type of deposition gradually changed to a more mature type of fluviatile and lacustrine deposition (Fig. 21F). Shallow epicontinental marine incursions may have occurred. Intermittent eruptions of ashfall tuff continued along the borders of the basin, particularly in the south.

Sedimentation in the Drummond Basin came to an end in the middle of the Carboniferous with the onset of the Kanimblan Orogeny. The sequence was folded, and the eastern part of the fold belt and western part of the geanticline (Anakie

St Ann's Fault.

Inlier) were uplifted during the Upper Carboniferous, Permian, and Mesozoic to form a cratonic arch which supplied detritus to the Galilee and Bowen Basins (Fig. 20).

In the north, the connexion between the Drummond and Yarrol Basins, between the Ravenswood Arch and Anakie Inlier, was destroyed by plutonic intrusion and vast eruptions of acid volcanic rocks over the truncated Drummond Basin structures.

Structure

The major tectonic units in the region are shown in Figure 4.

Sedimentation kept pace with the slow and continuous subsidence of the basin. The occasional abrupt epeirogenic movements and accompanying widespread volcanism in the border areas caused cyclic sedimentation and local transgression and regression. Deformation began during sedimentation, but the main phase of folding was in the middle of the Carboniferous during the Kanimblan Orogeny, when the region was finally stabilized.

The deformation of the Drummond Basin sequence resulted in the formation of a large number of gentle anticlines and synclines, with a zone of tight folding in the north to the west of the Anakie Inlier (Fig. 23; Pl. 5).

The most striking feature of the folding is the variation in axial trend. In the south the folds trend north-northeast and swing to north-northwest and north, to form a structural embayment, where the axial traces of the folds are concave toward the outer edge of the fold belt (Badgley, 1965, p. 57). It is here referred to as the Bogantungan Embayment. In the north, a structural salient, the Scartwater Salient (Fig. 23), was formed where the fold axes are draped around the northern part of the Anakie Inlier. The folding was accompanied by extensive faulting. The only major faults are the Chinaman Fault in the south and the St Anns Fault in the north, both of which are reverse faults along the mobile eastern margin of the basin. There is also an important northeasterly trending fault zone in the north.

Bogantungan Embayment

The Bogantungan Embayment is named after the township of Bogantungan near its centre. The southern limb of the embayment comprises a series of en echelon north-northeasterly supratenuous folds with long sinuous axes. The structures are most prominent in the Drummond Basin sequence, in which the Mount Beaufort Anticline is the most important. The core of the anticline consists of a rhyolite dome which formed an elevated area during the deposition of the Telemon and Mount Hall Formations, but which was completely overlapped by the Raymond Formation and subsequent units. The flank dips of 45° are the result of differential compaction and middle Carboniferous tectonism. Toward the south, the rocks involved in the folding become progressively younger (from Upper Carboniferous to Cretaceous) and the dip gradually decreases to the south, from 10° to 15° in the Joe Joe Formation, about 5° in the Permian strata, about 3° in the Triassic, about 1° in the Jurassic, to less than 1° in the Cretaceous rocks. The structure is due to differential compaction, and decreases in intensity as the depth to basement increases. Between this zone of long sinuous folds and the eastern margin of the Nebine Ridge, there are a number of very gentle northerly, northeasterly, and easterly trending flexures (Fig. 24). The lack of a distinctive fold pattern

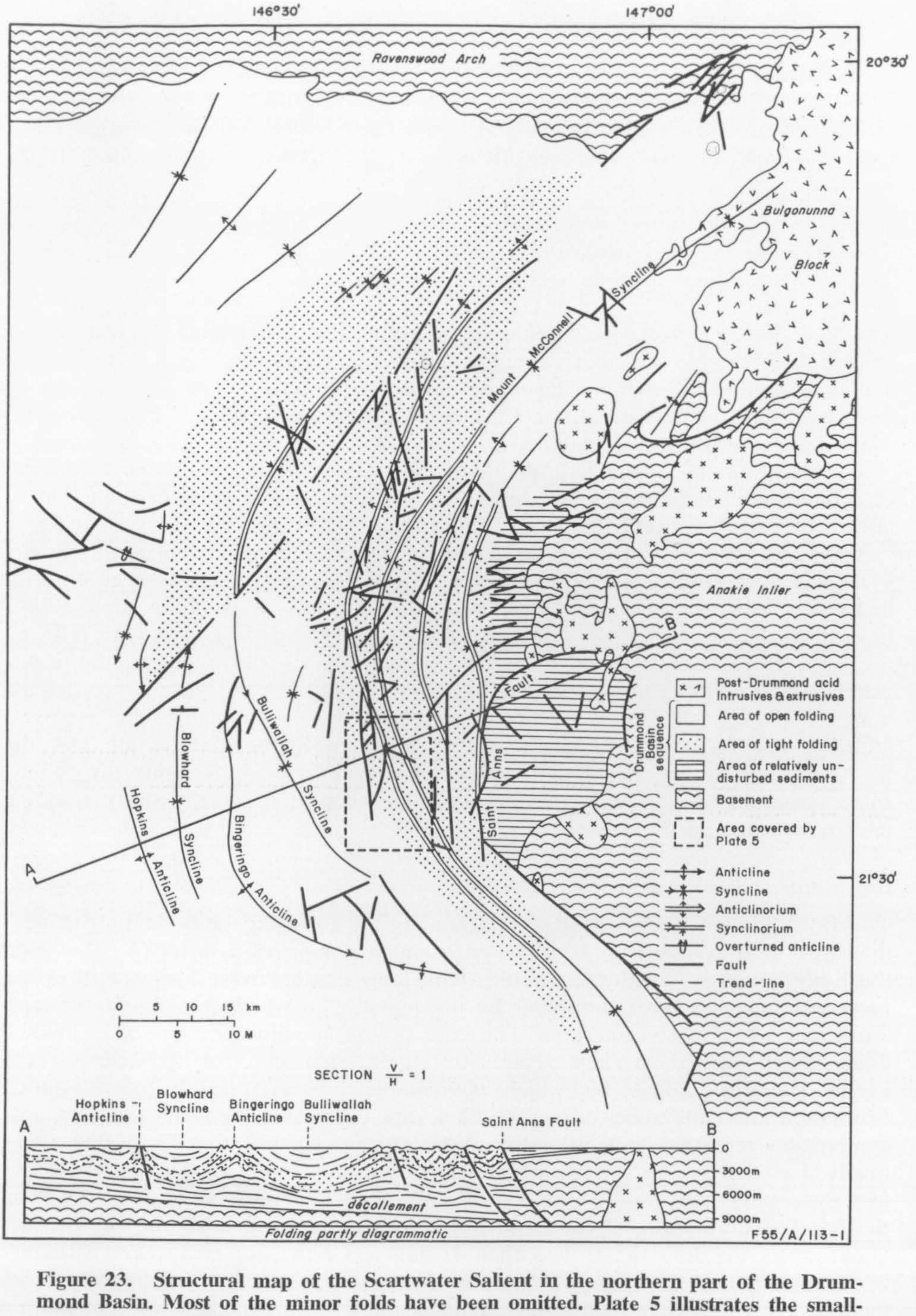


Figure 23. Structural map of the Scartwater Salient in the northern part of the Drummond Basin. Most of the minor folds have been omitted. Plate 5 illustrates the small-scale folding in part of the southern limb of the salient.

in this area may be due to the absence of a pronounced trend in the basement in the central part of the Nebine Ridge.

The north limb of the Bogantungan Embayment trends northwesterly. It is partly faulted against the Anakie Inlier and comprises three sets of north-northwesterly and northerly en echelon folds. The southern set consists of large gentle anticlines and synclines, including the Pebbly Creek and Zamia Anticlines, which are separated from the Anakie Inlier by the Chinaman Fault. The axes of the folds are sinuous and the west flanks are generally steeper. The northwesterly and southwesterly extensions of this zone of folding are obscured by younger sedimentary rocks and basalt. The Chinaman Fault is a large left-reverse oblique slip fault. Farther north and in line with the fault there is another set of en echelon folds which includes the Narrien Anticline and a number of smaller flexures to the southeast and northwest. The folded zone, which plunges to the northwest under younger sediments, is cut by a number of transverse faults which trend at right angles to the fold axes. The most northerly set of en echelon folds, comprising the tightest folds in the embayment, covers a small area near Mount Gregory. It is surrounded by Cainozoic deposits. The change in axial trend from north-northeast in the south limb of the embayment to north-northwest in the north limb occurs abruptly just south of the Bogantungan Syncline (Pl. 7; Fig. 24).

Scartwater Salient

The Scartwater Salient is named after Scartwater homestead. It is an arcuate belt of complexly folded and faulted Drummond Basin sediments draped around the northwest margin of the Anakie Inlier (Fig. 23). The inlier is overlain by and separated from the salient by a sequence of sediments gently dipping to the west. The east-central part of the salient consists of a large number of tight folds (Pl. 5). It is partly separated from the relatively undisturbed sediments to the east by the St Anns Fault, and it is suspected that the remainder of the eastern boundary is also faulted. The folds are concentric and their amplitude decreases to the west. Dips are generally steep. Two anticlinoria and two synclinoria, plunging to the north-northeast and south-southeast, can be recognized within this tightly folded zone which grades to the north, south, and west toward the outer edge of the salient into larger more open structures, the most prominent of which are the Bulliwallah Syncline and Bingeringo Anticline (Fig. 23). The change from tight to open folding is abrupt east of the Bulliwallah Syncline (Pl. 5). The tight folding in this area is restricted to the outcrop belt of the Mount Hall Formation, whereas farther north it also involves the Raymond and Star of Hope Formations.

The Scartwater Salient is cut by a major northeasterly fault zone (Figs 23, 24). The southern part of the zone consists of oblique faults cutting across the regional trend, and the northern part of longitudinal faults parallel to the regional trend. The regional distribution of rock units suggests that the movement on the faults was right reverse oblique slip. The St Anns Fault along the eastern margin of the salient is an important reverse fault, east block up, on which there was also some clockwise movement (left reverse oblique slip).

Structural Interpretation

The Scartwater Salient, the most striking tectonic feature in the region, was formed by a primary compressional force from the east (Fig. 24). Movement took place along northwesterly and northeasterly reverse faults and fault zones, and the Drummond Basin sediments were folded into a series of flexures draped around

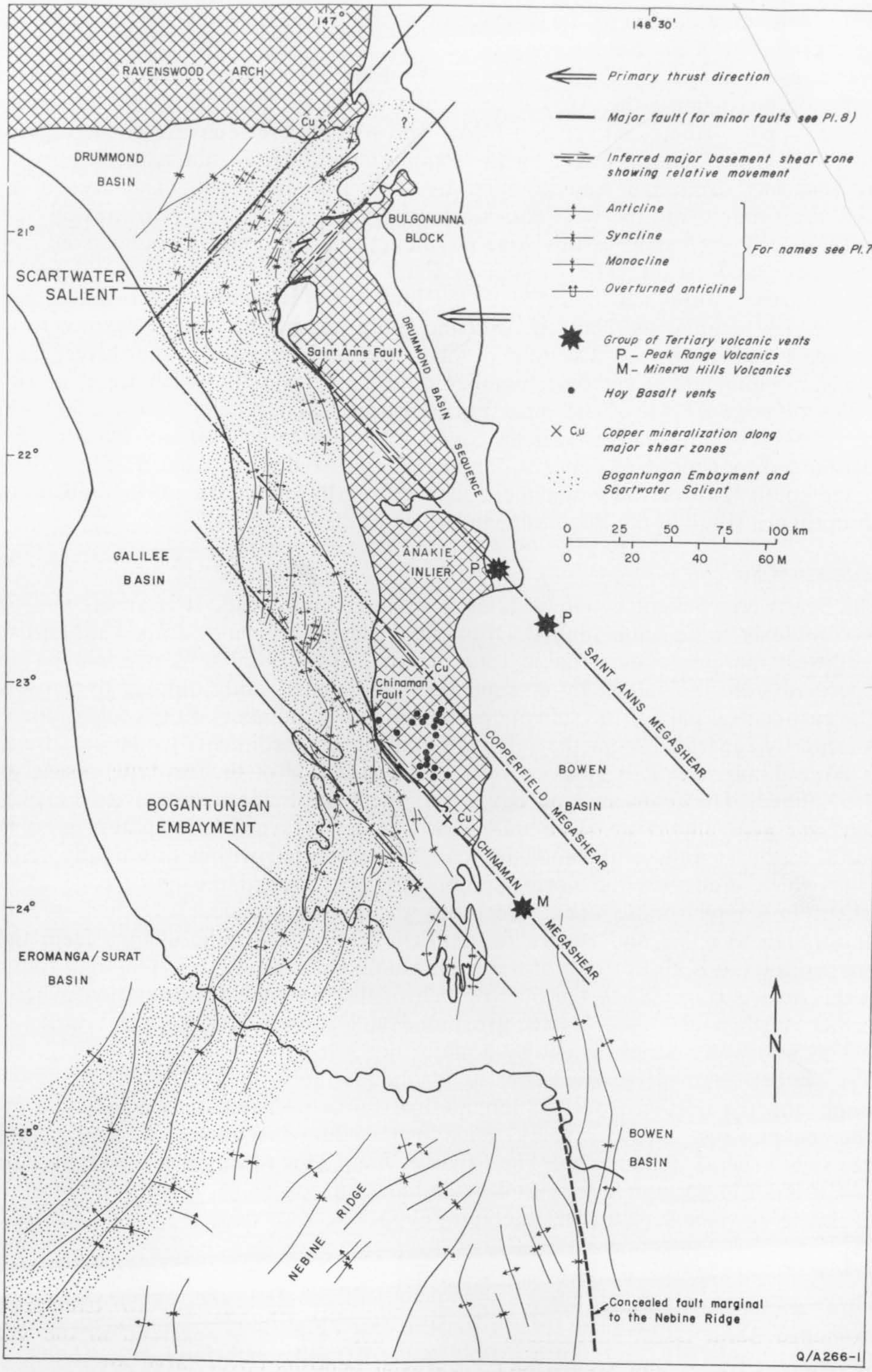


Figure 24. Main structural features.

the apex of the west moving block. The northern limb of the salient was squeezed between this block and the Ravenswood Arch. A décollement was formed at the base of the Drummond Basin sequence (section, Fig. 23). Extensive secondary faulting, both transverse and longitudinal, took place. Movement also occurred along at least two and possibly more major fault zones parallel to those bounding the primary moving block. The most prominent of these is the Chinaman megashear, part of which (Chinaman Fault) forms the southwest margin of the Anakie Inlier. Regional coupling caused by movement on the Chinaman Fault formed a set of en echelon folds in the southwest wall of the fault, and farther northwest, where the megashear is not exposed at the surface as a fault, simple shearing in the basement resulted in the formation of a set of en echelon folds in the Drummond Basin sediments directly overlying the megashear. These folds are cut by a series of slightly en echelon faults which strike perpendicularly across the fold axes (Pl. 7). This fault pattern is in sympathy with the shearing interpretation of the fold pattern.

The supratenuous folds of the southern limb of the Bogantungan Embayment have been discussed on page 51. They were mainly formed by differential deposition and compaction over north-northeasterly basement ridges.

The post-orogenic Upper Carboniferous granitic intrusives (Table 2) and related widespread acid volcanics (Bulgonunna Volcanics) were probably closely associated with the westward thrusting in the northern region. Three stocks, two northeast of Scartwater homestead and one west of Silver Hills homestead, were also emplaced within the Drummond Basin sequence at this time (Pl. 8).

The igneous activity in the Tertiary also appears to be closely related to the megashears. The Peak Range Volcanics were intruded and extruded along a zone in direct continuation of the St Anns megashear, and the Minerva Hills Volcanics along the Chinaman megashear, where it is intersected by the fault along the eastern boundary of the Nebine Ridge (Fig. 24). The Tertiary Hoy Basalt plugs were emplaced mainly in basement rocks between the Chinaman and Copperfield megashears. A northeast trend is discernible, and the plugs were possibly intruded along zones of weakness created by the coupling effect of the megashears. The greater angle between these zones of weakness and the megashears compared with the angle between the Chinaman megashear and the axes of the en echelon folds developed over it in the Drummond Basin sequence is due to the greater competency of the basement rocks.

POST-DRUMMOND VOLCANICS, SEDIMENTS, AND INTRUSIVES

After the middle Carboniferous folding of the Drummond Basin sequence and the uplift of the Anakie Inlier and eastern part of the Drummond Basin fold belt, volcanic rocks were extruded to the east of the uplifted block, and the Bowen and Galilee Basin sequences were laid down to the east, south, and west. The volcanic activity in the north was probably closely associated with the emplacement of Upper Carboniferous acid and basic intrusives. An isolated granite stock was emplaced in the south, west of Silver Hills homestead. The Galilee and Bowen Basin sequences are unconformably overlain by the Jurassic to Cretaceous Eromanga/Surat Basin succession. Volcanic activity was widespread in the Tertiary, and Tertiary and Quaternary superficial deposits cover large areas.

The relationships between the post-Drummond rocks are shown in Figure 25.

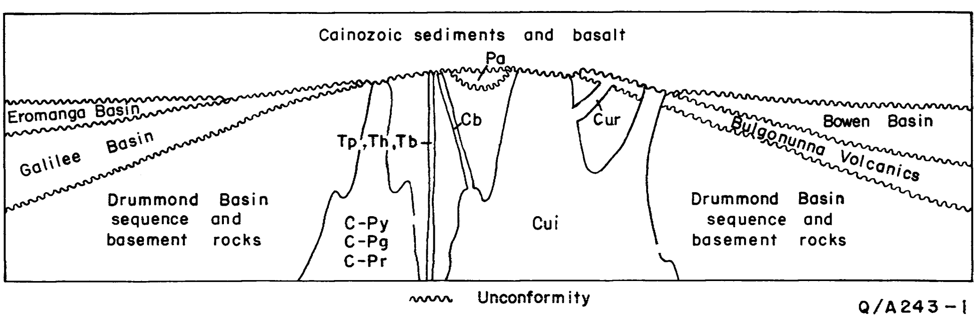
TABLE 2—POST-MIDDLE CARBONIFEROUS INTRUSIVE ROCKS

Age	*Rock Type* (map symbol)	*Relationships*	*Remarks*
TERTIARY	Alkaline trachyte and rhyolite (Tp)	Plugs, domes, and minor flows. Intrusive into Permian and older rocks in Fletchers Awl area NE of Clermont	More extensive in Peak Range SE of Fletchers Awl (Mollan, 1965). (See also Fig. 24)
	Porphyritic olivine basalt; olivine dolerite and gabbro with xenoliths of ultrabasic rocks (Th)	Plugs intrude Anakie Metamorphics, Retreat Granite, and Drummond Basin sequence	Source rock for precious stones, mainly sapphires, found on Anakie gemfields. (See also Fig. 24)
	Olivine basalt, trachybasalt, minor agglomerate (Tb)	Plugs rising above flood basalts E of Clermont. Plug 16 km SSE of Mt McConnel homestead intrudes St Anns Fm	Fillings of vents from which flood basalts were extruded
U. CARBONIFEROUS TO L. PERMIAN	Porphyritic rhyolite and microtrondhjemite (C-Pr)	Ring dykes intruding U. Carboniferous granite and volcanics (Cuv)	Intruded into ring fractures, possibly equivalent to L. Permian high-level granite stocks
	Granodiorite, adamellite, granite, quartz-feldspar porphyry (C-Pg)	Intrude Ravenswood Granodiorite, Mt Windsor Volc, and Drummond Basin sequence	Rim of stock 13 km S of Mt McConnel consists of quartz-feldspar porphyry similar to U. Carboniferous granite and volcanics (Cuv)
	Rhyolite, rhyolite breccia (C-Py)	Volcanic plugs at Mt Cooper, Mt Wickham, Mt McConnel and Mt Hope intrude Ravenswood Granodiorite, Mt Windsor Volc, and Drummond Basin sequence	Lithologically similar to Bulgonunna Volc and quartz-feldspar porphyry dykes (Cur). Probably U. Carboniferous
U. CARBONIFEROUS	Diorite, gabbro, monzonite, basalt, dolerite (Cb)	Intrude Drummond Basin sequence, mainly at St Anns and Mt McConnel homesteads	Age uncertain. Possibly associated with Carboniferous intrusive phase, but could be younger. Basic rocks of Tertiary age present in N region
	Granite, granodiorite, trachyte, rhyolite, quartz-feldspar porphyry (Cui)	Stocks and sills intrude Ukalunda Beds and Drummond Basin sequence	Emplaced in narrow N-NE-trending belt from Twin Hills in S to NE corner of area (Pl. 7). Solitary stock W of Anakie
	Quartz-feldspar porphyry (Cur)	Dykes emplaced in Drummond Basin sequence and along fault between it and Ukalunda Beds	Possibly feeder dykes to Bulgonunna Volc. Equivalent porphyries included in Bulgonunna Volc

Bulgonunna Volcanics

The Bulgonunna Volcanics (Malone et al., 1964) unconformably overlie the Drummond Basin sequence to the east of the Anakie Inlier (Fig. 4). The volcanics have a gentle regional dip to the east and form the basement to the Bowen Basin sequence. They consist mainly of porphyritic rhyolite containing quartz and feldspar phenocrysts in a flow-banded glassy or felsitic groundmass, with subordinate welded tuff, crystal tuff, and volcanic breccia and agglomerate. The volcanics are cut by small acid intrusives of similar composition; they are probably vent fillings which can possibly be correlated with the quartz-feldspar porphyry dykes (Cur) in the Drummond Basin sequence in the Sellheim River area. Several rhyolite domes in the Bulgonunna Volcanics can be recognized on the air-photographs by their dense joint pattern; they consist of vertically flow-banded rhyolite surrounded by massive breccias containing blocks of flow-banded rhyolite up to 2 m in diameter. Mount Hope, 11 km northwest of Mount Douglas homestead, is probably an exhumed rhyolite dome (C-Py) intruding the St Anns Formation.

The stratigraphic position of the Bulgonunna Volcanics suggests that they are Upper Carboniferous in age, and they are probably genetically related to the Upper Carboniferous granitic intrusions.



Tp,Th,Tb — *Acid and basic intrusives*
Pa — *Blair Athol Coal Measures*
C-Py,C-Pg,C-Pr — *Granite, rhyolite*
Cb — *Basic intrusives*
Cur — *Quartz - feldspar porphyry*
Cui — *Granite*

Figure 25. Relationships of the post-Drummond rocks.

In the north there are a number of isolated outcrops of acid to intermediate lavas and pyroclastics (Cuv). They are younger than the Ravenswood Granodiorite, and those at Camp Oven Mountain are younger than the Drummond Basin sequence, that is, they are post-Lower Carboniferous. The volcanics resemble the Bulgonunna Volcanics, with which they can probably be correlated.

Bowen/Galilee Basin Sequence

The Upper Carboniferous to Triassic Bowen and Galilee Basin sequences were laid down to the east, south, and west of the uplifted Anakie Inlier and Drummond Basin fold belt. In the south the basins merge across the Springsure Shelf. In the Galilee Basin about 2 700 m of sediment was laid down in the western part of the Buchanan Sheet area, while in the Bowen Basin 6 000 m of sediment was deposited in the Denison Trough in the Springsure Sheet area. On the relatively stable Anakie Inlier/Nebine Ridge axis, on the Springsure Shelf, about 1 500 m of sediment was laid down. The relationships between the units in the Bowen and Galilee Basins are set out in Figure 26.

In the Upper Carboniferous sedimentation started on the Springsure Shelf with the deposition of the glacial and fluvioglacial sediments of the *Joe Joe Formation*. The equivalent sequence (C-P; Fig. 26) was laid down in the Galilee Basin, but the easterly extent of the sedimentation into the Bowen Basin is unknown. The mainly terrestrial *Bulgonunna Volcanics* were extruded contemporaneously in the northeast.

Early in the Permian, subsidence started east of the Anakie Inlier with the formation of the Denison Trough, the earliest downwarp in the Bowen Basin. At first the trough subsided rapidly and at least 2 600 m of freshwater sediments (*Reids Dome Beds*) were laid down. The freshwater sedimentation extended on to the Springsure Shelf, where 36 m of sediment was laid down, and into the Galilee Basin (the Lower Permian sediments in the Galilee Basin are included in unit C-P). Volcanism continued in the northern part of the Bowen Basin with the extrusion of the *Lizzie Creek Volcanics* (Fig. 26) unconformably on the Bulgonunna Volcanics. The presence of fossiliferous marine tuffs near the top of the volcanics indicates a marine incursion in the northern part of the basin. General subsidence throughout the Bowen Basin followed and the sea spread southwards into the Denison Trough, where the *Tiverton Subgroup* of the *Back Creek Group* (Fig. 26) was laid down in the enlarged basin. There was no sedimentation on the western part of the Collinsville Shelf or on the Springsure Shelf, or in the Galilee Basin. The Tiverton Subgroup is overlain by the *Gebbie Subgroup*, which was laid down in a westerly transgressing sea. Farther west, the *Blair Athol Coal Measures* were probably deposited about this time (Evans, 1966) in an isolated basin on the Anakie Inlier. Subsidence also took place on the Springsure Shelf and in the Galilee Basin, where the fluviatile sands of the *Colinlea Sandstone* were laid down with slight unconformity on the older rocks. The *Blenheim Subgroup*, the youngest marine unit in the Bowen Basin, was deposited in a sea which transgressed still farther west. Marine sediments were laid down on the Springsure Shelf (*Peawaddy Formation*), but there is no evidence that the sea invaded the Galilee Basin, where fluviatile sedimentation probably continued.

Toward the end of the Upper Permian, the Bowen Basin lost its connexion with the sea and the *Blackwater Group*, including coal measures, was laid down in a huge basin east, south, and west of the Anakie Inlier/Drummond Basin fold belt. Freshwater sedimentation continued in the Triassic with the deposition of the mainly fluviatile *Mimosa Group*.

Sedimentation in the Bowen and Galilee Basins came to an end toward the close of the Triassic when the area was uplifted and mildly folded. The period of erosion which followed continued until renewed subsidence in the Lower Jurassic initiated the deposition of the Jurassic and Cretaceous freshwater and marine sediments in the Eromanga and Surat Basins.

Eromanga/Surat Basin Sequence

The Jurassic to Cretaceous sequence in the Eromanga and Surat Basins unconformably overlies the Galilee and Bowen Basin rocks. The sequence comprises the *Precipice Sandstone*, *Boxvale Sandstone Member* of the *Evergreen Formation*, and the *Hutton Sandstone* in the southwest corner of the region (Pl. 7). It is largely

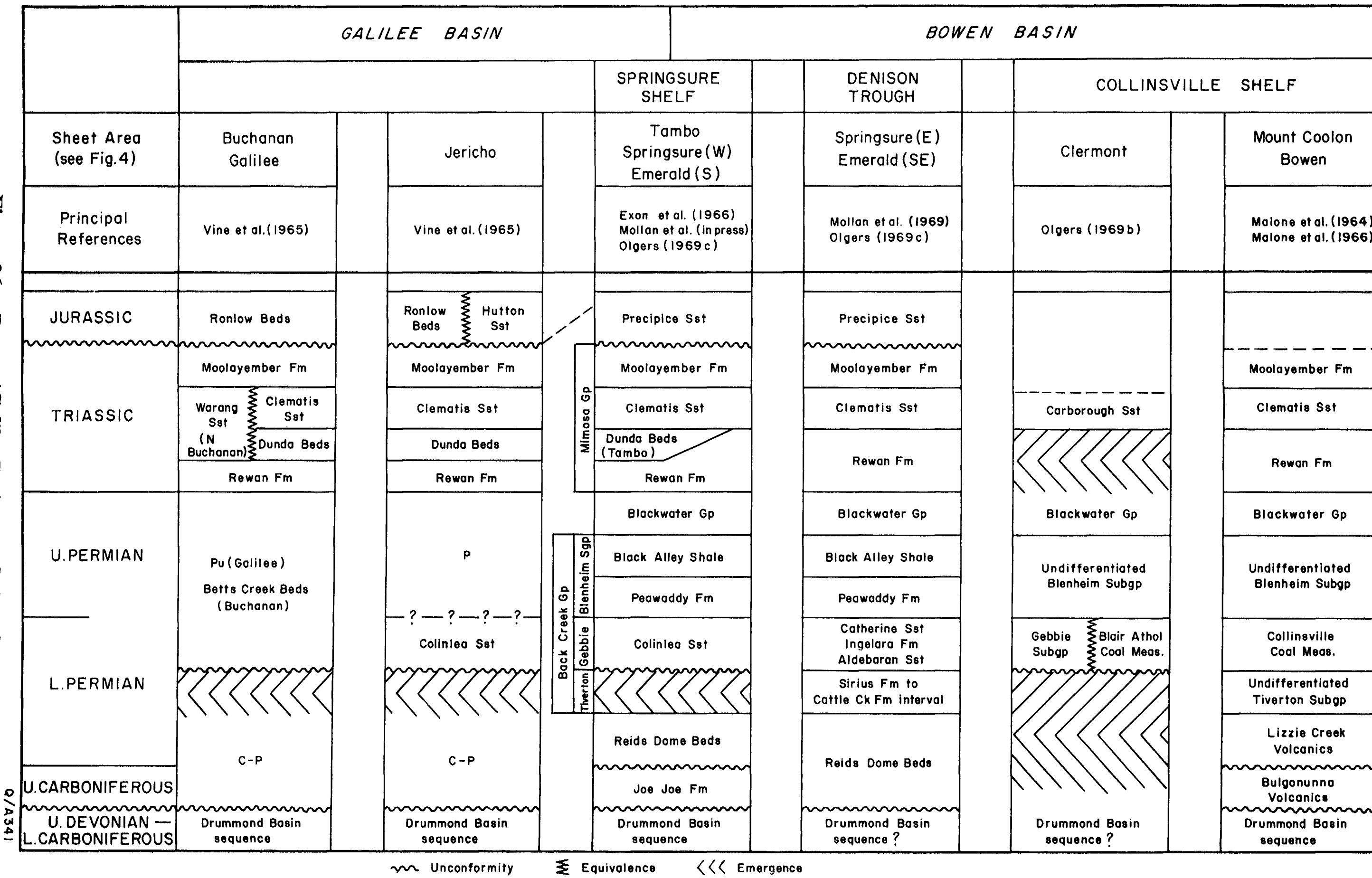


Figure 26. Bowen/Galilee Basin correlation chart.

of fluviatile origin, and has a maximum thickness of about 1 300 m (Exon et al., 1966).

Cainozoic Sediments and Basalt

In the Tertiary an extensive sheet of piedmont, fluviatile, and lacustrine deposits, up to 60 m thick, was laid down over most of the area (T, Tf, Ts). On the flanks of small hills the Tertiary sediments dip at angles of up to 10°. The beds are generally deeply weathered and commonly capped with silcrete and ferricrete. The Tertiary sediments, which are generally covered by a thin layer of superficial sand or sandy soil (Qs) have been deeply eroded, but remnants of the old land surface are preserved in large plateaux and mesas. Wide sheets of alluvium (Qa) were laid down between the Tertiary outliers during the Quaternary.

Tertiary basalts (Tb) were extruded over large areas in the Clermont district between the Anakie Inlier in the west and the Permian sandstone of the Blenheim Subgroup in the east. The basalts are up to 600 m thick, and extend southeastwards into the Emerald and Springsure Sheet areas, where they are interbedded with sediments. The basalts were extruded from fissures and circular vents now filled with olivine basalt or gabbroic rocks, which commonly contain nodules of peridotitic material (Veevers et al., 1964b). The Hoy Basalt plugs of the Emerald Sheet area may be related.

Small patches of basalt occur in the northern part of the Drummond Basin. West of Pyramid homestead they overlie Tertiary sediments and the St Anns Formation, and north of the Burdekin River they overlie the Star of Hope Formation.

Flat-lying magnesian limestone crops out in a low dissected plateau 13 km southeast of Clermont. It occurs in a black soil area and probably directly overlies Tertiary basalt. The limestone may have been deposited in a shallow lake or swamp (Veevers et al., 1964a).

Post-Middle Carboniferous Intrusives

The older intrusive rocks have been described with the basement complex. The post-Drummond intrusives are summarized in Table 2.

ECONOMIC GEOLOGY

Coal is now the only mineral mined in the region. Production at Blair Athol is steadily decreasing and is now less than 75 000 tons per year. Most of the coal is used by Queensland Railways; the demand is decreasing because of the increased use of diesel locomotives.

Numerous gold and copper shows and small mines occur in the Anakie Inlier and on the Ravenswood Arch. The mineralization is mainly associated with granitic intrusions; three copper shows, the abandoned Copperfield mine, a copper prospect on the Burdekin River, and a copper show west of Anakie, all occur on important fault zones (Fig. 24). Copper was mined mainly at Copperfield southwest of Clermont between 1862 and 1877, and gold was mainly produced from the Clermont goldfield and from the Mount Coolon goldmine.

Gemstones, won from the Anakie gem fields, were also an important mineral product of the region. The stones occur in the river gravels and were probably derived from the Tertiary Hoy Basalt.

The main mineral occurrences are dealt with separately and the prospects of the Drummond Basin sequence are discussed below.

TABLE 3—PETROLEUM EXPLORATION WELLS INTERSECTING THE DRUMMOND BASIN SEQUENCE

Well (reference)	*Thickness of Drummond Basin Sequence* (ft)	*Lithology*	*Possible Correlation*	*Hydrocarbon Shows*
Exoil Lake Galilee No. 1 (Pemberton, 1965)	9 320-11 175+ (1 855+)	Sandstone with minor interbeds of shale and siltstone. Sandstone: grey, fine to medium, generally well sorted, slightly micaceous, lithic, carbonaceous; rare pebble zones; interbeds and fine laminae of dark grey to black shale, containing poorly preserved plant fossils, and siltstone. Shale, siltstone, very fine-grained sandstone. Cross-bedding; scour and fill, mud cracks; poorly preserved plant fossils	Buckabie Fm and Mt Wyatt Fm	Drill stem test of interval 8 679-8 752 ft recovered 10 ft of 43° gravity oil and small flow of petroliferous gas from U. Carboniferous or L. Permian rocks
AOD Jericho No. 1 (Benedek, 1965)	5 507-9 142+ (3 635+)	Interbedded varicoloured shale, quartzose and lithic sandstone, conglomerate containing igneous, metamorphic, and sedimentary rocks, greenish feldspathic sandstone. Purplish red pebbly feldspathic quartz sandstone interbedded with thin beds of mudstone. Vitric crystal tuff	Silver Hills Volc in Mt Beaufort Anticline and Buckabie Fm of Adavale Basin	None
Planet Warrong No. 1 (Meyers, 1964b)	2 782-3 508 (726)	Grey to grey-green slightly carbonaceous shale; coarse conglomeratic varicoloured sandstone containing quartz, feldspar, and rock fragments in varying proportions; tuff, tuffaceous shale and sandstone; grey quartz sandstone	Ducabrook Fm	None
	3 509-3 579+ (70+)	Light grey fine well sorted quartz sandstone; conglomerate containing mainly quartz and quartzite pebbles	Raymond Fm and Mt Hall Fm	None
AFO Purbrook No. 1 (Minad, 1963b)	4 758-5 049+ (291+)	Grey-green and green, fine to medium, hard lithic quartz sandstone; green silicified and in part carbonaceous siltstone; green shale. Plants include *Leptophloeum australe*	Timbury Hills Fm, equivalent to lower part of Drummond Basin sequence	Indication of hydrocarbons in Permian sequence
AOD Pejobe No. 1 (Laing, 1968)	1 233-1 521+ (288+)	Siltstone: light grey slightly carbonaceous and calcareous in places; grey shale; tuffaceous siltstone; tuff	Ducabrook Fm	None

Petroleum

The Drummond Basin sequence, covering an area of about 78 000 km^2 in outcrop and in the subsurface west of the Anakie Inlier, has been tested for hydrocarbons in five widely spaced exploratory wells (Table 3). They are part of a large group of wells sunk to the west and south of the Drummond Basin outcrop belt, primarily to test the Galilee, Eromanga, and Surat Basin sequences. The lack of exploratory wells with primary targets in the Drummond Basin sequence is a clear indication that the basin is regarded as a poor prospect for hydrocarbons.

The Drummond Basin sequence consists mainly of continental sediments. Marine conditions occurred in the Upper Devonian in the north and may have extended into the southern part of the basin west of the Anakie Inlier. Marine incursions by a shallow epicontinental sea may have occurred early in the Lower Carboniferous; however, there is no fossil evidence to support this.

The succession is extensively folded. Deformation was probably partly contemporaneous with sedimentation, and culminated during the Kanimblan Orogeny in the middle of the Carboniferous, which marked the end of sedimentation in the Drummond Basin. The most intense deformation occurred in the mobile eastern belt adjoining the Anakie Inlier. The folds in the western part of the basin are probably more gentle.

The most promising area for the accumulation of hydrocarbons is the stable western side of the basin (Fig. 21A) which has been overlapped by the Galilee Basin sequence. Traps are provided by the unconformity between the Drummond and Galilee Basin successions and by pinchouts within the Drummond Basin sequence, particularly in the Raymond and Mount Hall Formations. Similar pinchouts have been observed in outcrop along the eastern margin of the basin and can be expected to occur along the western margin also. In the Lake Galilee 1 well in the western area shows of gas were encountered and a drill stem test of the interval from 8 679 to 8 752 feet (2 645·3-2 667·6 m) recovered 3 m of 43° gravity oil and a small flow of petroliferous gas. The age of the oil-bearing sand is not known; Pemberton (1965) considered it to be Permian in age and part of the Galilee Basin sequence. The porosity of the sandstone is very low owing to extensive diagenetic overgrowths on the quartz grains. The original porosity was good.

In the Thunderbolt 1 well (Amerada, 1967b), 95 km west of Lake Galilee 1 in the Eromanga Basin, shows of hydrocarbons were observed in several Permo-Carboniferous sands, but none were recovered from drill stem tests over prospective intervals. The well was drilled on a structural feature delineated by seismic surveys; the structure is due to drape over basement highs (Amerada, 1967a).

The hydrocarbons encountered in the wells may have originated in the Upper Devonian marine sequence in the northern part of the basin, or possibly in Middle Devonian marine rocks equivalent to the Ukalunda Beds in the northern part of the Anakie Inlier, and the Middle Devonian sequence in the Adavale Basin. The Ukalunda Beds probably extend subsurface into this western area beneath the Drummond Basin. They are deformed and mildly metamorphosed in the Anakie Inlier, but the metamorphism does not necessarily extend far to the west.

Only further exploratory drilling can determine the potential of the area.

Coal

Coal is now the only mineral mined in the area. It was discovered at Blair Athol, 15 km northwest of Clermont, in 1864, and production began soon after by small-scale underground mining. In 1920, the annual production was 150 000 tons. Production declined until 1936, but with the start of open-cut mining rose steadily, despite the cessation of underground mining in 1946. The greatest annual production was 390 000 tons in 1952; since then production has dropped to less than 100 000 tons per year. Systematic exploration started in 1936, and in 1939 the Aerial, Geological and Geophysical Survey of Northern Australia undertook a geophysical survey which was followed by drilling. In 1958, the Commonwealth Aluminium Corporation (Comalco) took an option on the leases and, after the Bureau of Mineral Resources had conducted a gravity survey (Neumann, 1959), undertook an extensive programme of drilling (Whitcher, McIver, & Knight, 1960). An extensive physical and chemical study of three 4-inch (10 cm) drill cores through the Big Seam was undertaken by the CSIRO Division of Coal Research (CSIRO, 1960).

Operations are at present restricted to the Big Seam, the greatest known thickness of which is 33 m; the maximum depth of its base is 256 feet (76·8 m). Proved reserves are at least 200 million tons with an overburden to coal ratio of 1·35; of these reserves, 55 million tons are available with an overburden to coal ratio of less than 1. It has been estimated that 90 percent of the reserves can be worked open-cut.

The seam contains high-volatile, non-coking, low-rank bituminous coal with an average calorific value of 11 810 Btu/lb (656·1 kcal/kg); it consists mainly of durain with some bands of vitrain. Soot beds are locally developed above the seam, and soot partings total 2 to 4 percent of the seam. An average of analyses of samples from the Big Seam is: 57·6 percent fixed carbon, 28·4 percent volatiles, 7·4 percent ash, 7·2 percent moisture at 110°C, and 0·29 percent sulphur. The Blair Athol coal is suitable for steam raising and power generation.

Phosphate

A small piece of black sedimentary rock containing 15 percent P_2O_5 was found south of St Anns homestead in the area where the St Anns Formation is exposed. Close investigation revealed two beds of calcareous feldspathic sandstone, 10½ and 24 m thick, containing up to 4 percent P_2O_5 (Doutch, 1966).

Samples collected from the St Anns Formation 3 km northeast of Scartwater homestead gave moderate to strong reactions with ammonium molybdate, but only traces of phosphate were indicated by the Shapiro test. The St Anns Formation crops out over a large area in the northern part of the Drummond Basin, and the potential can be evaluated only by detailed sampling.

Water

The Drummond Basin sequence and the rocks of the Anakie Inlier and Ravenswood Arch have poor groundwater potential. Supplies for stock and domestic purposes are drawn from earth tanks or very shallow bores or wells in the alluvium along creeks. The rainfall is sufficient to keep the tanks and shallow aquifers filled.

Numerous shallow bores have been drilled in the Tertiary basalt in the southeast. They produce good supplies of potable water from shallow depth (Veevers et al., 1964a, b).

The water potential of the Galilee and Eromanga Basin sequences to the west of the Drummond Basin (outside the area covered by Pl. 7) has been described by Vine et al. (1965). The Clematis and Colinlea Sandstones in the south yield good supplies of potable water, but in places the water is brackish to saline (Exon et al., 1966).

Gemstones

Gemstones, principally sapphires, were first recorded from the Anakie district in 1870. The field was described by Jack (1882) and in detail by Dunstan (1902). The most productive period was from 1906 to 1925; since 1925 production has steadily declined because the richer deposits have been worked out.

Most of the gems have been found in the vicinity of Sapphire and Rubyvale north of Anakie; the Willows field, 32 km to the southwest, is a small new field which has the highest current yield.

The gemstones occur as waterworn fragments in old river gravels which form low ridges rising above the present-day alluvium. The actual wash is generally from 0·5 to 1·5 m thick, and varies from surficial deposits to 12 m deep. It is worked either in shallow open cuts or in shafts.

Other minerals found with the sapphires include zircon, pleonaste, garnet, topaz, and tourmaline. Some diamonds have also been recorded.

Gold

Gold was discovered in the *Clermont district* in 1861 near Peak Downs. The discovery triggered one of Queensland's major gold rushes, and the Peak Downs copper lode at Copperfield was discovered during the early digging for gold. The Clermont goldfield was one of the major producers of alluvial gold in Queensland. Later, gold was discovered at Miclere, Black Ridge, and The Springs north of Clermont. Although no records are available for the period up to 1877, the Mining Warden's reports and other sources indicate that peak production occurred in this period. From 1878 to 1901, the Clermont goldfield produced gold valued at £711 000, and in 1904 nearly 6 900 oz were produced. After 1904 production declined steadily, but the discovery of new leads at Miclere in 1931 revived the field. According to files of the Geological Survey of Queensland this new find netted 40 000 oz of gold in the ensuing 25 years. Most of the shafts are now filled with water and have been abandoned. The only current production is by fossickers working the old dumps and the recent alluvium.

The gold occurs in quartz reefs in the Anakie Metamorphics and in alluvial deposits of Permian, Tertiary(?), and Recent age. Dunstan (1902) described over 25 reefs in the area, but production from the reefs was subsidiary to that from the deep leads. In the period from 1878 to 1901, reef gold amounted to 9 900 oz, but deep lead production was 175 500 oz. Most of the production after 1877 has come from the Permian deep leads. The gold in the deep leads was presumably derived from auriferous quartz reefs in the Anakie Metamorphics, although most of the quartz reefs cropping out are barren. The distribution of the gold in the leads is patchy, but appears to be controlled by small faults and quartz veins in the bedrock. These veins are barren, but because of their resistance formed bars across the watercourses and acted as riffles. Small displacements on the faults formed gutters in which gold accumulated. The shallower ground has probably been worked out at Miclere, but elsewhere many shafts could not reach the deeper Permian leads because of flooding. Gold probably remains in much of the so-called 'wet ground' around The Springs lead. Water also caused considerable difficulties at the Deep Creek lead, Wild Cat lead, and Chinamans Flat, south of Clermont. A re-assessment of many of these diggings in the light of modern pumping equipment may prove worthwhile. The gossan of the Peak Downs copper lode at Copperfield southwest of Clermont is reported to have contained 2 to 35 dwt of gold per ton. Details of the Clermont goldfield are given by Dunstan (1902) and

Ball (1906); more recent work has been done in the Miclere area by Morton (1934) and Ridgeway (1938).

Gold, copper, and silver were also mined in 1914-15 from claims about 2½ km west-southwest of *Fletchers Awl.* Values were generally low, but assays of up to 3 oz of gold and 10 oz of silver per ton and 27 percent copper were obtained. The country rock is Anakie Metamorphics and the mineralization is probably associated with the nearby granite intrusion.

At *Mount Clifford,* 6½ km southwest of Sapphire, gold was mined intermittently from 1896 to 1902 and again for a few years after 1926, but it appears that very little was produced (Dunstan, 1898; Morton, 1932). The gold occurred in hydrothermally altered slates associated with a diorite intrusion and in veins in the diorite. The lodes were first worked for silver associated with bornite, hematite, azurite, and malachite (Jack, 1882).

The *Mount Coolon goldmine* (Morton, 1935) produced about 197 500 oz of gold between 1914 and 1939. Approximately 60 000 oz of silver were produced after 1930; silver production before 1930 is not recorded. The gold was won from a single lode system contained in a local development of andesite. The lode consisted of siliceous rock adjacent to a shear in the andesite; away from the shear the lode graded into silicified andesite. The lode averaged 2 m in width and could be traced for about a kilometre. The gold was associated with pyrite mineralization and was largely confined to the siliceous lode. The source of the silicification and mineralization is thought to be a quartz diorite which intrudes the andesite and the Anakie Metamorphics to the west.

A geophysical survey was made of a small area southeast of the mine in 1937-38 (Oakes, Rayner, & Nye, 1941) to test the possible extent of the mineralized zone under the superficial deposits, but the results were disappointing.

The *Mount Wyatt* goldfield in the northeast was also one of the earliest known fields in Queensland (Reid, 1928). The presence of alluvial gold was known in 1886 and was reported on by Daintree (1870). The deposits are in granite or in the metamorphosed sediments around them. Small silver and copper lodes are also known in the goldfield, but they are uneconomic. The numerous diggings and shafts in the area are not shown on Plate 7 (for location, see Paine et al., in prep.).

Rutherfords Table, 13 km south of Mount Wyatt, is a mesa of the Tertiary Suttor Formation; gold-bearing river gravels occur at the base of the formation in a depression in the granite basement. The gold occurs as small flakes and scales and as wire gold. The size of the grains ranges from microscopic to 2 mm; fragments up to half a pennyweight have been recorded. Rounding and pitting of the grains suggests they have travelled a considerable distance (Levingston, 1953). Total production during the past 10 years is about 900 oz.

A large number of small mines, all part of the *Charters Towers* and *Ravenswood Gold and Mineral Fields,* occur in the northern part of the area in the Ravenswood Arch. The mineralization occurs within the Ravenswood Granodiorite Complex or near the contact in the Cape River Beds. The details of many mines in the fields have been described by Maclaren (1900), Cameron (1901, 1903), Maitland (1911), and Reid (1934). (For location of mines, see Wyatt et al., 1971).

Copper

The *Peak Downs copper lode* at Copperfield 6½ km southwest of Clermont was found in 1862 during the goldrush on the Peak Downs goldfield. The lode became the principal producer of copper in Queensland and was the first of significance.

About 100 000 tons of ore averaging 17 percent copper were mined by the Peak Downs Copper Mining Co. between 1862 and 1937, and smelted on the site. In addition, large amounts were smelted at Swansea. Towards the end of its activities the company issued a generous but unrealistic dividend, based on ore in transit, ore at grass, and an unusually high price for copper. Before the ore reached the markets, however, the price of copper dropped and the company was wound up. Since 1877 a number of efforts have been made to assess reserves and re-open the mine, but with little success.

The Peak Downs copper lode occurs as a replacement along a major fissure or shear zone in sericitic and chloritic schists of the Anakie Metamorphics. It forms a prominent outcrop, composed mainly of barren siliceous ironstone; it strikes 78° and dips southwards at 35° to 60°, but at depth the dip is 30° to 45°. The lode, which is roughly bisected by the Clermont-Rubyvale road, extends for about 2 km in three discontinuous sections. Most of the ore was produced from the section to the west of the Rubyvale road. The lode is cut by numerous dip faults, with a maximum throw of 18 m, and at depth is displaced by strike faults. Mineralization is probably controlled by the Copperfield megashear (Fig. 24) and associated secondary shear zones.

The Peak Downs copper mine was developed by a number of shafts with numerous cross-cuts and winzes; the deepest shaft went to the 714-foot (217·6 m) level along the lode (348 ft, 106·1 m, vertical depth).

The initial high returns from the Peak Downs copper mine were due to the extensive secondary enrichment of the sulphide ore to oxidized carbonate ore. The ore is enriched to the 180-foot (54·9 m) level (120 ft, 25·6 m, vertical depth), but most of the richer ore has been removed. However, in the period of mining activity it was not economical to break stone containing less than 12 percent copper; consequently ore containing up to 12 percent copper remains in the old stopes above the 180-foot (54·9 m) level. Very little sulphide ore has been stoped below this level. Mount Morgan Ltd sampled some of the primary ores, which are iron and copper pyrites, and obtained values around 3·78 percent copper for a width of 2 feet 3 inches (0·68 m). Most of the shafts are now flooded, and have collapsed; it is recorded that during an attempt to re-open the mine in 1899, iron rails, trucks, steel ropes, and other equipment recovered from the flooded workings had been almost entirely converted to copper. The recovery of copper from these waterlogged diggings by the cementation process may prove worthwhile.

The copper potential of this area should be re-assessed in terms of current economic grades, and in the light of more modern mining techniques. The area may warrant exploratory work to estimate the remaining reserves of secondary and primary sulphide ores.

The most recent published works on the Peak Downs copper lode are by Reid (1944) and Denmead (1945).

Slight copper mineralization has been recorded from several localities between Copperfield and Anakie (Morton, 1931a, b; Reid, 1945). All were near the contact of granite with the Anakie Metamorphics. A copper show is also present in the Silver Hills Volcanics west of Anakie.

A small copper mine about 5 km south of Mount Wyatt operated for some years but is now abandoned. The ore occurs in the Ukalunda Beds close to their contact with granite. It consists of malachite, azurite, chrysocolla, chalcopyrite, and pyrite in an epidote-rich country rock. Production figures are not available.

A copper prospect is presently being investigated near the junction of the Suttor and Burdekin Rivers in the northern part of the area. It lies on a major fault zone and is associated with acid dykes.

Silver

Silver was first produced in 1883 in the Sellheim River area around Two Mile Creek northeast of Ukalunda homestead (Jack, 1889). Several mines operated during the years 1883-93; after 1893, most of the production came from the Sunbeam mine. Total production for period 1883-1934 is estimated at 681 000 oz. The Sunbeam mine 8 km west-northwest of Mount Wyatt yielded some extremely rich ore, assaying as high as 1 200 oz of silver per ton, as well as some gold, copper, and bismuth. The ore occurs as fissure lodes in the Ukalunda Beds and in intrusive dolerites.

Bismuth-Arsenic-Gold

Bismuth, arsenic, and gold ores occur in fissures in granite in the Ukalunda district. The Daisy bismuth mine, the Walhalla workings, and the Carrington workings are located on fissure lodes and all three were reported on by Morton (1945a, b; 1946). The Daisy mine is 3 km northeast of Ukalunda homestead, and the other two are about 1 km south and 1 km east of the Daisy mine. The almost vertical Daisy fissure was worked over a length of 190 m and contained two ore shoots, 75 m apart. The mine produced gold, copper, silver, and bismuth ores in 1889 and 1890. The sulphides include chalcopyrite, pyrite, and bismuthinite; quartz and siderite are the main gangue minerals. Morton (1945b) considers that sulphide ores containing high aggregate values of gold, copper, silver, and bismuth remain in the ground.

Arsenic-gold ore was mined at the Salopia workings 2½ km southeast of Ukalunda homestead. The auriferous arsenopyrite occurs sparingly in small quartz veins and as minor disseminations in highly altered rocks of the Ukalunda Beds close to their contact with the intrusive granite.

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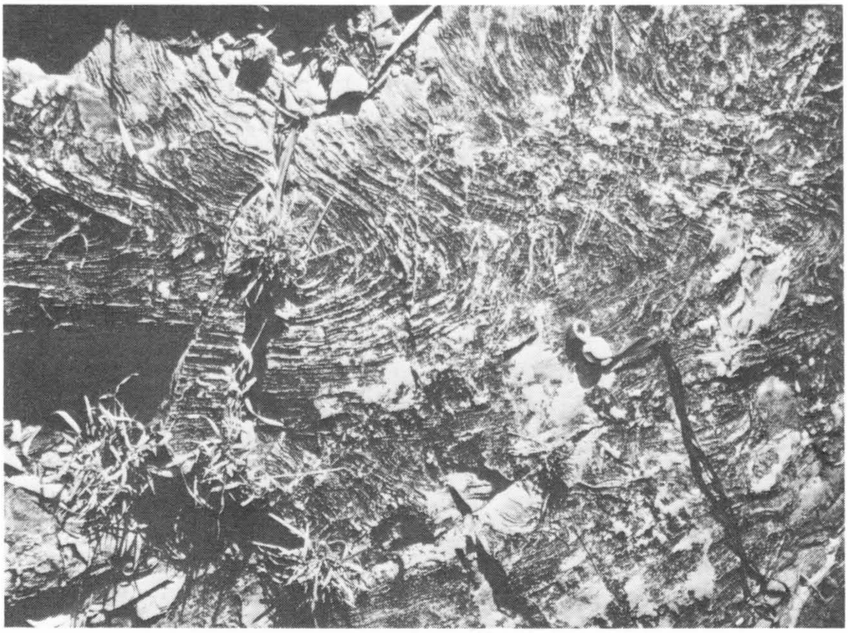


Plate 1, Fig. 1. Flow-banded rhyolite of the Silver Hills Volcanics, Red Mountain, 45 km west of Clermont.

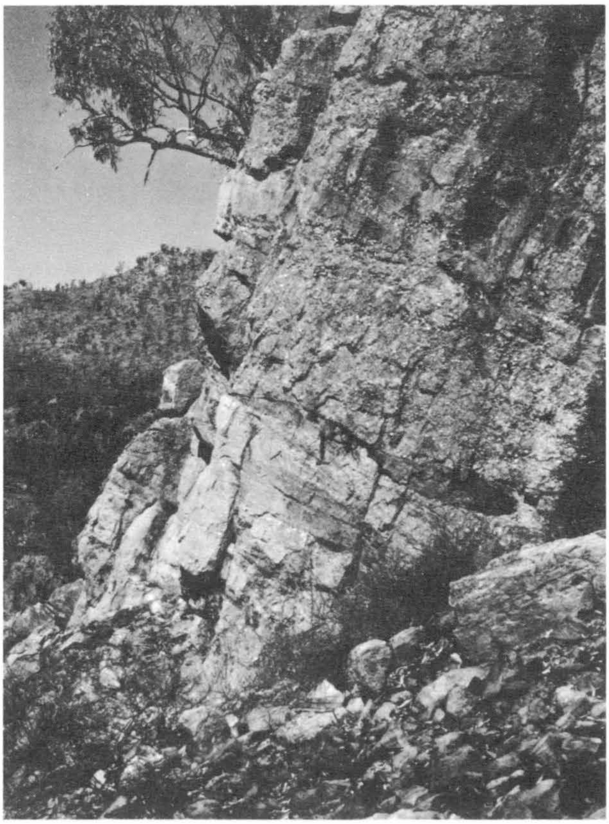
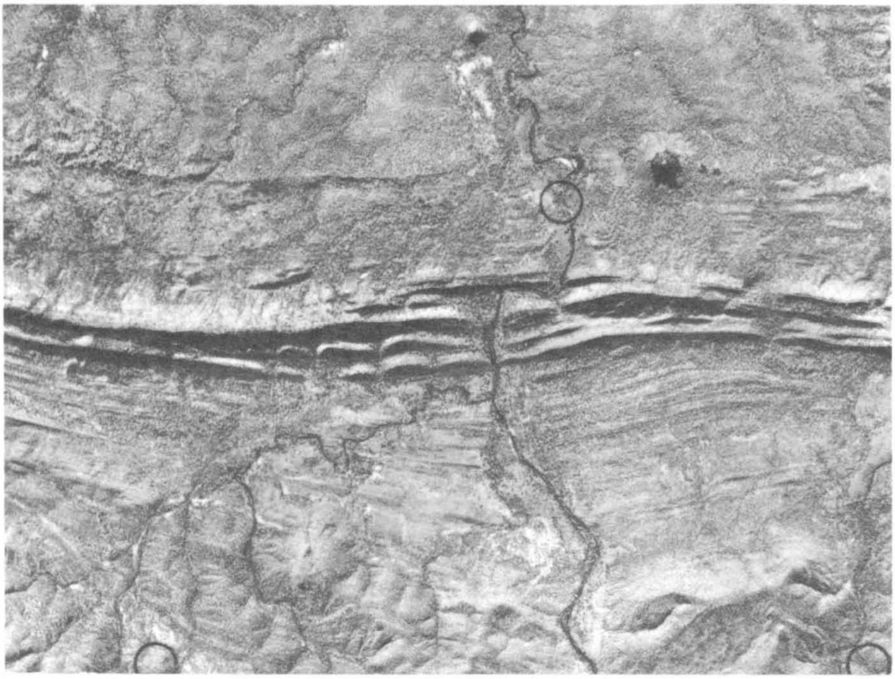


Plate 1, Fig. 2. Mount Hall Formation of Mount Donnybrook, Galilee Sheet Area.



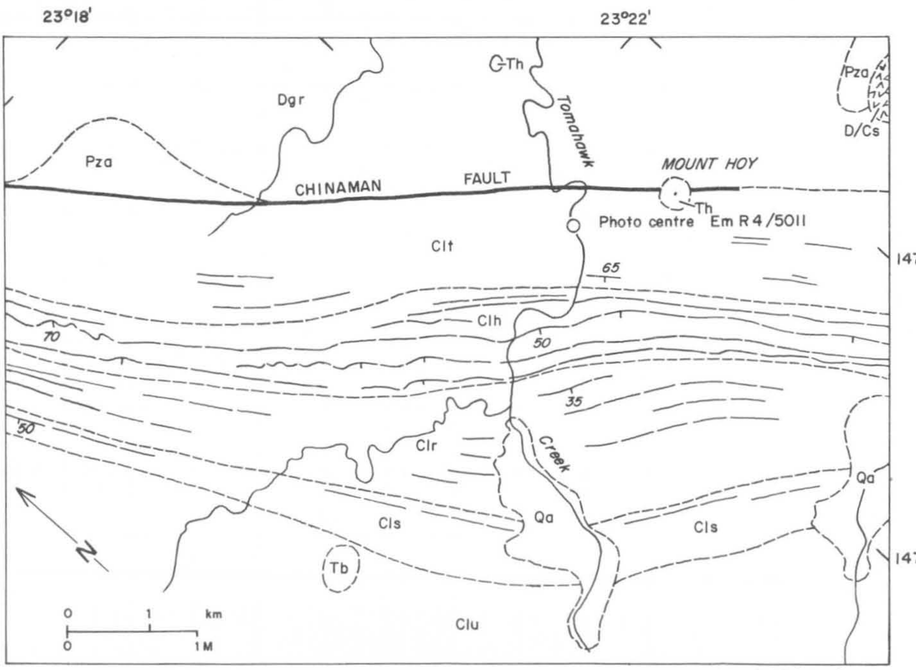


Plate 2. Margin of the Drummond Basin 40 km west-northwest of Anakie. Note lensing and cyclic sedimentation in the Mount Hall Formation (Clh) and to a lesser extent in the Raymond Formation (Clr). (cf. Pl. 3; see Pl. 7 for explanation of symbols.)

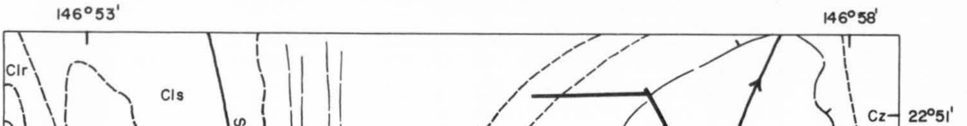


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Plate 3. Massive conglomerate and sandstone of the Mount Hall Formation in the core of the Narrien Anticline, in central part of the basin. (cf. Pl. 2; see Pl. 7 for explanation of symbols.) Note remnants of a Tertiary piedmont alluvial fan in the Star of Hope Syncline.

Plate 4, Fig. 1. Sandstone of the Raymond Formation, northern part of the Mount Beaufort Anticline.

Plate 4, Fig. 2. Bedding plane covered with mud pellets and plant debris, Raymond Formation, Narrien Anticline.

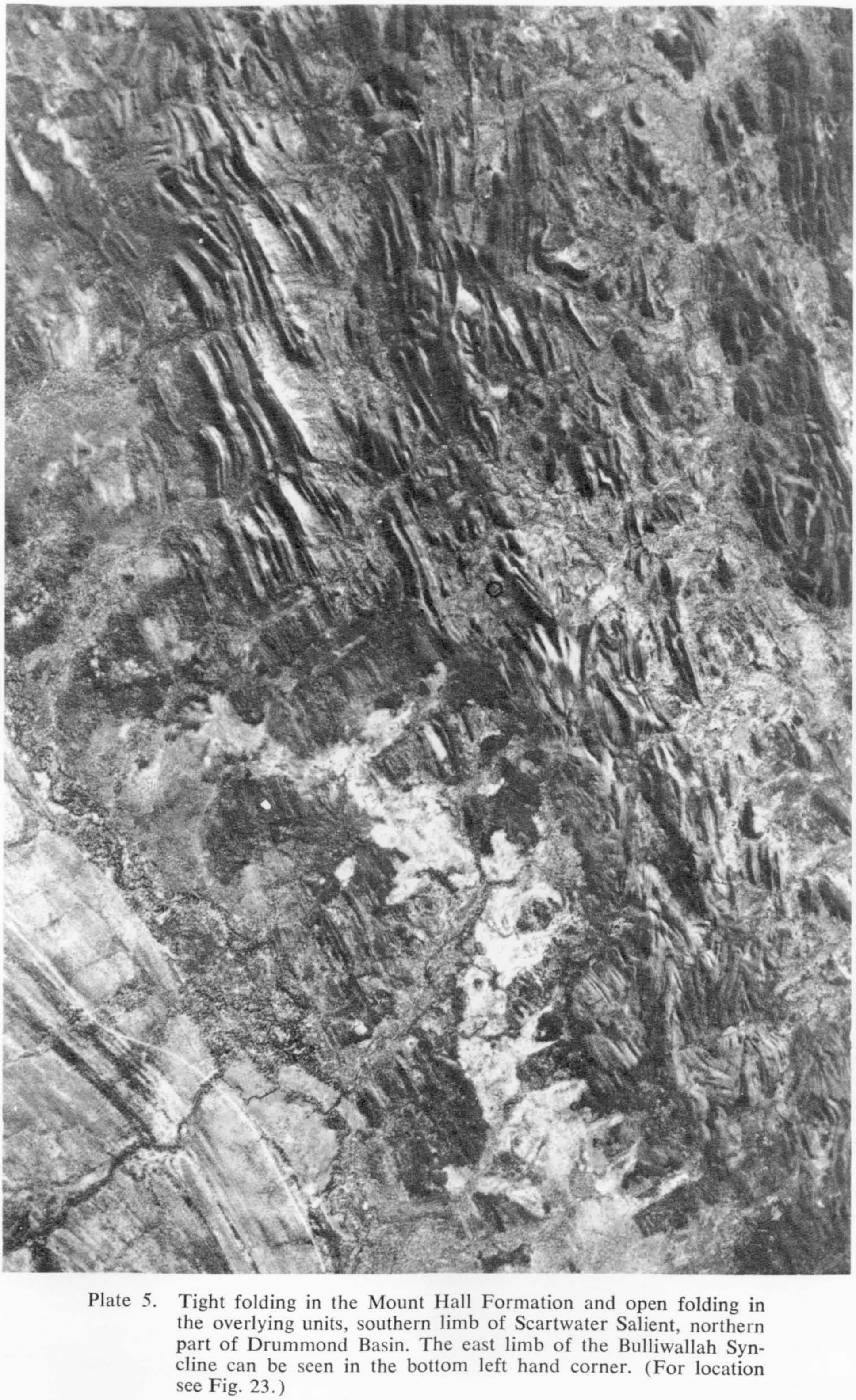
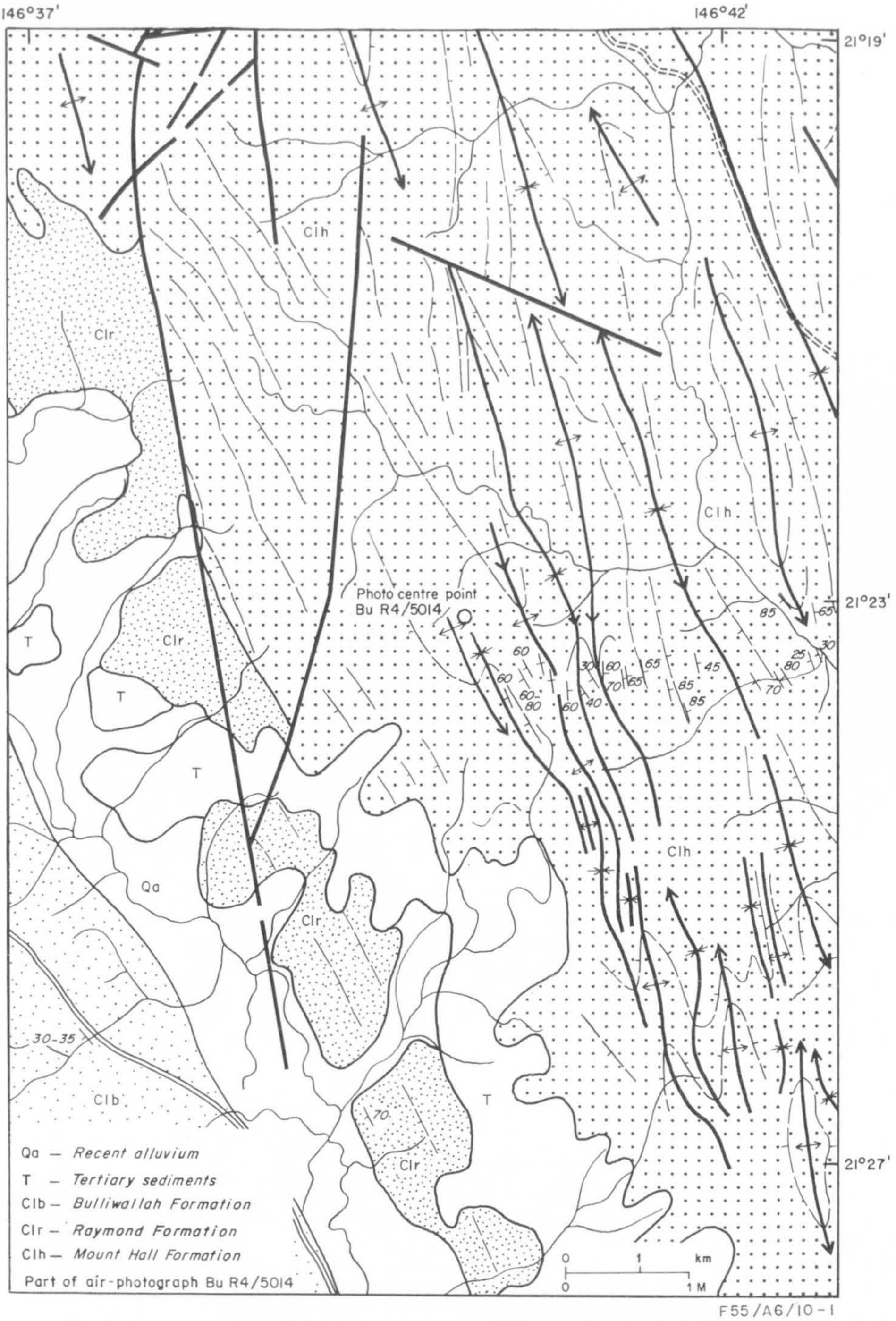


Plate 5. Tight folding in the Mount Hall Formation and open folding in the overlying units, southern limb of Scartwater Salient, northern part of Drummond Basin. The east limb of the Bulliwallah Syncline can be seen in the bottom left hand corner. (For location see Fig. 23.)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T — Tertiary sediments
Clb — Bulliwallah Formation
Clr — Raymond Formation
Clh — Mount Hall Formation
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Plate 6, Fig. 1. Typical outcrop of the Ducabrook Formation, road cutting on Clermont-Alpha road.

Plate 6, Fig. 2. Unconformity between the Colinlea Sandstone (top) and Ducabrook Formation, southern nose of the Nagoa Anticline.

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APPENDIX

PLANT FOSSILS FROM THE DRUMMOND BASIN, QUEENSLAND

by

Mary E. White

Plant fossils were collected from 57 localities in the Drummond Basin during field seasons from 1960 to 1967. A well preserved *Lepidodendron* flora of Upper Devonian and Lower Carboniferous age is present. Analysis of the occurrence of different species in the Drummond Basin sequence has contributed valuable information on the range of species.

The fossil locations are shown on the accompanying geological map (Pl. 7). Table A shows the distribution of species, and Plates A to H illustrate the flora.

The main facts established from the study of the collections are:

1. *Psilophytites* and *Protolepidodendron* are confined to the Devonian sequence.
2. *Leptophloeum australe* (M'Coy) is very abundant in the Upper Devonian sequence. It is known to persist into Lower Carboniferous horizons elsewhere in Australia. It is almost certainly the same plant as *Leptophloeum rhombicum* Dawson.
3. *Lepidodendron mansfieldense* M'Coy and *Lepidodendron volkmannianum* Stbg are characteristic of Upper Devonian and lowermost Carboniferous beds. *Lepidodendron mansfieldense* was re-described by Walkom as *Lepidodendron osbornei.*
4. *Lepidodendron veltheimianum* Stbg, the form-species name used for a wide range of forms which cannot be satisfactorily separated, occurs in the Upper Devonian and throughout the Carboniferous. A variety of the species with characteristic wrinkling of the leaf base tissue appears to be confined to Carboniferous horizons and may be a distinct species.
5. *Lepidodendron aculeatum* Stbg and *Lepidodendron dichotomum* Stbg are confined to the Carboniferous.
6. Non-lepidodendroid plants are very rare in the assemblage, except for equisetalean stem fragments which are of no use as index fossils.
7. There are no Upper Carboniferous plants present and the flora is essentially Upper Devonian to Lower Carboniferous.

Descriptions of Species

Psilophytites

The form-genus *Psilophytites* is used to describe small stems and twigs which show Psilophyte affinity. Some have a median sulcus, lateral branches of limited growth, and characteristic forking.

Protolepidodendron lineare Walkom (Pl. C, fig. 2)

The stems have leaf cushions which are arranged in distinct vertical series, and are separated from each other by straight vertical grooves. The leaf cushions are elongated vertically, and are not separated from each other by ridges but merge gradually into the adjacent leaf cushions above and below. There is an ascending spiral arrangement of leaf cushions.

LOCALITY AND REGISTRATION No.	*Cordaites australis* (McCoy)	Equisetalean stems	*Rhodea* sp.	*Rhacopteris digitata* Eth. fil.	Indet. lycopod stems	*Cyclostigma australe* Feist.	*Ulodendron*	*Lepidophyllum*	*Lepidostrobus*	*Stigmaria ficoides* Bgt	*Lepidodendron dichotomum* Stbg	*Lepidodendron aculeatum* Stbg	*Lepidodendron veltheimianum* Stbg	*Lepidodendron volkmannianum* Stbg	*Lepidodendron mansfieldense* McCoy	*Leptophloem australe* McCoy	*Protolepidodendron lineare* Walk.	*Psilophytes*	
Em26/5; F22059																●			Silver Hills Volcanics
Em26/8; F22069, 22070		●							●							●			Silver Hills Volcanics
Em26/10; F22059																●			Silver Hills Volcanics
Em32/1; F22071																●			Silver Hills Volcanics
Em36/2; F22072 – 22077																●			Silver Hills Volcanics
Em355/5; F22066																●			Silver Hills Volcanics
344; F22761-63, 22781		●											●						St Anns Fm
600; F22839													●	●					St Anns Fm
Mc886F										●							●		St Anns Fm
368A; F22769													●						St Anns Fm
205; F22927-22933															●			●	Mt Wyatt Fm
207; F22934-22936																●			Mt Wyatt Fm
267; F22949-22952		●														●			Mt Wyatt Fm
B12; B94; B1000																●	●	●	Mt Wyatt Fm
199; F22918-22920											●		●						Mt Wyatt Fm
200/1; F22923-22926												●			●				Mt Wyatt Fm
Mc81F									●		●				●				Mt Wyatt Fm
GSQ527; F8940-8955	●									●				●	●		●	●	D/Cv
GSQ508; F8762-8764		●		●															D/Cv
Em24/5; F22078										●									Telemon Fm
Sp54/5; F22089					●														Telemon Fm
Sp55; F22402					●														Telemon Fm
Sp80; F22338					●														Telemon Fm
943; F22833-22838			●											●	●				Telemon Fm
20; F22751-22758													●						Scartwater Fm
256; F22942-22948	●			●						●	●	●	●						Scartwater Fm
350; F22764-22766										●			●						Scartwater Fm
351; F22767															●				Scartwater Fm
359; F22768								●		●									Scartwater Fm
446; F22782-22789				●		●		●				●		●					Scartwater Fm
GSQ509; F8759 - 8761										●		●	●		●				Scartwater Fm
GSQ529; F8916															●				Scartwater Fm
Sp41; F22332					●														Mt Hall Fm
Sp89/1; F22339													●						Mt Hall Fm
236/1; F22937					●														Mt Hall Fm
925; F22840													●						Mt Hall Fm
469; F22778-22779										●			●						Raymond Fm
Sp363/4; F22391													●						Raymond Fm
GSQ504; F8723										●			●						Star of Hope Fm
GSQ532; F8939													●						Star of Hope Fm
GSQ533; F8938					●														Star of Hope Fm
24; F22922							●				●		●		●				Star of Hope Fm
435; F22771-22774										●			●						Star of Hope Fm
436; F22775-22777													●						Star of Hope Fm
B572F			●										●						Star of Hope Fm
C1303/10										●									Ducabrook Fm
C1362										●			●						Ducabrook Fm
Em349/5; F22064		●											●						Ducabrook Fm
Em349/10; F22065		●			●														Ducabrook Fm
Sp352/2; F22331		●																	Ducabrook Fm
Sp354/1; F22334		●																	Ducabrook Fm
Sp364/1; F22392					●														Ducabrook Fm
C1134								●	●	●		●							Mt Rankin Fm
255; F22938-22941										●			●						Mt Rankin Fm
785; F22841-22843										●			●						Mt Rankin Fm

Q/A340

Figure A. Distribution of plant species.

Leptophloeum australe (M'Coy) (Pl. A, figs 1 & 2; Pl. B, figs 1 & 2; Pl. C, fig. 1)

Plate A illustrates a range of forms which occur at localities Em36/2 and Em26/8 in the Silver Hills Volcanics. The characteristic rhomboidal pattern of the leaf bases is seen in Plate A, figure 1. This is the most common and widely occurring form of the species. Plate A, figure 2 and Plate B, figure 1 show interesting impressions in which leaf bases are crowded into wrinkled zones in the same way as described by Dawson (1862) in *Leptophloeum rhombicum* Dawson. In view of this evidence it is probable that the species are not distinct.

Plate C, figure 1 illustrates part of a cone showing sporophylls. This is probably referable to *Leptophloeum australe,* which is the only plant species determined at the locality. There is a similar specimen in the collection of the Sydney Museum associated with *Leptophloeum australe.*

Plate B, figure 2 shows an interesting specimen in which leaf bases are attached in bottle-brush fashion to a stem.

Lepidodendron mansfieldense M'Coy (Pl. D, figs 1-4)

In this species the leaf bases are widely spaced, kite-shaped, and have leaf trace scars near the top. The specimens in the Drummond Basin collection have been compared with type material in the Sydney Museum. They do not appear to be distinct from '*Lepidodendron osbornei* Walkom' which was presumably named in ignorance of M'Coy's species, which has precedence.

Associated with *Lepidodendron mansfieldense* at locality MC81F is a cone which is illustrated in Plate D, figure 3. It may be the cone of the species.

Lepidodendron volkmannianum Stbg (Pl. E, figs 3 & 4; Pl. F, fig. 1)

Young lycopod stems showing a characteristic pattern of leaf bases are referred to this species. A rhombic network is formed by the raised margins of the leaf bases. The leaf bases are heart-shaped pads enclosed by the margins, and the leaf-trace scars are almost central. These specimens resemble European material identified as *Lepidodendron volkmannianum* in the Sydney Museum. The species resembles and may not be distinct from *Lepidodendron clarkei* Walkom.

Lepidodendron veltheimianum Stbg (Pl. F, figs 1 & 3; Pl. G, fig. 1; Pl. H, figs 1 & 2)

A wide range of forms is included in this form-species. It has not been found practicable to separate varieties. In all specimens the leaf bases are roughly spindle-shaped and contiguous. Many Carboniferous examples show a characteristic wrinkling of the tissue of the leaf bases as seen in Plate G, figure 1.

An example of *Ulodendron* is illustrated in Plate G, figure 2. The leaf base pattern on the stem around the scar is of *Lepidodendron veltheimianum* type.

A young stem with attached leaves is illustrated in Plate F, figure 3 and a larger example in Plate H, figure 1.

Lepidodendron aculeatum Stbg (Pl. C, figs 3-6)

The pattern of leaf bases in this species differs from *Lepidodendron veltheimianum* in that they are wider in proportion to their length. Some leaf bases have a median sulcus. The leaves of the species were apparently wide and ribbon-like as seen in Plate C, figure 6. A cone illustrated in Plate C, figure 5, shows fine ensheathing bracts. It was associated with a large number of *Lepidodendron aculeatum* and may be the cone of that species.

Lepidodendron dichotomum Stbg (Pl. E, fig. 1)

Consists of stems with a pattern of leaf bases similar to *Lepidodendron veltheimianum* but with the leaf base margins forming an elongated diamond pattern mesh. It is uncertain whether this is a valid species or just a variety of compression form of *Lepidodendron veltheimianum.*

Stigmaria ficoides Bgt (Pl. F, fig. 2)

Examples of *Stigmaria ficoides* occur throughout the collection. The characteristic arrangement of circular or oval scars with a central point of attachment of stigmarian rootlets is seen in Plate F, figure 2. As all lycopod genera probably have stigmarian root buttresses, the fossils are of no value on their own in determining age.

Cyclostigma australe Feist. (Pl. E, fig. 4)

The figure illustrates an example of a stem referred to this species. The small oval scars on the stem are not enclosed by leaf base scars.

Rhacopteris digitata Eth. fil. (Pl. E, fig. 2)

A fragment of a frond referred tentatively to *Rhacopteris digitata* is illustrated in Plate E, figure 2. It is not impossible that it is a fragment of *Rhacopyllum diversiforme* or similar leaf. Fronds of this type occur in Lower Carboniferous horizons in New South Wales in considerable numbers.

Rhodea sp.

Leaf fragments showing dichotomy are referred to *Rhodea* sp. They are not fully determinate and could be referred to a number of Lower Carboniferous genera on available evidence.

Cordaites australis M'Coy

The leaf fragments showing parallel venation are referred tentatively to this species.

Reference

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EXPLANATIONS OF PLATES A TO H

A Fig. 1 *Leptophloeum australe* (M'Coy). Characteristic decortication form. CPC4351. Locality Em36/2.

Fig. 2 *Leptophloeum australe* (M'Coy). Young stem, crowded leaf bases. Magnification x 2. CPC4352. Locality Em36/2.

B Fig. 1 *Leptophloeum australe* (M'Coy). Stem with zones of wrinkled crowded leaf bases. CPC4353. Locality Em36/2.

Fig. 2 *Leptophloeum australe* (M'Coy). Stem with 'bottle-brush' of attached leaf bases. CPC4373. Locality Em36/2.

C Fig. 1 *Leptophloeum australe* (M'Coy). Part of cone. CPC4374. Locality Em26/8.

Fig. 2 *Protolepidodendron lineare* Walkom. CPC4348. Locality Mc886F.

Fig. 3 *Lepidodendron aculeatum* Stbg. Magnification x 2. CPC4385. Locality Cl134.

Fig. 4 *Lepidodendron aculeatum* Stbg. CPC4375. Locality 351.

Fig. 5 *Lepidodendron aculeatum* Stbg. *Lepidostrobus.* CPC4387. Locality Cl134.

Fig. 6 *Lepidodendron aculeatum* Stbg. Stem with attached leaves. Magnification x 2. CPC4384. Locality Cl134.

D Fig. 1 *Lepidodendron mansfieldense* M'Coy. Large stem. CPC4346. Locality Mc81F.

Fig. 2 *Lepidodendron mansfieldense* M'Coy. Young branching stem. CPC4376. Locality 351.

Fig. 3 *Lepidodendron mansfieldense* M'Coy. *Lepidostrobus.* CPC4344. Locality Mc81F.

Fig. 4 *Lepidodendron mansfieldense* M'Coy. CPC4377. Locality 351.

E Fig. 1 *Lepidodendron dichotomum* Stbg. CPC4378. Locality 24.

Fig. 2 *Rhacopteris digitata* Eth. fil. CPC4382. Locality 446.

Fig. 3 *Lepidodendron volkmannianum* Stbg. Magnification x 2. CPC4383. Locality 943.

Fig. 4 *Lepidodendron volkmannianum* Stbg. and *Cyclostigma australe* Feist. CPC4386. Locality 446.

F Fig. 1 *Lepidodendron volkmannianum* Stbg. CPC4388. Locality 351.

Fig. 2 *Stigmaria ficoides* Bgt. CPC4389. Locality 435.

Fig. 3 *Lepidodendron veltheimianum* Stbg. Young stem with leaves. CPC4390. Locality 435.

Fig. 4 *Lepidophyllum.* CPC4391. Locality 351.

G Fig. 1 *Lepidodendron veltheimianum* Stbg. Large stem with striated leaf bases. CPC4392. Locality 436.

H Fig. 1 *Lepidodendron veltheimianum* Stbg. Very large stem. CPC4393. Locality 20.

Fig. 2 *Lepidodendron veltheimianum* Stbg. *Ulodendron.* CPC4394. Locality 24.

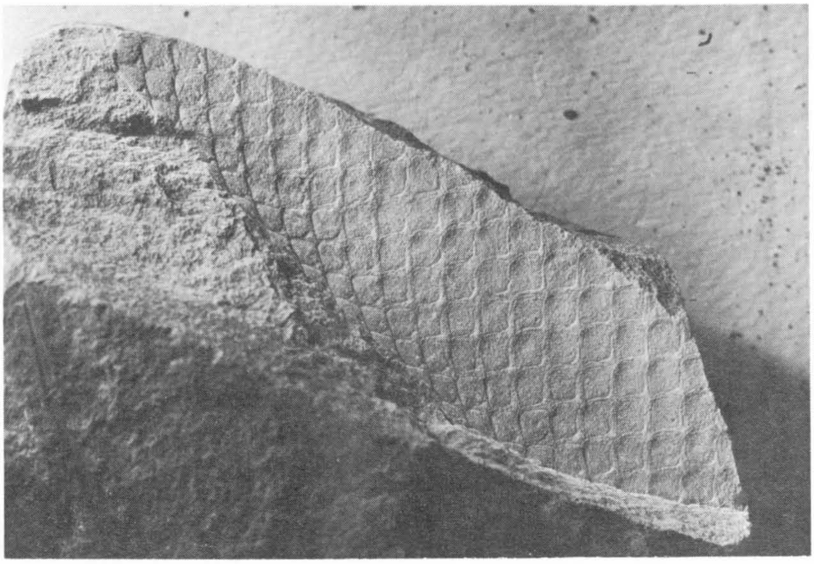


Fig. 1

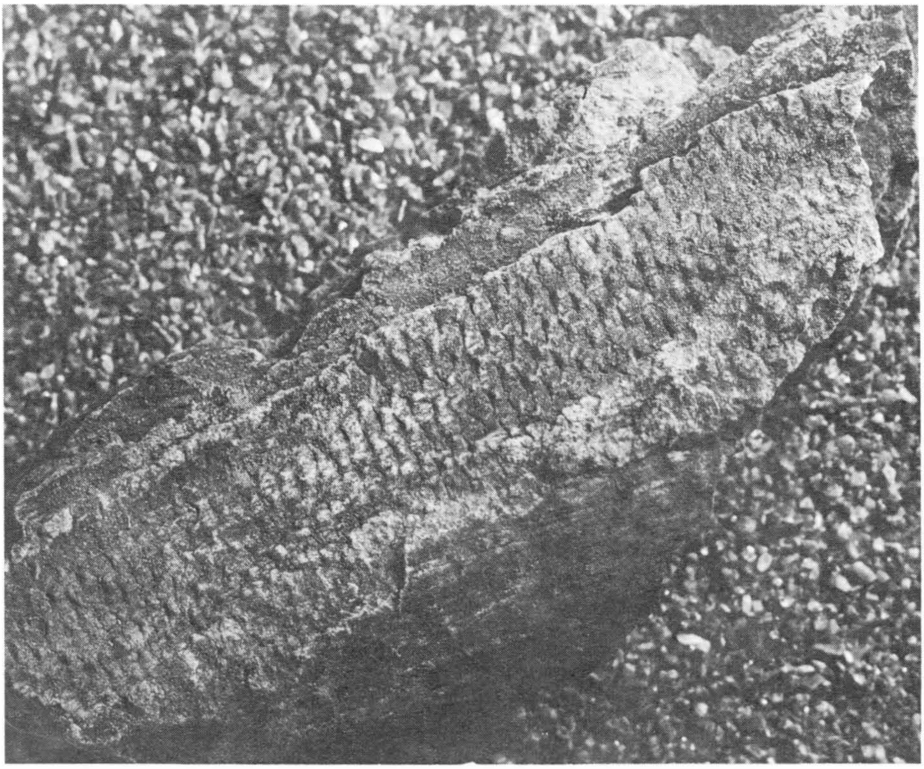


Fig. 2

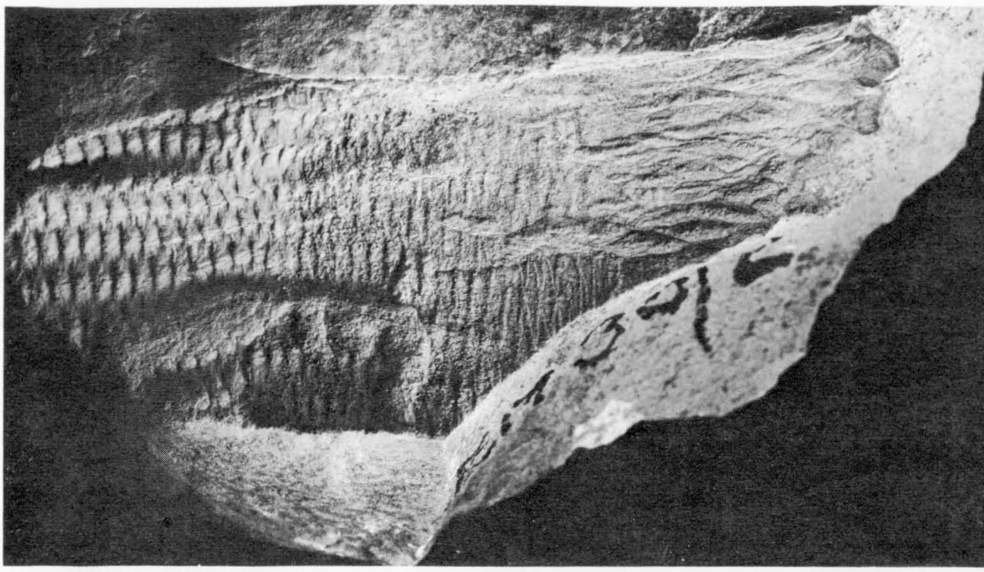


Fig. 1

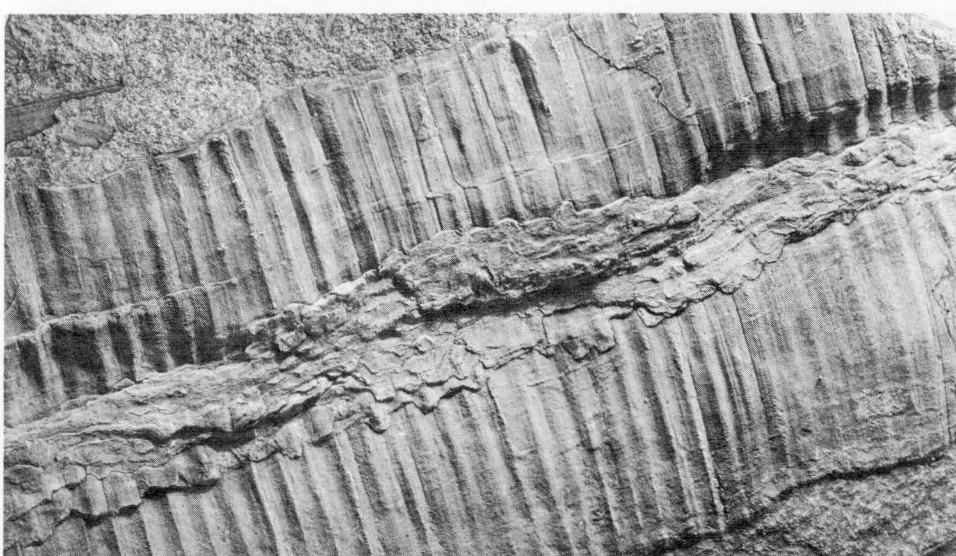


Fig. 2

PLATE C

Fig. 1

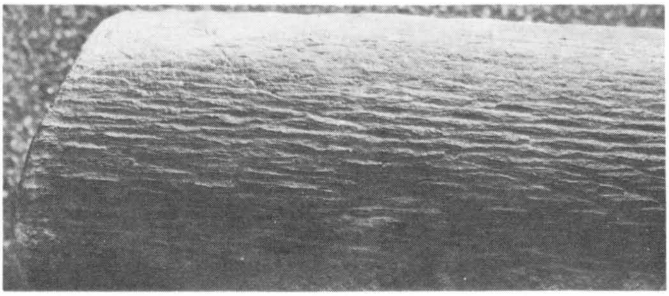


Fig. 2

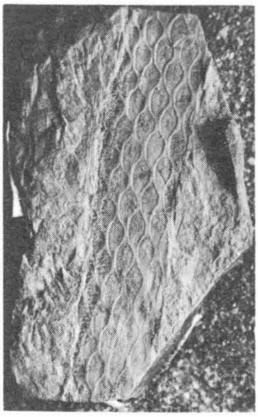


Fig. 4

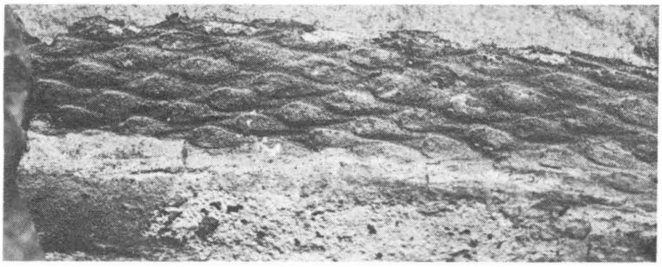
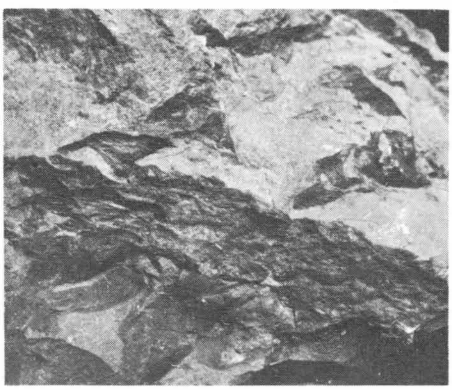


Fig. 3



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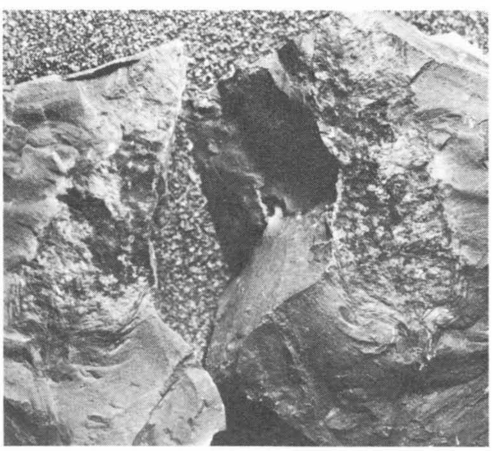


Fig. 5

Fig. 1

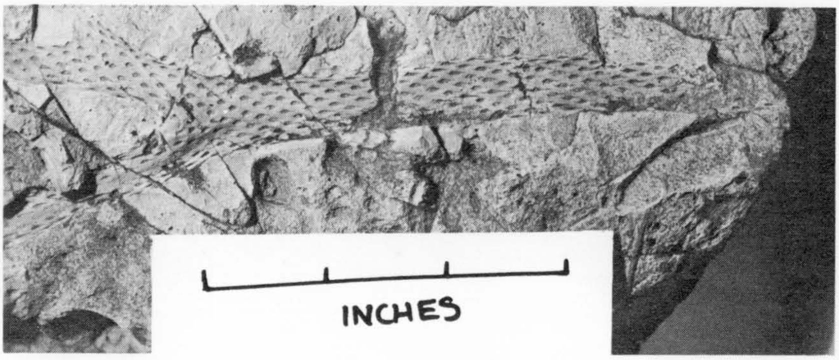


Fig. 2

Fig. 3

Fig. 4

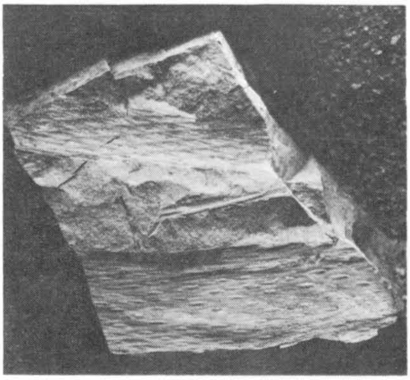


Fig. 1

Fig. 2

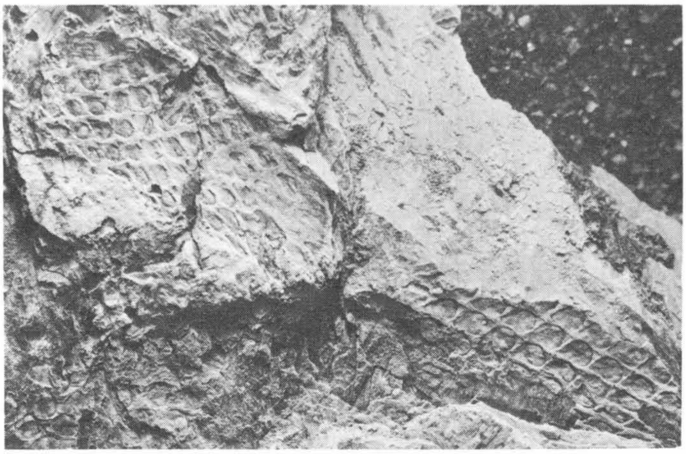


Fig. 3

Fig. 4

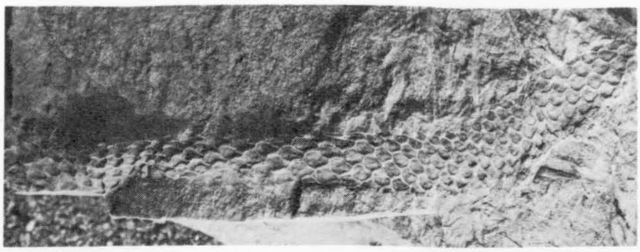


Fig. 1

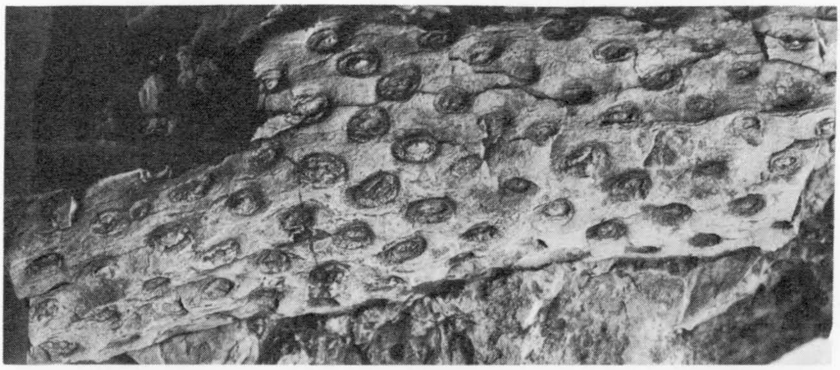


Fig. 2

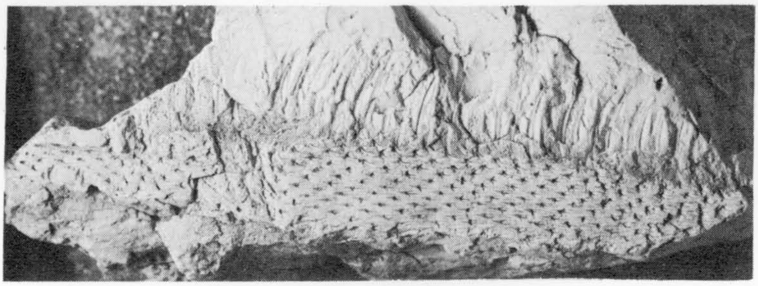


Fig. 3

Fig. 4

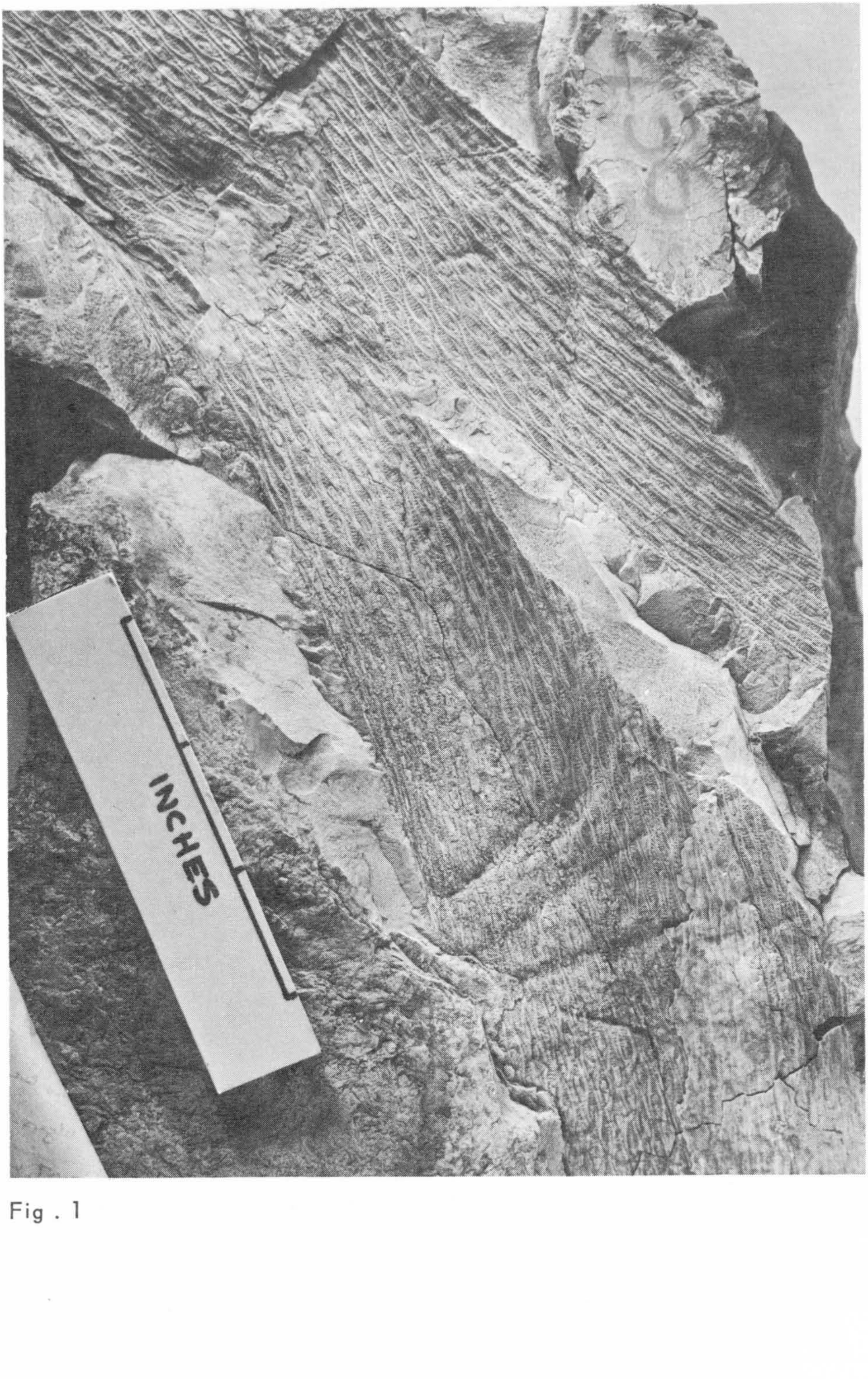


Fig . 1

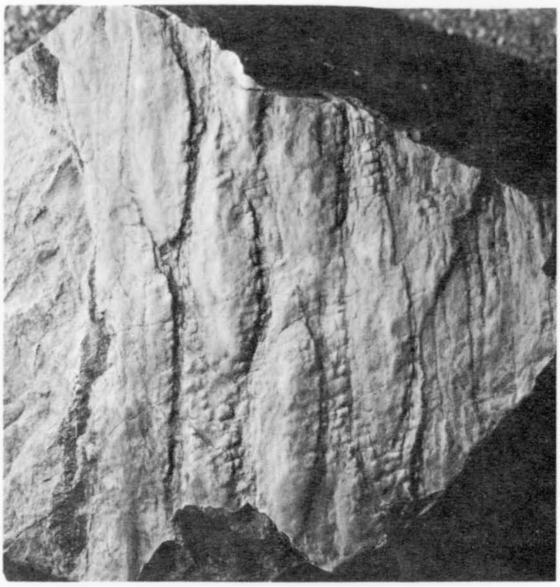


Fig. 1

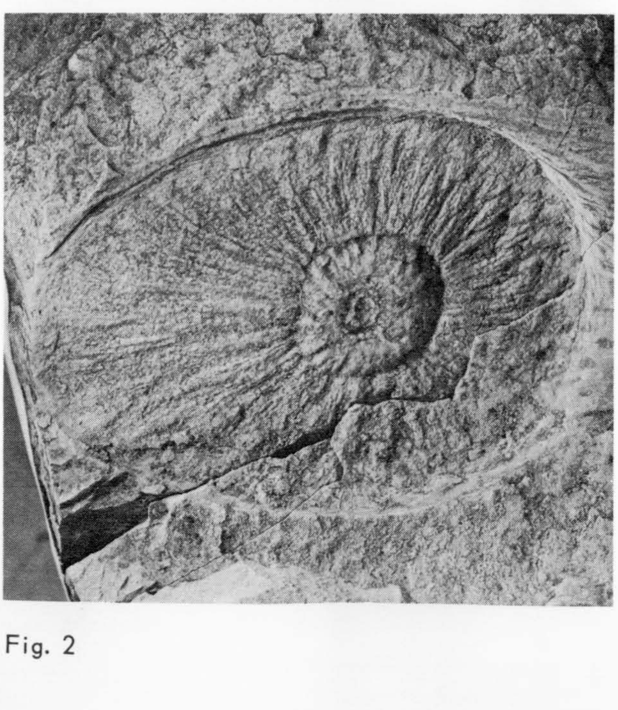
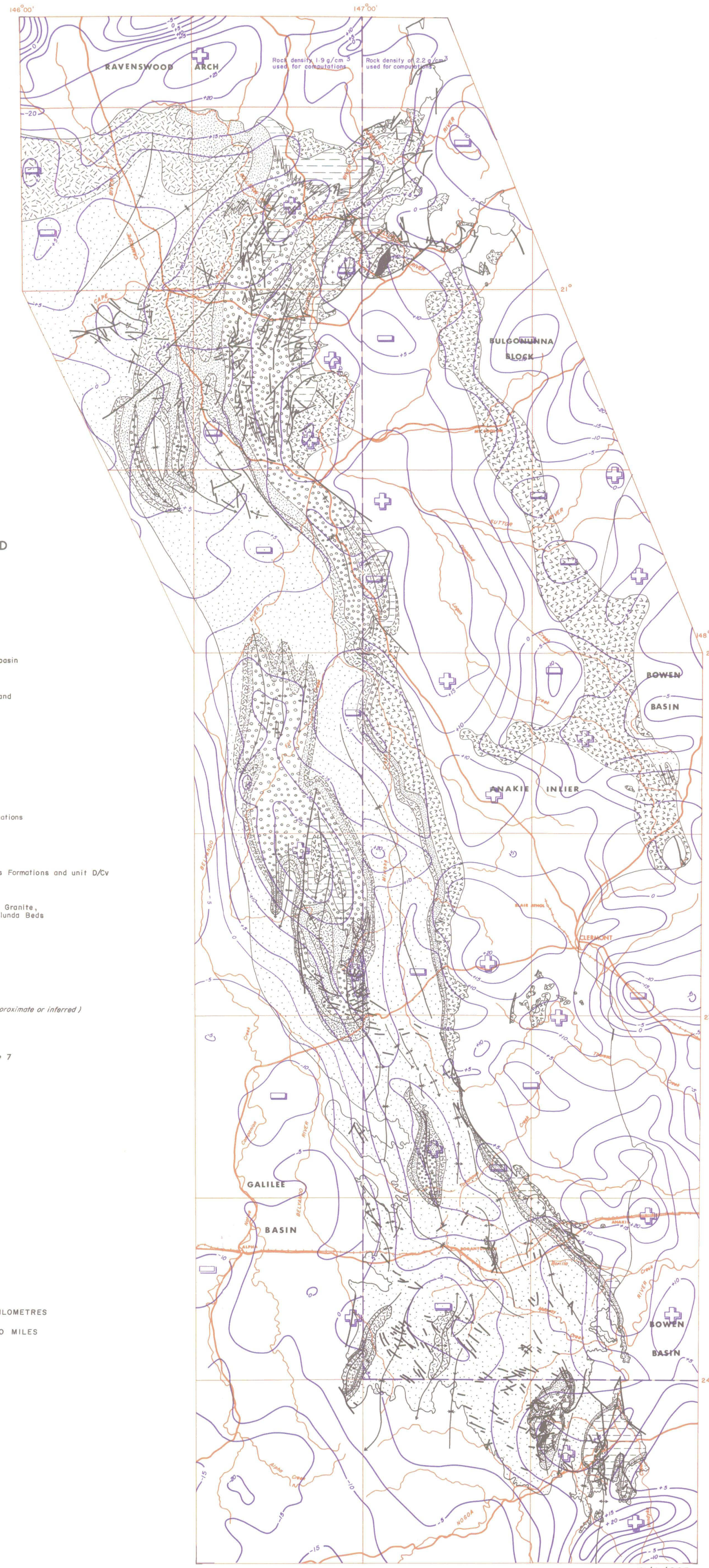


Fig. 2


GEOLOGICAL MAP
DRUMMOND BASIN
QUEENSLAND
1970
Scale 1:500,000
CROWN COPYRIGHT RESERVED
INDEX TO AUSTRALIAN 1:250,000 SERIES
Showing Magnetic Declination 1970
TECTONIC SETTING
RAVENSWOOD ARCH
DRUMMOND
ANAKIE
HIGH
BOWEN
BASIN
GALILEE
BASIN
Reference
CAINOZOIC
QUATERNARY
TERTIARY
Suttor Formation
Peak Range Volcanics
Hoy Basalt
MESOZOIC
LOWER JURASSIC
Hutton Sandstone
Evergreen Formation
Boxvale Sandstone Member
Precipice Sandstone
TRIASSIC
Moolayember Formation
Warang Sandstone
Clematis Sandstone
Dunda Beds
Rewan Formation
PALAEOZOIC
PERMIAN
Blair Athol Coal Measures
UPPER PERMIAN
Blackwater Group
LOWER TO UPPER PERMIAN
Back Creek Group
Blenheim Subgroup
Black Alley Shale
Peawaddy Formation
Gebbie Subgroup
Colinlea Sandstone
LOWER PERMIAN
Reids Dome Beds
UPPER CARBONIFEROUS TO LOWER PERMIAN
Joe Joe Formation
UPPER CARBONIFEROUS
Bulgonunna Volcanics
LOWER CARBONIFEROUS
Natal Formation
Bulliwallah Formation
Ducabrook Formation
Mount Rankin Formation
Star of Hope Formation
Raymond Formation
Mount Hall Formation
Scartwater Formation
Telemon Formation
UPPER DEVONIAN TO LOWER CARBONIFEROUS
Silver Hills Volcanics
Llanarth Volcanic Member
Saint Anns Formation
UPPER DEVONIAN
Mount Wyatt Formation
Retreat Granite
MIDDLE DEVONIAN
Ukalunda Beds
Dunstable Volcanics
Theresa Creek Volcanics
Douglas Creek Limestone
MIDDLE ORDOVICIAN AND UPPER SILURIAN OR LOWER DEVONIAN
Ravenswood Granodiorite Complex
LOWER PALAEOZOIC
Anakie Metamorphics
Cape River Beds
Mount Windsor Volcanics
DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS
NORTHERN DRUMMOND BASIN
SOUTHERN DRUMMOND BASIN
POST - DRUMMOND ROCKS
BASEMENT ROCKS
Unconformity
Equivalence
DRUMMOND BASIN
QUEENSLAND
Sections
(Cainozoic sediments omitted)
Printed by Mercury-Walch Pty. Ltd. Hobart



SOLID GEOLOGY

DRUMMOND BASIN QUEENSLAND

Granite intrusives within the basin

DRUMMOND BASIN SEQUENCE

LOWER CARBONIFEROUS
- Ducabrook, Bulliwallah, Natal, and Mount Rankin Formations
- Star of Hope Formation
- Raymond Formation
- Mount Hall Formation
- Telemon and Scartwater Formations

UPPER DEVONIAN TO LOWER CARBONIFEROUS
- Silver Hills Volcanics
- Mount Wyatt and Saint Anns Formations and unit D/Cv

UPPER DEVONIAN AND OLDER
- Basement inliers of Retreat Granite, Dunstable Volcanics and Ukalunda Beds

Geological boundary (dashed where very approximate or inferred)

Anticline
Syncline
Monocline
Overturned anticline
For names see Plate 7

Plunge of fold axes

Fault

Isogal

"High" anomaly

"Low" anomaly

SCALE 1:1 000 000

0 10 20 30 40 50 60 KILOMETRES

0 10 20 30 40 MILES

Q/A/295

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